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EDITED BY
Lexi Xu,
China United Network Communications Group, China

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Qilu University of Technology, China
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Malnad College of Engineering, India
Chaowei Wang,
Beijing University of Posts and Telecommunications (BUPT), China

*CORRESPONDENCE
Ayodele A. Periola
periola@hotmail.com

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Future aerial sustainable and environment-friendly transport using stratospheric platforms

Ayodele A. Periola[1]*, Opeyeolu Timothy Laseinde[2] and Olugbenga K. Ogidan[3]

[1]Electrical, Electronic and Computer Engineering, Cape Peninsula University of Technology, Cape Town, South Africa, [2]Mechanical and Industrial Engineering Technology, University of Johannesburg, Johannesburg, South Africa, [3]Electrical and Electronics Engineering, Elizade University, Ondo, Nigeria

Technological advances play an important role in future transport. Currently, assets such as fossil-fuel-based terrestrial vehicles, hybrid terrestrial vehicles and non−fossil fuel-based terrestrial vehicles are used in logistics. However, the use of terrestrial and aerial logistic assets faces challenges from cargo theft and hijacking. The occurrence of cargo theft and hijacking degrades the resilience of the organizational supply chain. It is important to reduce the success of cargo theft, and organizational loss. The presented research proposes the use of stratosphere based platform for cargo transport to reduce cargo theft and hijacking. The use of stratosphere based platforms is beneficial as its host geographical location, the stratosphere is significantly inaccessible to rogue elements. In addition, stratosphere utilization results in reduced cargo transport time due to the reduced air resistance. The proposed research presents the cargo intelligent network architecture which demonstrates how using stratospheric platforms for cargo transport solutions can address this challenge. Performance evaluation results show that using the proposed mechanism instead of the existing mechanism enhances the number of completed trips and reduces carbon emissions. The number of trips is enhanced by 50.4% on average. The carbon emissions is reduced by 89.6% on average.

KEYWORDS

stratospheric platforms, aerospace applications, future transport, intelligent systems, cargo transport, environment, carbon reduction

1 Introduction

High-altitude platforms are based in the stratosphere region of the atmosphere. They are also referred to as stratosphere-based platforms (SBPs) and find applications in near–space communications (Dicandia et al., 2022; Singya and Alouini, 2022; Setiawan, 2018), space tourism (Pelton, 2020; Yazici and Tiwari, 2021; Dursun, 2021) and scientific investigations (Pineda et al., 2019; Szondy, 2022; Periola and Falowo, 2018; Jet Propulsion Laboratory, 2022).

Dicandia et al. (2022) presents a review on the usefulness of SBPs in future communication networks. The discussion in Dicandia et al. (2022) recognizes that SBPs can be used to enable a mediation of network service provisioning from satellites. In addition, SBPs are suitable for broadband connectivity in wireless communication networks with capability to function in different network topologies. The discussion in Singya et al., (Singya and Alouini, 2022) corroborates the role of SBPs in future networks. In Singya and Alouini (2022), the role of SBPs in different network initiatives such as HAPCOS and CAPANINA is recognized. The discussion in Singya and Alouini (2022) recognizes that HAPs have a crucial role to play in the realization of Gigabits networks. The concerned HAPs is one that utilizes free space optical links or radio frequency links. Setiawan (2018) recognize that SBPs can enable the bridging of the digital divide by extending network connectivity into rural areas as a cost effective option to satellites. Pelton (2020) identify that SBPs are suitable low cost networking alternatives to the use of satellites in network solutions. The notion of a low cost networking alternative in Pelton (2020) shares the same position with Setiawan (2018).

Yazici and Tiwari (2021) identify the crucial role of sub-orbital flights as core service in the framework of the future of space tourism. The sub-orbital flight altitude as identified in Yazici and Tiwari (2021) aims to reach altitudes beyond the stratosphere extending to the edge of space as seen in Virgin Galactic. However, the stratosphere based tourism is recognized to be feasible as the stratosphere provides a view into the space. This is suitable for new startups in the space tourism services provisioning sector.

Furthermore, scientific experiments intending to study and analyse the atmosphere can be based in the stratosphere. Such instrumentation hosted on stratospheric balloons can be used in astronomy related scientific studies as seen in Dursun (2021), Pineda et al. (2019), Szondy, 2022, Periola and Falowo (2018), and Jet Propulsion Laboratory (2022).

SBPs benefit from the use of renewable solar energy since the use of electricity from the grid is infeasible at SBP operational altitudes. The use of renewable energy also implies that SBPs have low greenhouse gas emissions. Therefore, they can be used in contexts where a reduction of carbon emission is desired. An example of such an important area is aerial cargo transport. The use of SBPs in cargo transport is beginning to receive research attention (Lieret et al., 2022; Clausen et al., 2013; Kavlak et al., 2022; Kurt et al., 2021).

The use of SBPs for cargo transport and human transport applications can reduce the emissions associated with the existing use of trucks (Peters et al., 2023; Kellner, 2022; Moussa, 2022). The use of electric truck vehicles also reduces carbon emissions (Li et al., 2015; Kasten et al., 2017; Lebkowski, 2017). In addition, there have been significant advances in the use of artificial intelligent with the goal of realizing autonomous driverless electric trucks (Othmann, 2022; Bagloee et al., 2016). These advances in electric trucks are beneficial to the realization of climate protection and emission reduction. However, trucks are subject to significant threat risks (Mlepo, 2022; Justus et al., 2018; Urciuoli, 2020). The high susceptibility of trucks (electric and non–electric) to physical threats and hijacks can cause disruptions to the supply chain of organizations.

Hence, this concern should be addressed while ensuring that the logistics domain makes a climatic protection-related contribution. The use of SBPs for the application of cargo transport has the potential to address the challenges associated with theft, and increased environment emissions. However, the adoption of SBPs is not without significant challenges. The discussion in this paper considers these challenges in the context of a cash-constrained developing economy. The challenges are considered from the perspective of three stakeholders. These stakeholders are: (1) Government, (2) Private Organizations, and (3) Employee Unions. The latter, i.e., the employee union are being considered due to their capacity to cause disruptions in the transport sector.

The focus of the solution is the design of cargo intelligent network architecture (CINA). The proposed CINA integrates entities enabling the realization of job creation (government interest); job preservation (employee union) and private organization (improved efficiency and reduced risks). The use of SBPs in this case is recognized to contribute to the goal of reduced carbon emissions.

In addition, the proposed research considers the use of SBPs as a potential entity for the realization of carbon removal. The focus on carbon removal in this case aims to leverage on the use of the proposed SBPs for active climate protection (ACP). As ACP entities, the cargo conveying SBP removes emissions from its traversing path. In this case, the SBP executes the tasks of emission tracking, observation and subsequently emission removal. The research in Periola et al. (2022) noted that the orientation of entities in renewable energy systems can influence the interaction between the components of light electromagnetic waves in a manner that influences carbon removal. However, this notion is yet to be applied to the high altitude entities such as SBPs in the course of transforming them to active carbon removal entities (ACREs).

The problem addressed in the presented research is that of designing environment friendly solutions for future cargo transport. Currently, the use of electric trucking solutions is suitable to address this challenge. However, electric trucks are terrestrial and the delivery via these approaches is susceptible to logistical delays.

The considered delays arise from (i) theft incidences as described by Justus et al. (2018) in Brazil, Mlepo (2022) in Southern Africa (Mlepo, 2022), and Urciuoli (2020) in Brazil, Mexico and South Africa. Terrestrial and land based cargo transport is also affected by national based transport union disputes in South Africa as observed by Mlepo (2022). In addition to the potential loss of life, the occurrence of such risks has devastating effects on the client when expensive cargo is concerned. The identification and discussion of the risks associated with cargo transport via road freight necessitates the design of a new transport approach.

Another plausible approach is to use air cargo transport. However, this approach is challenging as planes utilize fossil fuel based powering products. Therefore, they are not a potential solution option. The use of SBPs is also beneficial in comparison to conventional air cargo transport as cargo transport can take a shorter duration. The benefit of shorter duration arises because of lower air resistance in the stratosphere in comparison to the lower troposphere where conventional commercial aircraft operate.

Therefore, the new transport mode should ensure cargo transport for logistics services organizations (with satisfied clients) without being hindered by these challenges. In this regard, the use of SBPs as cargo transport entities is most suitable. SBPs are deemed suitable because their operation is non-terrestrial making them immune from terrestrial criminal elements. In addition, they have a reduced theft susceptibility. This is because the number of criminals with aerial attack access technology is fewer in comparison to terrestrial based criminals. The lower number is due to the sophistication and cost of tools required for aerial theft attacks. Secondly, SBPs, have low susceptibility of being disturbed due to civil transport union disputes. In addition, the SBPs utilize solar energy thereby achieving environment-friendly operation. Furthermore, SBPs reduce cargo delivery time in comparison to conventional cargo aerial solutions. This is identified to be due to the reduced air resistance in the stratosphere in comparison to the troposphere (where cargo planes operate). The contributions of the presented research are threefold and enumerated as:

i. First, the paper proposes the SBP application for cargo transport to reduce cargo theft and hijacking. The use of terrestrial transport technologies such as vehicles (trucks) and thefts is recognized to be highly susceptible to the incidence of cargo theft and hijacking. The use of SBPs is challenging for criminal elements as they need sophisticated aerial attack hardware. The gaining of access to such tools is challenging in comparison to accessing similar tools for conducting cargo theft and hijacking in terrestrial transport technologies. In addition, the use of SBPs that are solely reliant on solar energy is recognized to be environment friendly. The environment-friendly benefit arises in comparison to fossil fuel powered air cargo transport solutions. In addition, harnessing SBPs reduces cargo transport time in comparison to existing air cargo transport with increased air resistance being located in the troposphere.

ii. Second, the research proposes the cargo intelligent network architecture (CINA) to present an SBP based cargo transport solution. CINA comprises the ground segment and aerial segment. In addition, CINA describes the relation enabling the transmission of information for navigating the cargo transporting SBP. The navigation and processing of navigational data (meteorological related) is executed by human pilots, human engineers and supporting human crew. In this regard, it is important to note that the use of the proposed approach utilizing SBP does not result in job loss within the cargo transport services sector. Rather, it presents a new opportunity to enable the safe transport of high risk and high cost cargo such as refined minerals. Furthermore, the use of SBPs enables the civilian cargo transport industry to handle logistics high priority deliveries. This opens up a new service line of high priority for individuals and organizations seeking to transport cargo between different locations.

iii. Third, the presented research formulates and investigates how the use of the proposed SBP as cargo transport entity enhances the number of completed trips and reduces the emissions. In its capacity to reduce emissions, the SBP is considered as an active carbon removal entity (ACRE). The ACRE hosts synthetic chloroplasts that execute carbon removal.

