

Novel tier reclassification architecture for non–terrestrial data centre systems

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Abstract

Data centres play an important role in hosting and enabling content access in wireless communication networks and computing applications. The use of data centres is accompanied with high operational costs due to the necessity of powering and cooling. In addition, data centres are mostly terrestrial facilities with different performance levels influenced by the data centre tier rating. The need to reduce operational costs has prompted the siting of data centres in non–terrestrial locations such as the ocean and stratosphere with free cooling benefits. The location of future data centres raises new challenges such as reclassifying data centre Tiers. The Tier reclassification challenge should be addressed to identify factors that influence the performance of non-terrestrial data centres. This paper addresses the challenge of designing tier classification architecture for non-terrestrial data centre systems. In this paper, primary and secondary criteria required for the Tier classification of ocean and stratosphere data centres are identified. The proposed tier re–classification architecture is also compared with the Tier 5 data centre standard recently proposed for terrestrial data centres.

Keywords: *Future Computing, Networking, Data Centres, Non–Terrestrial Locations, Tier Re–Classification*

Introduction

Data centres play an important role in cloud computing and future networks. They have different performance levels in terms of availability (fraction of period in a year where the data centre is expected to be function) and support for redundancy. The performance level of a data centre facility is described by the data centre’s tier rating. Data centres are classified into different Tiers i.e. Tier I, Tier II, Tier III and Tier IV (Rytoft, 2013; Balodis et al. 2012, Chen et al, 2016, Uptime Institute, 2018). The requirements considered in each Tier classification are system component redundancy, number of distribution paths, compartmentalization, fault tolerance and concurrent maintainability (Turner et al., 2008). Some of the additional parameters that are also used to determine data centre performance are power usage effectiveness (PUE) (Ayanoglu, 2019), water usage effectiveness (WUE) (Penaherrera, 2018) and water footprint (WF) (Evans et al, 2016). The WUE and WF derive their importance from the reliance of data centres on water for cooling. The aforementioned criteria used in the existing data centre Tier classification applies only to terrestrial data centres.

The necessity of cooling increases data centre operational costs. This has motivated data centre operators to seek solutions to reduce data centre operational costs and enhance the PUE. An approach from Google using the Google DeepMind artificial intelligence solution is described in (Evans et al, 2016). Data centre operational costs can also be reduced by siting data centres in non-terrestrial locations such as the ocean (Periola et al, 2020, Cutlers et al, 2017, Periola, 2019) and the stratosphere (Periola, 2019). Ocean data centres benefit from the low temperature available at the ocean's depths. In a similar manner, stratospheric cooling is beneficial to the cooling of stratosphere data centres.

The siting of data centres in the ocean and stratosphere pose new challenges to the environment because they directly interact with the environment and influence biological conservation. This is because the ocean and stratosphere cannot be easily partitioned like the terrestrial domain. Besides the biological conservation challenge, ocean and stratosphere data centres are affected by different physical threats such as aerial and underwater missiles. These factors necessitate re-classifying data centre tiers arising from a change in the geographical location. A change in the geographical location necessitates considering environmental sustainability concerns. The inclusion of environmental sustainability necessitates re-designing data centre Tier classification. The reclassification of Tiers for data centres sited in non-terrestrial locations enables the identification of suitable infrastructure, enabling energy and communication technologies, security and environmental concerns. These factors influence the functioning of non-terrestrial data centres and are identified for stratosphere and ocean-based data centres. This paper addresses the challenge of classifying Tiers for ocean and stratosphere data centres. The challenge is addressed by discussing the performance concerns (alongside identifying the required technologies) for data centres in the ocean and the stratosphere.

The contributions of this paper are described as follows:

- 1) The paper proposes tier classification architecture for non-terrestrial data centres. The proposed classification architecture uses criteria in two categories. The first category is the primary criteria that focus on the technological specifications required for the realization, ensuring the continued functioning of data centres at a given non-terrestrial geographical location. The concern of ensuring addressing environmental sustainability and preserving biodiversity at a given non-terrestrial location is also a primary criterion. The secondary criteria focus on how non-terrestrial data centres interact with existing applications at a given non-terrestrial location, potential applications and required supporting technologies for data centre located in a given non-terrestrial location.
- 2) Second, the paper identifies and discusses the role of primary and secondary criteria for stratosphere-based data centres. In this case, the primary criteria are stratosphere altitude and location, aerial vehicle classification, physical security, influence on avian habitat and supported communication capability. The secondary criteria are number of existing aerial applications, aviation policy, number of service providers, and support for open computing, computing payload technology and operational stratosphere temperature.
- 3) Third, the paper identifies and discusses the role of primary and secondary criteria for ocean-based data centres. The primary criteria are location i.e. ocean zone, vessel category, number of computing platform service providers, electricity and power consumption, marine

conservation interests, and security. The secondary tier classification criteria for ocean-based data centres are computing payload architecture, computing payload update frequency, type of computing payload, number of accessible underwater optic cables, and support for compute intensive deep learning workload.

- 4) In addition, the discussion in the paper describes how different values of the factors considered in the primary and secondary criteria are combined to give rise to the emergence of novel Tier classification names in the proposed non – terrestrial data centre Tier classification architecture.

This paper is divided into three parts. Sections 2 and 3 discuss data centre Tier re-classification for ocean and stratosphere-based data centres, respectively. Section 4 is the conclusion.

1. Tier Re-Classification of Ocean Based Data Centres

The ocean-based data centre is sited in an environment where marine biodiversity conservation is important. An ocean-based data centre can be located in different ocean regions depending on the ocean's depths. The ocean's regions are the (1) Epipelagic, (2) Mesopelagic, (3) Bathypelagic, and (4) Abyssopelagic zones. The support for scalability should also be considered in underwater data centre Tier classification. Additional factors that should be considered include data centre upgrade costs, vessel category (required for inserting and removing the underwater data centre from the ocean), size of data centre crew, and number of cloud service providers owning the data centre payload. Furthermore, the source of power for operating the underwater data is considered to be the grid, renewable or hybrid. Grid-based underwater data centres derive their operational electricity from the grid as seen in the Phase 2 of Microsoft Project Natick tested at Orkney Island, UK (Roach, 2018). Renewable energy based underwater data centres utilize tidal or wave or marine energy for operation. These underwater data centres have onboard wave energy generators. Hybrid underwater data centres utilize electricity from the grid and renewable sources.

In addition, the performance of underwater data centres should consider the role of additional parameters such as system component redundancy, fault tolerance, concurrent maintainability, number of distribution paths and compartmentalization. It is also necessary to determine the re-usability of some performance factors and metrics that have been previously defined and found to be suitable for terrestrial data centres. Nevertheless, a peculiar factor such as the unique design of the suitable artificial reef that supports computing payload arises due to the use of underwater technology and should be recognized. The approach of a uniquely design artificial reef is considered for two reasons. First, it allows cloud service providers to develop artificial reefs that suit their preferences. Second, artificial reef data centre