The rest of the presented is organized as follows. Section 2 focuses on the existing research background. Section 3 describes the problem being addressed. Section 4 presents the solution. Section 5 formulates the performance model. Section 6 evaluates the performance benefits. Section 7 concludes the paper.

2 Background and existing work

The discussion in this aspect of the presented research discusses how advances and policies have influenced the use of SBPs. This is done with the aim of examining the existing and future applications that have been considered feasible. The focus of the discussion in this direction is to enable literature coverage of the applications driving SBP technology development.

The high altitude platforms (HAPS) alliance in HAPS Alliance (2021) recognizes that stratospheric platforms are suitable for the provisioning of network connectivity solutions. The connectivity solutions can be provided in the context of a backhaul link. It is also recognized that the HAPS aerospace technology has latency comparable to that of terrestrial networks. The discussion in GSMA (2022) posits that the SBP's potential to provide connectivity in future networks and applications are sufficient seed for the development of an enabling policy. In this case, the SBPs are recognized to be suitable for realizing ubiquitous communication networks.

The GSM Alliance (GSMA) in GSMA (2022) present different use cases in which SBPs acting as sky—based towers in communication networks provide network coverage and data connectivity. This is being done with the GSMA's goal of enhancing digital inclusion. The discussion in GSMA (2022) executes a comparison between artificial satellites communication systems with SBPs driven communications. The suitability of HAPs is recognized in the cases of providing rural communications, emergency communications and disaster recovery, tourism hotspot network and enabling air mobility. The recognition of the usefulness of SBP's aerospace technology as being capable of enabling urban air mobility provides vertical integration from SBPs as network nodes into the transport application area. However, this aspect requires further research consideration.

The stratosphere is recognized as a region with application potential in HAPS Alliance (2021)). The discussion in HAPS Alliance (2021) extends that in HAPS Alliance (2021) and GSMA (2022) and considers the stratosphere and its role in global connectivity as decoupled entities. This is an advance in leveraging on the potential of the stratosphere beyond its role in global connectivity as well as roles in future cloud computing (Periola et al., 2020) and scientific investigation (Szondy, 2022; Periola and Falowo, 2018).

Miyakawa (2019) in a similar manner to HAPS Alliance (2021) and GSMA (2022) recognizes the suitability of HAPS (SBPs) for providing network coverage and internet connectivity. The discussion in Miyakawa (2019) recognizes the multi-sector transformation effect of internet access and connectivity. It recognizes that the occurrence of natural disasters provides a significant disruption to benefitting from existing networks which are mostly terrestrial. The use of SBPs is also recognized to be capable of providing continuous communications when natural disasters such as earthquakes or tsunamis occur. It is also noted in Miyakawa (2019) that the region of the stratosphere has the favourable characteristic of having a steady air current when there are unfavourable strong wind conditions in the terrestrial (ground) segment. This observed condition diversity has the potential to enable multiple application development. However, this requires further research contribution. It is also noted in HAPS Alliance (2021)) that HAPs find usefulness in different areas such as internet connectivity, critical infrastructure solutions, defense, security and disaster management. Nevertheless, it is noted that all these applications have a central core functionality of networking and communications. Applications out of this core context and which utilize the stratosphere require further research consideration. For example, the role of the stratosphere in providing a platform for astronomy research as seen in Szondy (2022) and Periola and Falowo (2018) is not explicitly identified in HAPS Alliance (2021).

In HAPS Alliance (2020)), the suitability of HAPs (SBPs) to provide novel solutions in different application areas is recognized to be gaining increasing global recognition. However, the explicit identification of such novel application areas requires more research consideration. The technology direction that has been covered from the output of the work on HAP Alliance has mostly focused on the use of the stratosphere for realizing future communications. This can be seen in Arum et al. (2022), where Arum et al. uses the flight test results from practical HAPs as the basis for the development of networking technology targeting HAPs applications. The practical flight test results are provided by corporate technical members of the HAP Alliance. A similar notion on the role of HAP Alliance as enabling a closer integration between the networking and aerospace technologies domain can be found in Kurt et al. (2021), Hokazono et al. (2021), and Ngcaba (2020).

The discussion in Ngcaba (2020) focuses on the development of an ecosystem targeting HAP technology development and application deployment in third world contexts. The focus of (Ngcaba, 2020) is from the perspective of a start-up, solutions developer and services provider. However, the focus is on bridging the digital divide in rural communities in the African context. It can be seen that the consideration of HAPs and SBPs technologies has received significant attention. This has been mostly in the area of communication networks. Hence, the exploration of the future role of HAPs in other application areas and domain require further consideration.

In addition, the high altitude platform (stratosphere based platform) has inherent operational benefits arising from the stratosphere's atmospheric environment. Firstly, the stratosphere's cold environment makes it suitable for hosting future data centers as seen in Periola (2018), Periola (2024), Periola et al. (2023), and Periola (2023). The second operational benefit is the efficiency of aerial cargo transport via airplanes that travel in the troposphere (Cizrelioğullari et al., 2023; Speight, 2017). The troposphere has a greater air resistance than the stratosphere where SBPs operate. Being closer to the outer space environment than the troposphere, the stratosphere has a less dense earth environment than the troposphere. This results in reduced air resistance leading to reduced cargo time. However, the stratosphere benefit of a reduced cargo time has not been utilized in developing a stratosphere–anchored cargo transport solution.

3 Problem description

The challenge scenario being considered in the research being presented recognizes that there is significant occurrence of cargo theft for road freight. Cargo theft in road related freight is observed to be significant as seen in Peter (2023) and TAPA (2023). The discussion in Peter (2023) notes that South Africa is at the top of the list of countries with the highest incidence of cargo theft for 9 months (40,742 incidences) leading up to 30 September 2023. The list of targeted items in this case are Phones, Cash, Metal, Food and Drink and Miscellaneous Electronics. Additional countries that are also recognized to be significantly affected are the United Kingdom, Germany, France, and Sweden with 3,397, 1,770, 814, and 682 reported incidents in 9 months, respectively.

The total value associated with South Africa, United Kingdom, Germany and France are € 18.5 m, €79.6 m, €134.1 m, and €41 m, respectively. The countries with the top 10 cargo crime incidences are recognized as: (i) South Africa (40,742 incidences, €18.5 m), (ii) United Kingdom (3,397 incidences, €79.6 m), (iii) Germany (1,770 incidences, €134.1 m), (iv) France (814 incidences, €41 m), (v) Sweden (682 incidences, €564 k), (vi) Italy (588 incidences, €20.6 m), (vii) Spain (481 incidences, €21.7), (viii) Poland (115 incidences (115, €2.2 m), (ix) Netherlands (90 incidences, €2.9 m), and (x) Russia (81 incidences, €4.4 m).

Furthermore, the total financial loss realized by product differentiation is observed from Peter (2023) to be €524.2 m (exceeding half a billion Euros). For the 2024 year, the transported asset protection association observes a high incidence of cargo related crimes for July 2024, August 2024, and September 2024 (TAPA, 2023). The total loss associated with 5% of these crimes has a value of nearly € 24 m. The discussion in TAPA (2023) recognizes seven countries with double digit cargo crime rates. These countries are Germany, United Kingdom, Italy, France, Netherlands, Greece, and South Africa with cargo crime rates of 32.4, 12.4, 12.1, 11.4, 14, 14 and 10%, respectively. The occurrence of the implied cargo crime events implies low supply chain resilience. Therefore, the problem being addressed aims to develop supply chain resilience.

The scenario being considered in this case is one concerning a cargo company (transport solutions provider). The case of this organization receives attention as that of communications and networking has received significant attention in research. Let α be the set of terrestrial locations lying between the pick–up point and delivery point for cargo being handled by the cargo company, i.e., the transport solutions provider such that:

$$\alpha = \{\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_A\} \tag{1}$$

The Equation 1 has a maximum number of A terrestrial locations in the consideration.

In addition, let $I_w(\alpha_a, t_y) \in \{0,1\}, \alpha_a \in \alpha, t_y \in t, t = \{t_1, \ldots, t_Y\}$ denote the occurrence of wind inoperable conditions on the a^{th} terrestrial location α_a at the y^{th} epoch t_y. Inoperable wind conditions occur and do not occur in the location α_a at the y^{th} epoch t_y when $I_w(\alpha_a, t_y) = 0$ and $I_w(\alpha_a, t_y) = 1$, respectively. In this case, inoperable wind conditions signify the occurrence of unfriendly weather leading to difficulty in terrestrial cargo transport. Furthermore, let the air traffic volume and density associated with the aerial locations linked to a^{th} terrestrial location α_a at the epoch t_y be given as $\gamma_1(\alpha_a, t_y)$. The threshold air traffic volume and density (essentially the air traffic) is denoted as γ_{thresh}. The use of road and existing air freight cargo transport solutions becomes challenging when:

$$I_w(\alpha_n, t_n) = 0, n \in \{1,2,3,..,N\}, \alpha_n \in \alpha, t_n \in t \tag{2}$$

$$\frac{1}{(A-1)} \frac{1}{(Y-1)} \left(\sum_{a=1}^{A} \sum_{y=1}^{Y} \gamma_1(\alpha_a, t_y) \right) \geq \gamma_{thresh} \tag{3}$$

The scenario described in Equation 2 describes a case where terrestrial cargo transport is challenging due to the occurrence of inoperable wind conditions, i.e., unfriendly weather. In addition, the Equation 3 describes a case where there is significantly high air traffic arising from passengers as the mean air traffic exceeds the threshold. This high passenger traffic leads to inability to execute cargo transport over the considered epochs.

In the case that Equations 2 and 3 holds true, the transport solutions provider is not able to utilize the road network (terrestrial plane) and air space (aerial plane) for deploying client's cargo. Furthermore, let $I_R(\alpha_a, t_y) \in \{0,1\}$ denote the use of renewable (non–fossil fuel based) power sources in the a^{th} terrestrial location α_a at the y^{th} epoch t_y. The consideration in this case deems that the

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transport solutions provider has access to fossil fuel based road trucks, and aerial vehicles. The transport solutions provider also has hybrid terrestrial and aerial transport assets. Furthermore, the transport solutions provider has terrestrial (cars, trucks) and aerial (planes) assets that solely rely on the use of renewable energy systems and associated technologies. The transport technology a^{th} terrestrial location α_a at the y^{th} epoch t_y does not and does use renewable energy technologies when $I_R\left(\alpha_a, t_y\right) = 0$ and $I_R\left(\alpha_a, t_y\right) = 1$, respectively. Let the total emissions associated with the location α_a at the epoch t_y be denoted as $\gamma_2\left(\alpha_a, t_y\right)$. Given that the threshold emissions is γ^2_{thresh}. A significant challenge (associated with the environment) arises when:

$$\frac{1}{(A-1)}\frac{1}{(Y-1)}\left(\sum_{a=1}^{A}\sum_{y=1}^{Y}\gamma_2\left(\alpha_a, t_y\right)\right) \geq \gamma^2_{thresh} \tag{4}$$

Equation 4 describes the case where the expected, i.e., mean carbon emissions associated with the use of aviation cargo transport exceeds the emissions threshold. In this case, the threshold emissions being exceeded implies that the aviation cargo transport has significant carbon emissions. In this case, the operation is not environment-friendly.

The challenge in Equation 4 is associated with the terrestrial and aerial based transport technology solutions. In addition, the challenges in Equations 2–4 can hold true for a duration described by the same sequence of epochs. The challenge in Equation 2 prevents and limits service delivery by the transport solutions provider due to bad weather which limits driver roadside visibility. In addition, the challenge in Equation 3 limits the use of the airspace by the transport solutions provider due to the occurrence of significant air traffic for applications have a higher priority. An example of such a case can be in a conflict zone such as that arising from the ongoing and current Russia–Ukraine situation. In this case, the conventional air space is hosting a significant number of aerial vehicles being simultaneously deployed for different applications. The challenge in Equation 3 can also arise when there is high air traffic in a given region by existing aerial applications. Such a case can arise in a highly industrialized nation or region. A scenario in which the conditions in Equations 2–4 hold true is being considered and is addressed in the presented research solution. The solution is the focus of the next section, i.e., Section 4.0.

4 Proposed solution

The discussion in this section presents the solution and it has two aspects. The first aspect presents the proposed cargo intelligent network architecture (CINA). The second aspect focuses on the role of SBPs as an active carbon removal entity (ACRE).

4.1 Cargo intelligent network architecture

The cargo intelligent network architecture (CINA) enables cargo transport when Equations 2 and 3 holds true. In this case, the concerned cargo are those identified by the transported assets protection association to have high value and high susceptibility to theft attempts and incidences. CINA enables relations between the transport solution provider entity (TSPE), meteorological reporting entity (MRE), and communication networking entity (CNE). The TSPE has ground and aerial segments. The ground segment comprises a ground navigation facility that utilizes results acquired by its meteorological sensors. The aerial segment hosts the stratosphere platform cargo system (SPCS).

The meteorological sensors are hosted on the MRE aboard the SPCS. The submitted weather forecasts are received by the ground navigation facility. The received is used to make navigation decisions that are communicated to the pilot for necessary SPCS navigations. The CNE links the TSPE and MRE. It also enables communications with the human piloted stratosphere platform cargo system (SPCS). In this case, human pilots and engineers wear protective clothing to provide shielding from stratosphere related radiation. Multiple human pilots execute SPCS steering from start location to the intended destination location. The SPCS, i.e., TSPE's aerial component hosts onboard human engineers. The engineers ensure transmission and processing of the meteorological data. The received results arise from ground segment.

The MRE provides weather related data forecasting the occurrence of conditions preventing the use of terrestrial based transport facilities. The TSPE communicates with the MRE via the CNE. The MRE–TSPE communications enables the TSPE to submit weather forecast requests to the MRE. It also enables the MRE to send weather forecast requests to the TSPE. The CNE–SPCS links provides communications enabling the monitoring of the sojourn of the SPCS when it is deployed.

The realization of the proposed system requires the specification of entities executing the different tasks associated with the entities aboard the proposed architecture. The implementation of the recognized entities is as presented in Table 1. As seen in Table 1, the use of the proposed architecture involves the roles of human engineers, pilots, and an implied SPCS support crew. The proposed approach does not result in job reduction but in job creation. Moreover job preservation is expected as logistic organizations and service companies embrace a phased and gradual adoption approach.

The relation between the TSPE, MRE, CNE and SPCS is shown in Figure 1. In Figure 1, the TSPE hosts the stratosphere sub–entity (SSE). The MRE hosts the transport sub–entity (TSE). The SSE is the segment of the TSPE that engages in communications with the MRE. In addition, the TSE is the layer in the MRE that responds to TSE requests. In Figure 1, the SPCS monitoring entity (SME) enables the TSPE to acquire and request data from the SPCS for monitoring purposes. The proposed CINA architecture is also suitable for the case when Equation 3 holds true. In this case, the TSPE communicates with the computing systems belonging to civil aviation entities (CAEs). The information from the CAEs is held by the TSPE in the aerial evaluation entity (AEE). The integration of the AEE in the TSPE and associated communications is shown in Figure 1. In the proposed CINA, the aerial locations (paths) corresponding to the terrestrial locations (paths) are mapped and the concerned information is provided by the CAE.

The architecture presented in Figure 1 shows how the proposed CINA meets the expectations of the government (job creation), job preservation (employee union) and private organization (improved efficiency and reduced risks). The architecture enables the use of the stratosphere as a medium of cargo transport in addition to the existing channels of terrestrial and aerial modes. This enables the TSPE to provide services in the case of limiting weather conditions thereby

TABLE 1 Entities and executed functionalities.

S/N	Entity	Role Implementation
1	Transport Solution Provider Entity (TSPE)	Cargo company offering services using the SPCS with significant ground segment and navigation facility.
2	Meteorological Reporting Entity (MRE)	Hosts SPCS's meteorological and weather sensors and acquires navigation-related weather data. It can be realized via an external weather services and not necessarily the TSPE.
3	Communication Networking Entity (CNE)	Non-terrestrial network enabling the transfer of data from the MRE to the ground navigation facility. Network is realized via low earth orbiting satellite constellation. CNE operation at the aerial and ground segments is enabled via human engineers.
4	Stratosphere Platform Cargo System (SPCS)	Aerial segment of the TSPE. It hosts the MRE, its sensors and a crew. The crew comprises human pilots and communication engineers that ensure receipt and processing of data for navigational execution.

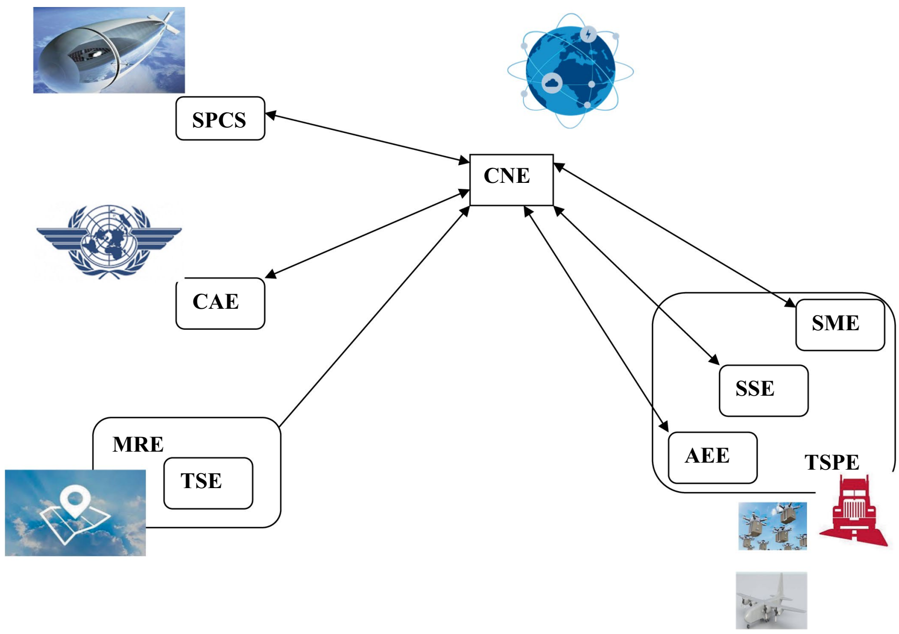

FIGURE 1
Inter-entity relations in the proposed CINA.

meeting client needs and generating more revenue from which the government benefits via taxation. In addition, the introduction of the SME by the TSPE provides jobs for employees (with expertise in aerospace navigation) while retaining jobs associated with terrestrial and aerial cargo logistics as seen in Figure 1. CINA satisfies the government, employee union and private organization.

The system architecture in Figure 1 describes how the deployed SPCS interacts with other functionality enabling entities. In the presented architecture, the SPCS is owned by a logistics services provisioning organization. The CAE are supporting infrastructure entities owned by governmental controlled facilities, i.e., an airport enabling the delivering of the intended logistics services. The MRE, and TSE enable the use of the meteorological data to make decisions regarding SPCS navigation along the sojourn path. The CNE is a central network enabling the passage of information between the SPCS, MRE, TSE and the CAE. The SPCS, and TSE related communications occurs via the CNE (a network supporting the stratosphere related cargo) and anchored in the CAE endorsed facility. The CAE endorsed facility can be realized as a separate strato-port or integrated into the existing infrastructure of an airport.

The system in Figure 1 shows the entities anchored in the CAE endorsed strato-port or airport extended facility and which is monitored for compliance to civil aviation standards on the left hand side. The system relations on the right hand side describe the entities owned and controlled by the TSPE. These entities enable the TSPE to acquire information and environmental data for advanced decision making and sojourn progress monitoring. Therefore, the realization of the architecture presented in Figure 1 requires the formation of a partnership between the public and private sector. The public sector in this case will provide regulatory oversight to ensure safety during service delivery by logistic service providers. In addition, public can also enable the extension of existing airport facilities to support SPCS cargo delivery. This is a better and low cost option in comparison to a construction of entirely new facilities. In this regard, the sharing of runway facilities can be coordinated by the relevant civil aviation authority via an issuance of timetables for facility sharing where applicable. The development of such a timetable requires participation between the public and private sectors. Private sector in this case engages in the development of the SPCS and its supporting subsystems. This is in addition to deployment of additional facilities enabling a safe and aviation compliance regulation.

Therefore, the realization of the proposed architecture is feasible in a developing context. In this case, the public sector, i.e., governmental department provides the facility for the flight take-off and landing of SPCS. The governmental department is able to do this considering the existing capability to operate airports. Furthermore, the public sector develops a timetable for the sharing of runway facilities and airspace resources. The public sector also develops, designs and ensures adherence to aviation safety standards. The private sector engages in the acquisition of the SPCS and delivers logistic services via the SPCS compliant airport. In addition, the realization of the architecture in Figure 1 requires the acquisition of computing systems. The acquisition of computing systems is already being done by service providers in aviation cargo services.

A use case describing the applicability of the architecture presented in Figure 1 is described as follows. The concerned scenario is one where an organization seeks to transport up to 35 kg of highly refined gold. The scenario is one in which the transport of significant mass of high cost cargo is intended. Such cargos are recognized to attract hijackers because of their high monetary value. Examples of cargos that fit in this category are solar panels, and cables. Given that an organization engages in post-processing and mining beneficiation and seeks to sell highly refined gold to other organizations. The intended transportation is scheduled to take place between two countries involving a cross-border mobility. The transport between these nations involves the use of road freight and transport across multiple zones with high frequency of cargo hijackings in terrestrial trucking solutions. In this case, cargo hijackings has been observed to be successful in the past. The intended transport is to be done within a short duration and without incidence of cargo hijacking. A road transport can be done with accompanying security personnel to reduce the success probability of cargo hijackings. However, this approach comes with a risk of attack and loss of life especially for the accompanying security personnel. Such a risk arises with the occurrence of large scale mob orchestrated and organized hijacking. The post-processing mining organization is only able to deploy a road freight transport solution but seeks to minimize the identified and aforementioned risks. In seeking an improved solution, the post-processing mining organization seeks delivery services from an logistics service provisioning organization.

The logistics service providers provides delivery options with nearly zero cargo hijacking susceptibility. In this case, the logistics service providers has an existing interface with the civil aviation authority. The logistics service provider also utilizes the SPCS in the proposed CINA. The use of the proposed CINA involves a shorter duration transport to the logistics service provider. In this case, the logistics service provider hosts an in-residence SPCS enabling flight pad. The destination location also has a supporting destination flight pad and facility. Therefore, the use of road freight in this case minimizes exposure to road cargo hijackers by limiting the distance travelled by road in the course of cargo delivery.

The use of the proposed SPCS in the CINA architecture can also function as an active carbon removal entity (ACRE). This further complements its role in cargo transport as described above. The description of the CINA and SPCS in being active carbon removal entities (ACREs) receives focus in the next section.

4.2 Aspect of the active carbon removal

CINA and SPCS also function as ACREs by hosting a chemical payload of synthetic chloroplasts. In this role, synthetic chloroplasts act to slightly reduce the carbon in the stratosphere. The motivation for the slight reduction is ensuring that a non-degradation of the stratosphere's radiative cooling performance. The cooling in this case is deemed important to ensure that electronic payload aboard the SPCS is maintained at operational temperature and ensuring the removal of heat load. Nevertheless, a reduction in this case makes a significant contribution to the realization of de-carbonization. This de-carbonization is important in relation to the SPCS.

The choice of including chloroplasts has been made due to their capability to absorb carbon dioxide in the presence of sunlight (Gan et al., 2019). This is because of the absence of trees at the high altitude associated with the SPCS. The use of synthetic chloroplasts is feasible due to technological advances (Barras, 2020; Miller et al., 2020). Advances in Barras (2020) and Miller et al. (2020) demonstrate the technological realization of artificial chloroplasts. However, the application of artificial chloroplasts in the SPCS is proposed to realize ACREs capability in SPCS is yet to receive sufficient consideration.

In its role as an ACRE, the sojourning SPCS receives information from an onboard carbon sensor. Furthermore, the SPCS has a pre–configured carbon level which is deemed appropriate to indicate a normal environmental state. The carbon sensor measures the amount of carbon in the path along which the SPCS traverses. In addition, the SPCS receives information merged among the CAE and MRE. The merged information indicates the average, i.e., expected value of the carbon value along the traversing path of the SPCS. The synthetic chloroplasts are held in the SPCS's chemical payload and activated to receive sunlight and also remove carbon dioxide when the average of the carbon volume from the onboard carbon sensor and received forecasted carbon volume from CAE and MRE via the CNE equals or exceeds the threshold carbon volume.

The use of the proposed SPCS aerial solution has operational benefits in comparison to other aerial solutions such as drones, and hybrid electric aerial solutions because of its enabling features. The comparison is conducted with the background that stratosphere based aerial solutions have been considered for communication networks (Singya and Alouini, 2022; Setiawan, 2018; Pelton, 2020; Kurt et al., 2021; HAPS Alliance, 2021; Periola et al., n.d.; Miyakawa, 2019; HAPS Alliance, 2020; Arum et al., 2022; Ngcaba, 2020). The applicability of high altitude platforms to its role in communication networks has been the main focus in developing regions such as Africa as seen in Ngcaba (2020). The perspective in Ngcaba (2020) has been shaped by the international telecommunications union. This perspective has also shaped the application roles of drones and other aerial vehicle solutions. The benefits of SPCS in comparison to other aerial solutions, i.e., drones, and aerial vehicles is in Table 2.

In the carbon removal process, multiple carbon sensors are deployed aboard the SPCS. In this case, it is feasible to envisage multiple low–powered carbon sensors with power consumption in the range of tens–hundreds milliwatts as seen in Dubey et al. (2024) and Basyooni et al. (2023). The power consumption in this case is estimated to be a minimum and maximum of 4,575 mW and 8,250 mW, respectively. The estimate considers that the SPCS hosts 10,000 carbon sensors. This is feasible as seen in Coutinho et al. (2023), where a carbon sensor has a minimum and maximum energy

TABLE 2 Characteristics and differences between drones, HAPs, and SPCS.

S/N	Feature	Aerial Vehicle		
		Drones	HAPs	SPCS
1	Use of solar and battery systems as power sources	✓	✓	✓
2	Main use as being in communication networks	✓	✓	×
3	Communication Network entities being the main payload	✓	✓	×
4	Main application being to bridge the digital divide	✓	✓	×
5	Application as being post-disaster networks	✓	✓	×
6	Use of low carbon emitting renewable energy sources	✓	✓	✓
7	Carbon removal role functionality	×	×	✓
8	Cargo transport functionality and application	×	×	✓
9	Flight zone as being the troposphere	✓	×	×
10	Flight zone as being the stratosphere	×	✓	✓
11	Validity of data sovereignty concerns	✓	✓	×
12	High cost and high theft risk cargo as main payload	×	×	✓
13	High level of stationarity in function execution	✓	✓	×
14	High level of mobility in function execution	×	×	✓
15	Necessity of array deployment in function execution	✓	✓	×
16	Significantly high number of end-users and subscribers	✓	✓	×
17	Comparatively low number of end-users and subscribers	×	×	✓
18	Expected and significant long-lived functional duration	✓	✓	×

consumption of 0.4575 mW, and 0.825 mW, respectively. The synthetic chloroplasts are enclosed in transparent enclosures and can be selectively exposed via the operation of low powered onboard motors. In this case, the power consumption is of the order of hundreds of Watts such as 200 W. Such motors are feasible as seen in Coutinho et al. (2023). In this case, the minimum and maximum total energy consumption are estimated to be 200.5 W and 200.8 W, respectively. Therefore, the power consumption of the system can be estimated to be 210 W and can be over-provisioned as 1 kW. Such a solar powered system can be realized using five 200 W output solar panels. Therefore, five 200 W output solar panels can be dedicated to operating the SPCS sub-system comprising 10,000 carbon sensors and the associated motor. In addition, the flowchart showing carbon removal by the ACRE and the artificial chloroplasts is in Figure 2.

The proposed SPCS is deployed to execute a sojourn transporting cargo between two locations. In this case, SPCS can operate for long periods in excess of 20 h as seen in Lobner (2024) and Burns et al. (2023). The CIRA hybrid high altitude platform system has been observed to be capable of operation, i.e., flight of up to 4 months (Lobner, 2024). In addition, it has a nighttime flight duration of up to 15 h. A balloon realized stratospheric platform has been found to have a feasible flight duration of up to 240 days in analytic performance evaluation (Burns et al., 2023).

Furthermore, the discussion in Burns et al. (2023) recognizes the flight duration of stratospheric based platforms. The Airbus's Zephyr stratosphere based platform with an HAPS fixed-wind flight record of up to 64 days, i.e., 2 months 4 days. In addition, the Sunglider HAPS fixed-wing aircraft with an LTE network payload with mass exceeding 45.4 kg is observed to have a flight duration of up to 15 h. Therefore, the proposed SPCS can be expected to have a flight duration of 15 h before requiring maintenance. Furthermore, the application of a flight duration reduction factor can enable the realization of a flight duration of up to 10 h given a reduction factor of 33%.

The operational lifespan of transplanted chloroplasts from the natural plant environment to the mammalian environment been observed to be up to 2 days (48 h) by Aoki et al. (2024). A reduction in the operational duration by up 38 h (reduction by 20.83%) enables their use aboard a 10 h SPCS flight. In the SPCS, a significant number of synthetic chloroplasts is deployed to reduce the maximum amount of carbon.

The use of the SPCS alongside the artificial chloroplast or synthetic chloroplast is expected to have a minimum flight duration of up to 10 h and transporting a cargo of up to 50 kg. Therefore, the flight duration of up to 10 h is realizable prior to the conduct of maintenance. This is suitable for transporting high theft risk cargo of up to 48 kg within the South African Development Community (SADC). In the SADC region, the total flight duration for a flight between any two constituting countries does not exceed 10 h. In a similar manner, this is applicable for flight between any two constituting countries in East Africa, European Union, North Africa, and West Africa.

It is important to note that the deployment and use of synthetic chloroplasts may prove infeasible due to the infancy of this technology. An example of such a challenge in this case arises when the synthetic chloroplast cannot function for the projected and planned flight duration of 10 h. If such an incidence arises, the SPCS exits its functionality as an ACRE. The stop of ACRE functionality does not affect SPCS functionality due to the necessity of radiative cooling in the stratosphere. The presence of carbon dioxide has been recognized to play a dominant role in the stratosphere's mechanism of radiative cooling (Ollila, 2023; Mlynczak et al., 2024). The rationale for this decision is that

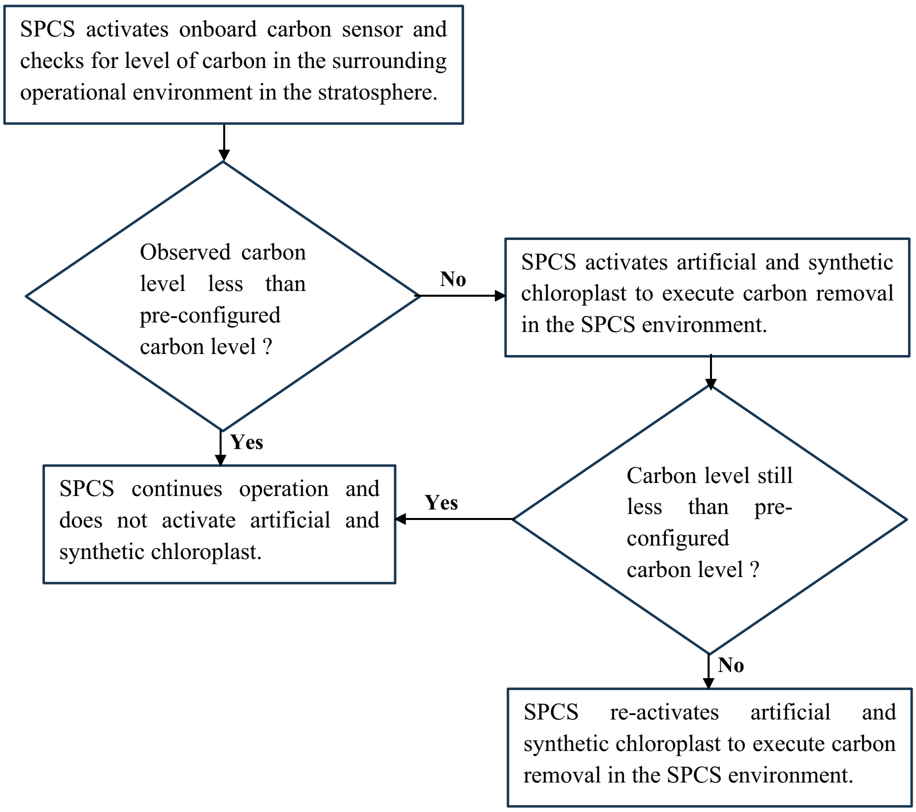

FIGURE 2
Flowchart showing the sequence of tasks associated with chloroplast activation and de-activation.

the SPCS utilizes renewable solar energy without contributions to atmospheric carbon. The second motivation is that the carbon in the stratosphere contributes to radiative cooling. The occurrence of radiative cooling is beneficial for other applications. Examples of such applications are stratosphere based data centres (Periola et al., 2022.; Periola et al., 2020; Periola, 2018; Periola, 2024; Periola et al., 2023; Periola, 2023)] that leverage on the stratosphere's natural cooling environment.

4.3 Platform deployment and technical aspects

The proposed SPCS is realized using high altitude platforms or stratospheric platforms with significant payload bearing capacity. The discussion in Frontex and European Union (2023) recognizes that aerial solutions and vehicles can be categorized as small, medium and large aerial solutions (vehicles). The stratospheric platform is deemed as separate from this categorization. In this case, the proposed SPCS is manned and operates for periods of up to 10 h. The discussion in Frontex and European Union 2023) examines the commercial outlook and appeal of high altitude platforms. It is recognized that stratospheric platforms can be launched via a runway. Therefore, an extension of airport facilities can be done to accommodate the launch of the proposed SPCS. In addition, the international telecommunications union (ITU) recognizes that the high altitude platform and the SPCS has a payload capacity of 1,200 kg (ITU, 2002). The concerned application in ITU (2002) is the integration of high altitude platforms in communication networks. Therefore, it is feasible to have expect that the proposed SPCS will be able to support a payload capacity of more than 50 kg. For example, it is indicated in Frontex and European Union (2023) that the Sunglider stratospheric platform has a payload capacity of 150 lbs. (68 kg) with a feasible operational duration of 5 h 38 min. In addition, the Stratobus stratospheric platform also has a payload capacity of approximately 250 kg (Frontex and European Union, 2023), and a feasible operational duration of up to 8 h.

Furthermore, it is observed in Frontex and European Union (2023) that the stratospheric platform, Capgemini Engineering has a payload capacity of up to 1,000 kg. The Capgemini Engineering stratospheric platform has a maintenance–free operational duration of up to 48 months. Therefore, the assertion that the SPCS can carry a payload exceeding 50 kg is feasible. In addition, stratospheric platforms with fixed wing (heavier than air) configuration are recognized to be aeronautically operable.

Therefore, the Sunglider, Stratobus, and Capgemini Engineering stratospheric platforms can be considered to have a maintenance-free flight duration of 5 h 38 min, 8 h, and 48 months, respectively. A five-hour maintenance-free flight duration is therefore deemed realizable. After 5 hours, the cargo bearing SPCS lands for maintenance using the runway facilities at a given airport. The realization of flight of the proposed SPCS necessitates the extension of airports to provide new runways capable of supporting the flight-take off and landing procedures. This is executable via the development of a national airport development plan, and such an approach is proposed in the presented research.

In addition, the stratospheric platforms such as the proposed SPCS are aeronautical solutions that utilize the high air space region and execute high air space operations. International Civil Aviation Organization (n.d.) has recognized the need to ensure the operational and safety accreditation of stratospheric platforms. Furthermore, the HAPS Alliance has presented accreditation paths for achieving applicant-neutral stratospheric platforms development as seen in HAPS Alliance (2024). The cost of using high altitude platforms has been observed to be lower than commercial aircraft for similar scale comparison as seen in Sriram (2024). The costs in Sriram (2024) compared to the discussion in Oloyede et al. (2023) shows that the high altitude platforms cost less than conventional aircraft.

For example, the discussion in Sriram (2024) notes that the Sceye high altitude platform has an acquisition cost of less than $10 m. The discussion in Oloyede et al. (2023) observes that 30 A330s would have a basic price of $11 billion post-concession. The Airbus A330 unit price in this case, i.e., (Sriram, 2024) is obtained as $ 366.7million. Therefore, it can be inferred that the conventional aircraft costs more than the high altitude platform and be extension SPCS. Furthermore, the discussion in Oloyede et al. (2023) points out that the manned plane has an higher capital cost than an uncrewed stratospheric platforms (airships). The manned plane has a capital cost as observed in Oloyede et al. (2023) of $ 24.9 m. The uncrewed stratospheric platform has a capital cost as observed in Oloyede et al. (2023) of $12.5 m. It is projected that the capital cost of a crewed stratospheric platform will be higher than $12.5 m with a feasible increase of 40%. Therefore, the expected capital cost of a crewed stratospheric platform $17.5 m. This is still less than $24.9 m.

The use of the proposed SPCS (stratospheric platforms) is deemed to have a lower operational cost than the existing approach of conventional cargo planes. The SPCS utilizes renewable solar energy since it has onboard solar panels while the conventional cargo plane being deployed in a developing context utilizes fossil based jet fuel. From an operational perspective, the cost of re-fuelling with jet fuel is significantly higher than that applicable with renewable solar energy. Given that other operational charges such as runway use costs, clearing to fly related costs, and clearing to land related costs are applicable to conventional cargo and SPCS; the fuelling cost is the significant difference between SPCS and jet-fuel conventional cargo plane. Therefore, the SPCS has a lower operational cost than the fossil-fuel based conventional cargo plane.

5 Performance formulation

The discussion in the previous section has explained the various aspects of the operation of SPCS. However, additional work is required to formulate the performance of the proposed CINA. This is the focus of the discussion in this section. The use of the proposed CINA instead of the existing approach of using fossil—fuel or hybrid or renewable based vehicles is expected to have benefits for the transport solutions provider. In addition, it is also expected to have environmental benefits. The metrics associated with benefitting the transport solutions provider is the number of completed trips given the occurrence of unfriendly weather conditions and high air traffic in the terrestrial plane and aerial plane, respectively. The environmental benefit is described by the metric associated with the emitted carbon volume especially as the SPCS uses only renewable solar energy. A similar transition is yet to be significantly recorded with the case of hybrid terrestrial and aerial cargo vehicle assets.

Let β_1, β_2 and β_3 denote the set of SPCS, existing terrestrial vehicles and existing aerial vehicles, respectively.

$$\beta_1 = \left\{\beta_1^1, \beta_1^2, \ldots, \beta_1^P\right\} \tag{5}$$

$$\beta_2 = \left\{\beta_2^1, \beta_2^2, \ldots, \beta_2^Q\right\} \tag{6}$$

$$\beta_3 = \left\{\beta_3^1, \beta_3^2, \ldots, \beta_3^S\right\} \tag{7}$$

Equation 5 shows that the maximum number of SPCS is P. In addition, the total number of existing terrestrial vehicles is Q as presented in the Equation 6. Furthermore, the maximum number of existing aerial vehicles as presented in Equation 7 is given as S. As seen in the Equations 5–7, the total number of existing SPCS, existing terrestrial vehicles, and existing aerial vehicles are not equal. This is due to the varying levels of adoption of each of the identified cargo technologies.

In addition, let $I_F\left(\beta_1^p\left(\alpha_a, t_y\right)\right) \in \{0,1\}$ denote the use status of the p^{th} SPCS, $\beta_1^p, \beta_1^p \in \beta_1$ at the a^{th} terrestrial location α_a at the y^{th} epoch t_y. The p^{th} SPCS, β_1^p is used at the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I_F\left(\beta_1^p\left(\alpha_a, t_y\right)\right) = 1$. In addition, the p^{th} SPCS, β_1^p is not used at the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I_F\left(\beta_1^p\left(\alpha_a, t_y\right)\right) = 0$.

A similar use status indicator is applicable to the case of the existing terrestrial vehicle. In this case, the existing terrestrial vehicle indicator is denoted as $I_F\left(\beta_2^q\left(\alpha_a, t_y\right)\right) \in \{0,1\}$ for the q^{th} existing terrestrial cargo vehicle, $\beta_2^q, \beta_2^q \in \beta_2$ on the a^{th} terrestrial location α_a at the y^{th} epoch t_y. The q^{th} existing terrestrial vehicle, β_2^q is used at the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I_F\left(\beta_2^q\left(\alpha_a, t_y\right)\right) = 1$. In addition, the q^{th} SPCS, β_2^q is not used at the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I_F\left(\beta_2^q\left(\alpha_a, t_y\right)\right) = 0$.

Furthermore, the use status of the existing aerial vehicle is denoted $I_F\left(\beta_3^s\left(\alpha_a, t_y\right)\right) \in \{0,1\}, \beta_3^s, \beta_3^s \in \beta_3$ for the s^{th} existing aerial vehicle, β_3^s on the a^{th} terrestrial location α_a at the y^{th} epoch t_y. The s^{th} existing aerial vehicle, β_3^s is being used at the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I_F\left(\beta_3^s\left(\alpha_a, t_y\right)\right) = 1$. In addition, the s^{th} existing aerial vehicle, β_3^s is not being used at the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I_F\left(\beta_3^s\left(\alpha_a, t_y\right)\right) = 0$.

Furthermore, let $I_C\left(\gamma 2\left(\alpha_a, \beta_3^s, t_y\right)\right) \in \{0,1\}$ denote the occurrence of air traffic congestion indicator for the aerial vehicle β_3^s in the aerial location corresponding and mapped to the a^{th} terrestrial location α_a at the y^{th} epoch t_y. Air traffic congestion is deemed not to occur and occurs when $I_C\left(\gamma 2\left(\alpha_a, \beta_3^s, t_y\right)\right) = 1$ and $I_C\left(\gamma 2\left(\alpha_a, \beta_3^s, t_y\right)\right) = 0$, respectively. The number of completed trips before and after using the using the proposed CINA are denoted θ_1 and θ_2, respectively.

$$\theta_1 = \sum_{q=1}^{Q}\sum_{s=1}^{S}\sum_{a=1}^{A}\sum_{y=1}^{Y}\left(I_F\left(\beta_2^q\left(\alpha_a, t_y\right)\right)\right) + \left(I_F\left(\beta_3^s\left(\alpha_a, t_y\right)\right) \times I_C\left(\gamma 2\left(\alpha_a, \beta_3^s, t_y\right)\right)\right) \tag{8}$$

$$\theta_2 = \sum_{p=1}^{P}\sum_{a=1}^{A}\sum_{y=1}^{Y} I_F\left(\beta_1^p\left(\alpha_a,t_y\right)\right)\times\left(\begin{array}{l}\left|I_F\left(\beta_2^q\left(\alpha_a,t_y\right)\right)=1\right|+\\ \left|I_C\left(\gamma_2\left(\alpha_a,\beta_3^s,t_y\right)\right)=0\right|\end{array}\right) \quad (9)$$

Equation 8 describes the number of completed trips associated with the existing case. In the existing case, the cargo transport entities are the existing terrestrial vehicles, and aerial vehicles. The relation presented in Equation 9 considers that the number of trips successfully executed by the existing aerial vehicles is a product of the air traffic congestion indicator and the use indicator of the existing aerial vehicles.

Equation 9 considers the case where the proposed SPCS is included alongside the cases where existing terrestrial and aerial vehicles are used in cargo delivery. In this case, new cargo types with high susceptibility to theft and hijacking incidences are transported via the proposed SPCS. The scenario considered is one where epochs of occurrence of air traffic congestion are included.

The level of carbon emissions associated with the entities β_1^p, β_2^q and β_3^s at the a^{th} terrestrial location α_a at the y^{th} epoch t_y are denoted as $\phi\left(\beta_1^p,\alpha_a,t_y\right)$, $\phi\left(\beta_2^q,\alpha_a,t_y\right)$ and $\phi\left(\beta_3^s,\alpha_a,t_y\right)$, respectively. The associated carbon emissions in the existing case and proposed case are denoted C_1 and C_2, respectively.

$$C_1 = \sum_{q=1}^{Q}\sum_{s=1}^{S}\sum_{a=1}^{A}\sum_{y=1}^{Y} h_m\left(\beta_2^q,\alpha_a,t_y\right)\phi\left(\beta_2^q,\alpha_a,t_y\right)I\left(\beta_2^q,\alpha_a,t_y\right)+ h_m\left(\beta_3^s,\alpha_a,t_y\right)\phi\left(\beta_3^s,\alpha_a,t_y\right)I\left(\beta_3^s,\alpha_a,t_y\right) \quad (10)$$

$h_m\left(\beta_2^q,\alpha_a,t_y\right)$ and $h_m\left(\beta_3^s,\alpha_a,t_y\right)$ are the operational proportion where the hybridized implementation of the vehicular entities β_2^q and β_3^s are using renewable energy in the a^{th} terrestrial location α_a at the y^{th} epoch t_y, respectively.

$I\left(z,\alpha_a,t_y\right)\in\{0,1\}, z\in\left\{\beta_2^q,\beta_3^s\right\}$ is the location indicator for entity z. The entity z is inactive and active in the a^{th} terrestrial location α_a at the y^{th} epoch t_y when $I\left(z,\alpha_a,t_y\right)=0$ and $I\left(z,\alpha_a,t_y\right)=1$, respectively.

The associated carbon emissions for the proposed case (utilizing CINA and SPCS) is modelled as arising from the difference between the carbon emissions for the existing terrestrial and aerial logistics vehicles. This is because the proposed SPCS is considered as being suitable when there is a gap and neither terrestrial transport entity nor aerial transport entity is deemed appropriate.

$$C_2 = \sum_{q=1}^{Q}\sum_{s=1}^{S}\sum_{P=1}^{P}\sum_{a=1}^{A}\sum_{y=1}^{Y} A_1\left(q,s,a,y\right)A_2\left(q,s,a,y\right)\left(1-h_o\left(\beta_1^p,\alpha_a,t_y\right)\right) \quad (11)$$

$$A_1\left(q,s,a,y\right)=\left|h_m\left(\beta_2^q,\alpha_a,t_y\right)-h_m\left(\beta_3^s,\alpha_a,t_y\right)\right| \quad (12)$$

$$A_2\left(q,s,a,y\right)=\left|\phi\left(\beta_2^q,\alpha_a,t_y\right)-\phi\left(\beta_3^s,\alpha_a,t_y\right)\right| \quad (13)$$

$h_o\left(\beta_1^p,\alpha_a,t_y\right)$ is the proportion of time when the SPCS chemical payload is active. It values lie in the range $0 < h_o\left(\beta_1^p,\alpha_a,t_y\right) < 1$.

6 Performance evaluation

The performance evaluation related results is presented and discussed in this section. The simulation considered two cases, i.e., Case 1, and Case 2. Case 1 is one in which terrestrial vehicles and aerial vehicles alone are used for cargo transport. This is the existing case. Case 2 involves the introduction of the proposed SPCS alongside the terrestrial vehicle and aerial vehicle. The increased diversity enables the transport of high cost and high risk cargo with high theft and hijacking susceptibility as recognized by the protected asset transportation association. Examples of such items include refined and pure minerals in the post-processing stage or military aerial hardware moving through unsafe terrain. The metrics evaluated for Case 1, and Case 2 are the total number of trips and volume of emitted carbon.

The performance evaluation is executed via simulation. The simulation is done in MATLAB with the parameters presented in Table 3. The Equations 10–12, and 13 are utilized to investigate the carbon emissions in the performance evaluation. The performance parameters presented in Table 3 describe a scenario where the existing approach utilizes existing terrestrial cargo vehicle and aerial cargo vehicle. In this case, the terrestrial and aerial cargo vehicles are jointly utilized. The terrestrial cargo vehicle being used for more simulation epochs. In the proposed scenario, the SPCS is used for the entire simulation epoch. Furthermore, there are no incidences of air traffic congestion for the existing case and proposed case. Terrestrial cargo vehicles are deemed to emit a maximum volume of carbon of 0.969m^3. This is feasible in a week or on a daily basis as seen in Zhang et al. (2024). Aerial cargo vehicles, i.e., aviation cargo emits a maximum volume of carbon of 7.9 m^3 for a cargo plane that has travelled 2 km and which emits 10.7 kg of carbon for every kilometre. This is feasible for a scenario in which the cargo plane is considered to have a smaller carbon emission than passenger planes such as the Boeing 777 (Kumar and Rutherford, 2024). However, the choice of the emitted carbon in Table 3 is lower than that found in Zhang et al. (2024) and Kumar and Rutherford (2024). Therefore, a conservative choice of the emitted carbon has been considered in the simulation to prevent a greedy estimate of the performance benefit of the proposed CINA. In the simulation drones have not been used as the transportation of high mass and high weight cargo is being considered.

The cargo transport scenario being considered has a duration of 10 h for multiple cargo deliveries between different locations. In the existing case, aviation cargo transport solutions are deemed to be used for at least a duration of 4% of the total 10 h period, i.e., 24 min, and for at most 99.95% of the 10 h period, i.e., 599 min. In addition, terrestrial cargo transport solutions are used for at most a duration of 95.4% of the 10 h period, i.e., 572 min. The simulation considers a scenario where multiple cargo transport assets in the existing case and proposed case are deployed to deliver cargo over different routes. For the proposed SPCS, the deployed chloroplast has varying functional duration proportion out of the 10 h period. The minimum and maximum functional duration of the synthetic chloroplast are 26 min, and 588 min, respectively. Minimum functional duration is applicable to a case where low carbon emissions are detected. The maximum functional duration is applicable to a case where high carbon missions are detected.

The results for the total number of trips and volume of emitted carbon are presented in Figures 3, 4, respectively.

The results presented in Figure 3 shows that an increasing number of trips can be executed given the adoption of the proposed

TABLE 3 Simulation parameters used for performance evaluation.

S/N	Parameter	Value
1	Proportion of Epochs for which the Terrestrial Cargo Vehicle is active	50%
2	Proportion of Epochs for which the Aerial Cargo Vehicle is active	20%
3	Proportion of Epochs for which the proposed SPCS is active	100%
4	Proportion of Epochs for which Air Congestion is active	0%
5	Minimum Volume of Carbon Emitted by Terrestrial Cargo Vehicle	0.179 m^3
6	Mean Volume of Carbon Emitted by Terrestrial Cargo Vehicle	0.553 m^3
7	Maximum Volume of Carbon Emitted by Terrestrial Cargo Vehicle	0.969 m^3
8	Minimum Volume of Carbon Emitted by Aerial Cargo Vehicle	0.0200 m^3
9	Mean Volume of Carbon Emitted by Aerial Cargo Vehicle	0.2822 m^3
10	Maximum Volume of Carbon Emitted by Aerial Cargo Vehicle	0.9193 m^3
11	Minimum Operational Proportion of Terrestrial Cargo Vehicle	0.14%
12	Mean Operational Proportion of Terrestrial Cargo Vehicle	41.32%
13	Maximum Operational Proportion of Terrestrial Cargo Vehicle	95.4%
14	Minimum Operational Proportion of Aerial Cargo Vehicle	2.36%
15	Mean Operational Proportion of Aerial Cargo Vehicle	53.61%
16	Maximum Operational Proportion of Aerial Cargo Vehicle	99.95%
17	Minimum Operational Proportion of the SPCS Hosted Chloroplast	4.34%
18	Mean Operational Proportion of the SPCS Hosted Chloroplast	53.07%
19	Maximum Operational Proportion of the SPCS Hosted Chloroplast	98.00%

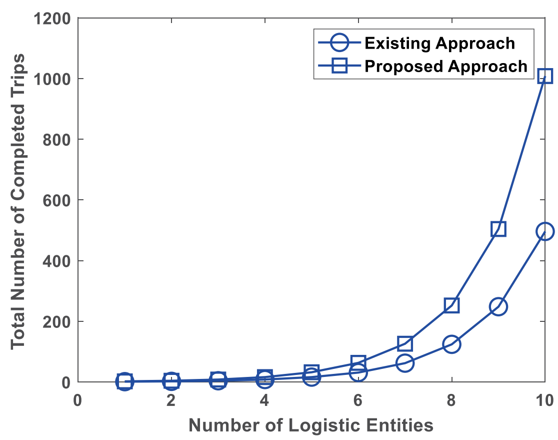

FIGURE 3
Performance evaluation showing the total number of completed trips in the absence of the occurrence of air congestion.

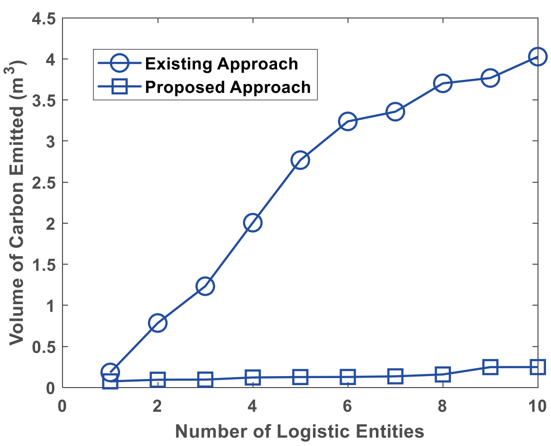

FIGURE 4
Performance evaluation showing the volume of carbon emitted in the absence of air congestion.

approach in comparison to the existing case. In the existing case, the proposed SPCS is not used while in the proposed case, a limited number of existing aerial cargo related technology is still incorporated. This enables the realization of a diversity as envisaged for Case 2 in the considered simulation scenario. Analysis of the results in Figure 3 shows that the use of the proposed approach instead of the existing approach increases the number of completed trips by 50.4%. The increase in the number of successful trips has been observed for a case where the air congestion is 0%. In the case where the air congestion increase, there is a drop in the performance improvement. An increase in the air congestion number of occurring epochs by 10, 20, 30, 40 and 50% reduces the number of successful trips by an average of 30.4, 16.3, 7.94, 3.62, and 1.56%, respectively.

The use of the proposed approach instead of the existing approach demonstrates that the adoption of the proposed SPCS is more environment-friendly. This is due to the significant reduction in the volume of emitted carbon. Therefore, the volume of emitted carbon in the proposed case is lower than that in the existing case as presented in Figure 4. In addition, analysis of results in Figure 4 shows that the use of the proposed approach reduces the volume of carbon emissions by 89.6% on average.

7 Conclusion

The discussion in the presented research proposes the future use of the stratosphere for future cargo transport applications. The

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use of the stratosphere is recognized to have received significant attention with regards to realizing ubiquitous global communication networks. The discussion recognizes that terrestrial logistics and transport faces challenges from high cargo theft and hijacking incidences. The use of aerospace technologies such as that of stratospheric platforms is recognized to be more suitable in comparison to existing terrestrial cargo transport solutions due to their low susceptibility to successful cargo theft and hijacking incidences. The use of aerial cargo transport modes and technologies are also deemed unsuitable due to environmental challenges. The environmental challenges arises due to increased carbon emissions as the existing air cargo transport approach is reliant on the use of fossil fuels. The use of the stratosphere based platform (SBP) in the proposed manner also provides benefits regarding reduced cargo transport time. The reduced air resistance in the stratosphere (hosting SBPs) in comparison to the troposphere (hosting existing air cargo transports). Furthermore, SBPs are beneficial to the environment as they use onboard renewable solar energy. This enables them to have lower carbon emissions in comparison to existing terrestrial and aerial logistics assets. The presented research also proposes the use of stratospheric platforms as active carbon removal entities. In this capacity, stratospheric platforms host synthetic chloroplasts aboard a chemical payload. Performance evaluation shows that the use of SBPs enables the future transport solutions provider to complete more trips while reducing the carbon emissions. Future work aiming to conduct a pilot study or real life test for a use case scenario will be considered as part of next phase research. In addition, future work aims to conduct a techno-economic analysis incorporating a qualitative research survey. The aim of the qualitative survey is to acquire data regarding the adoption of stratospheric platforms in the transport sector for developing countries.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AP: Formal analysis, Investigation, Conceptualization, Writing – original draft, Writing – review & editing. OL: Formal analysis, Investigation, Project administration, Supervision, Writing – review & editing, Conceptualization. OO: Formal analysis, Investigation, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aoki, R., Inui, Y., Okabe, Y., Sato, M., Takeda-Kamiya, N., Toyooka, K., et al. (2024). Incorporation of photosynthetically active algal chloroplasts in cultured mammalian cells towards photosynthesis in animals. *Proc. Japan Acad. Ser. B* 100, 524–536. doi: 10.2183/pjab.100.035

Arum, S. C., Grace, D., and Mitchell, P. D. (2022). Delivering extended cellular coverage and capacity using high-altitude platforms. *Electronics* 11:1508. doi: 10.3390/electronics11091508

Bagloee, S. A., Tavana, M., Asadi, M., and Oliver, T. (2016). Autonomous vehicles: challenges, opportunities, and future implications for transportation policies. *J. Modern Trans.* 24, 284–303. doi: 10.1007/s40534-016-0117-3

Barras, C. (2020). Cyber-spinach turns sunlight into sugar', Nature, News, 07 May 2020.

Basyooni, M. A., Zaki, S. E., Tihtih, M., Boukhoubza, Issam, En-nadir, Redouane, and Attia, G. F., (2023). Fundamentals and classifications of CO_2 sensors. pp. 1–36.

Burns, A.J., Johnson, M., Jung, J., and Fladeland, M., (2023). High altitude platform system (HAPS) communication support for wildland firefighting – annual estimates and considerations', NASA STI Program Report Series, pp. 1–29.

Cizrelioğullari, M. N., Imanov, T. V., Gunay, T., and Amir, A. S. (2023). Trend in tropopause warming and its influence aircraft performance. *Aircr. Eng. Aerosp. Technol.* 96, 1014–1025. doi: 10.1108/aeat-05-2022-0128

Clausen, U., Frye, H., and Sieke, H. (2013). "Integrated air cargo hub (IACH)" in The air cargo transport chain of the future. eds. U. Clausen, M. ten Hompel and M. Klumpp, Efficiency and Logistics (Springer, Berlin, Heidelberg: Lecture Notes in Logistics).

Coutinho, H., Toledo, J. A., Adolpho, L., and Maia (2023). Design and implementation of a low-cost and low-power converter to drive a single-phase motor. *Mach. Des.* 11:673. doi: 10.3390/machines11070673

Dicandia, F. A., Fonseca, N. J. G., Bacco, M., Mugnaini, S., and Genovesi, S. (2022). Space-air-ground integrated 6G wireless communication networks: a review of antenna technologies and application scenarios. *Sensors* 22:3136. doi: 10.3390/s22093136

Dubey, R., Telles, A., Nikkel, J., Cao, C., Gewirtzman, J., Raymond, P. A., et al. (2024). Low-cost CO2 NDIR sensors: performance evaluation and calibration using machine learning techniques. *Sensors* 24:5675. doi: 10.3390/s24175675

Dursun, M. T. (2021). Web tabanlı astro-turizm: aas worldwide telescope programı. *Balıkesir Üniversitesi Sosyal Bilimler Enstitüsü Dergisi* 24, 1333–1342. doi: 10.31795/baunsobed.1022255

Frontex and European Union (2023). HAPS market report: research study on high-altitude pseudo satellites.

Gan, P., Li, R., Wang, S., and Luo, J. (2019). Chloroplasts—beyond energy capture and carbon fixation: tuning of photosynthesis in response to chilling stress. *Int. J. Mol. Sci.* 20:5046. doi: 10.3390/ijms20205046

GSMA (2022). High altitude platform systems towers in the skies version 2.0. Available at: https://www.gsma.com/futurenetworks/wp-content/uploads/2022/02/HAPS-Towers-in-the-skies-draft-v-2.1-clean.pdf (Accessed March 10, 2024).

HAPS Alliance (2020). Loon–the stratosphere, High Altitude, Higher Ambitions. May 1, 2020, Available at: https://hapsalliance.org/wp-content/uploads/formidable/12/Stratosphere_Whitepaper_May1-1.pdf (Accessed July 13, 2022).

HAPS Alliance (2021). Creating an enabling regulatory environment for HAPS deployment. Available at: https://hapsalliance.org/wp-content/uploads/formidable/12/Creating_an_Enabling_Regulatory_Environment_for_HAPS_Deployment_-_HAPS_Alliance_-_February_2021_.pdf (Accessed July 13, 2022).

HAPS Alliance (2021). Driving the potential of the stratosphere', Available at: https://hapsalliance.org/wp-content/uploads/formidable/12/Driving_the_potential_of_the_stratosphere_HAPSAlliance_082021.pdf (Accessed July 13, 2022).

HAPS Alliance (2024). High altitude Platform Station: HAPS certification pathways.

Hokazono, Y., Kishiyama, Y., and Asai, T. (2021). Research on NTN technology for 5G evolution and 6G. *NTT Tech. Rev.* 19, 35–43. doi: 10.53829/ntr202111fa3

International Civil Aviation Organization. (n.d.). Working paper – Agenda item 31: Aviation safety and air navigation standardization – Higher airspace operations. A41 – WP/85 TE/14, 26/7/22.

ITU (2002). Report on high altitude platform stations: an opportunity to close the information gap', ITU-D study group 2nd study period (1998–2002).

Jet Propulsion Laboratory (2022). NASA's stratospheric balloon mission gets telescope with giant mirror. Available at: https://phys.org/news/2022-06-nasa-stratospheric-balloon-mission-telescope.html (Accessed March 15, 2024).

Justus, M., Ceccato, V., Moreira, G. C., and Kahn, T. (2018). "Crime against trading: the case of cargo theft in São Paulo" in Retail crime: International evidence and prevention. eds. V. Ceccato and R. Armitage (Cham: Springer International Publishing), 297–323.

Kasten, P., Bracker, J., Hacker, F., and Timpe, C., (2017). Climate benefit from electromobility: will it happen automatically? Insights from the BMUB project 'ensuring climate benefit from electromobility. In: Netzintegration der Elektromobilität.

Kavlak, H., Ertem, M. A., and Satir, B. (2022). Intermodal humanitarian logistics using unit load devices. *Arab. J. Sci. Eng.* 47, 3821–3846. doi: 10.1007/s13369-021-06001-y

Kellner, F. (2022). Generating greenhouse gas cutting incentives when allocating carbon dioxide emissions to shipments in road freight transportation. *OR Spectr.* 44, 833–874. doi: 10.1007/s00291-022-00675-y

Kumar, S.N., and Rutherford, D., (2024). Lifetime emissions from aircraft under a net-zero carbon budget. The International Council on Clean Transportation.

Kurt, G. K., Khoshkholgh, M. G., Alfattani, S., Ibrahim, A., Darwish, T. S. J., Alam, M. S., et al. (2021). A vision and framework for the high altitude Platform Station (HAPS) networks of the future. *IEEE Commun Surv Tutor* 23, 729–779. doi: 10.1109/COMST.2021.3066905

Lebkowski, A., (2017). Electric vehicle trucks, – overview of technology and research selected vehicle. Zeszyty Naukowe Akademii Morskiej w Gdyni, nr 98, marzec, pp. 157–165.

Li, C., Cao, Y., Zhang, M., Wang, J., Liu, J., Shi, H., et al. (2015). Hidden benefits of electric vehicles for addressing climate change. *Sci. Rep.* 5:9213. doi: 10.1038/srep09213

Lieret, M., Kreis, B., Hofmann, C., Zwingel, M., and Franke, J. (2022). Aerial grasping and transport Using an unmanned aircraft (UA) equipped with an industrial suction gripper. In: *Ann. Sci. Soc. Assem., Hand. Indust. Robot 2021*. (eds) Schüppstuhl, T., Tracht, K., Raatz., A. Cham: Springer. doi: 10.1007/978-3-030-74032-0_8

Lobner, P., (2024). CIRA high altitude platform systems (HAPS).

Miller, T. E., Beneyton, T., Schwander, T., Diehl, C., Girault, M., McLean, R., et al. (2020). Light – powered CO2 fixation in a chloroplast mimic with natural and synthetic parts. *Science* 368, 649–654. doi: 10.1126/science.aaz6802

Miyakawa, J. (2019). Stratospheric telecommunications platform HAPS. Available at: https://cdn.softbank.jp/en/corp/set/data/news/conference/pdf/material/20190425_01.pdf (Accessed July 13, 2022).

Mlepo, A. T. (2022). Attacks on road-freight transporters: a threat to trade participation for landlocked countries in southern Africa. *J. Transp. Secur.* 15, 23–40. doi: 10.1007/s12198-021-00242-6

Mlynczak, M. G., Hunt, L. A., Garcia, R., Lopez-Puertas, M., Mertens, C. J., Nowak, N., et al. (2024). Energy conservation in the cooling and contracting upper mesosphere and lower thermosphere. *Geophys. Res. Lett.* 51:9757. doi: 10.1029/2024gl109757

Moussa, R. R. (2022). Reducing carbon emissions in Egyptian roads through improving the streets quality. *Environ. Dev. Sustain.* 25, 4765–4786. doi: 10.1007/s10668-022-02150-8

Ngcaba, A. (2020). Building Africa's high altitude Platform Station (HAPS) ecosystem. Avalable at: http://andile.co.za/index.php/2020/11/02/building-africas-high-altitude-platform-station-haps-ecosystem/

Ollila, A. (2023). Radiative forcing and climate sensitivity of carbon dioxide (CO2) fine-tuned with CERES data. *Curr. J. Appl. Sci, Technol.* 42, 111–133. doi: 10.9734/cjast/2023/v42i464300

Oloyede, A., Grace, D., and Faruk, N. (2023). A techno-economic model for future deployment of fixed broadband services to stimulate development across rural Africa. *Int. J. Mob. Commun.* 21:181. doi: 10.1504/IJMC.2023.128819

Othmann, K. (2022). Exploring the implications of autonomous vehicles: a comprehensive review. *Innov. Infrastruct. Solut.* 7:165. doi: 10.1007/s41062-022-00763-6

Pelton, J. N. (2020). "High altitude platform systems (HAPS) and unmanned aerial vehicles (UAV) as an alternative to small satellites" in Handbook of small satellites: Technology, design, manufacture, applications, economics and regulation. eds. J. N. Pelton and S. Madry (Cham: Springer), 385–399. doi: 10.1007/978-3-030-36308-6_19

Periola, A. (2018). Incorporating diversity in cloud-computing: a novel paradigm and architecture for enhancing the performance of future cloud radio access networks. *Wirel. Netw* 25, 3783–3803. doi: 10.1007/s11276-018-01915-2

Periola, A. A. (2023). Power usage effectiveness in stratosphere based computing platforms: re-evaluation and need to re-establish performance benefits via an intelligent light server selection architecture. *Wirel. Pers. Commun.* 132, 1577–1591. doi: 10.1007/s11277-023-10676-x

Periola, A. A. (2024). TCP Stratos for stratosphere based computing platforms. *J. Cloud Comput.* 13, 1–27. doi: 10.1186/s13677-024-00620-0

Periola, A. A., Alonge, A. A., and Ogudo, K. A., (2020). Intelligent scheduling for stratosphere cloud platforms, " 2020 international conference on artificial intelligence, big data, Computing and Data Communication Systems (ic ABCD). pp. 1–7.

Periola, A. A., Alonge, A. A., and Ogudo, K. A., (2022). "Renewable energy systems - carbon removal and light component diversity." in 2022 30th Southern African Universities Power Engineering Conference (SAUPEC).

Periola, A. A., and Falowo, O. E. (2018). Instrumentation location diversity paradigm for future astronomy observations. *Wirel. Pers. Commun.* 103, 2475–2499. doi: 10.1007/s11277-018-5940-x

Periola, A. A., Ogudo, K. A., and Alonge, A. A. (2023). Realizing the potential of stratosphere utilization via stratosphere data centers.

Peter (2023). A look at cargo crimes reported to the TAPA EMEA intelligence system (TIS) in the first nine months of 2023," TAPA EMEA. Availale at: https://tapaemea.org/news/a-look-at-cargo-crimes-reported-to-the-tapa-emea-intelligence-system-tis-in-the-first-nine-months-of-2023/ (Accessed December 26, 2024)

Peters, L. J. B., Chattopadhyay, G., and Tuck, M. A. (2023). Studies on the impact of road freight transport and alternative modes in Australia: a literature study. *Int. J. Syst. Assur. Eng. Manag.* 14, 954–960. doi: 10.1007/s13198-022-01693-3

Pineda, J.L., Siles, J.V., Kawamura, J., Langer, W.D., Goldsmith, P.F., Lis, D C, et al. (2019). The far-infrared astronomy stratospheric balloon facility. Astro 2020: decadal survey on astronomy and astrophysics, APC White Papers, No 177.

Setiawan, E., (2018). The potential use of high altitude Platform Station in rural telecommunication infrastructure, " 2018 international conference on ICT for rural development (IC-ICTRuDev), pp. 35–37.

Singya, P. K., and Alouini, M.-S. (2022). Mixed FSO/RF based multiple HAPs assisted multiuser multiantenna terrestrial communication. *Front. Comms. Net* 3:746201. doi: 10.3389/frcmn.2022.746201

Speight, J. G. (2017). Chemicals and the environment. *Environ. Org. Chem. Eng.*, 1–41. doi: 10.1016/b978-0-12-804492-6.00001-0

Sriram, A., (2024). Sceye partners with NASA, USGS to monitor wildfires, storms from the edge of space," Reuters,. Available at: https://www.reuters.com/technology/space/sceye-partners-with-nasa-usgs-monitor-wildfires-storms-edge-space-2024-10-29/ (Accessed January 4, 2025).

Szondy, D. (2022). 'Stratospheric balloon to lift telescope with giant mirror over Antarctica.' Available at: https://newatlas.com/space/nasa-giant-telescope-mirror-stratosphereover-antarctica-balloon/

TAPA (2023). €19.2m of cargo stolen from supply chains in EMEA in 30 days – TAPA EMEA. Availale at: Tapaemea.org. https://tapaemea.org/news/e19-2m-of-cargo-stolen-from-supply-chains-in-emea-in-30-days/ (Accessed December 08, 2024).

Urciuoli, L. (2020). Fuel theft in road freight transport: understanding magnitude and impacts of anti-theft devices. *J. Transp. Secur.* 13, 1–18. doi: 10.1007/s12198-020-00207-1

Yazici, A. M., and Tiwari, S. (2021). Space tourism: an initiative pushing limits. *J. Tour. Leisure Hosp.* 3, 38–46. doi: 10.48119/toleho.862636

Zhang, Y., Gao, Y., Zheng, Y., Li, N., and Dai, X. (2024). Analysis of truck carbon emissions per month on highway road. *Adv. Eng. Res.*, 191–202. doi: 10.2991/978-94-6463-516-4_23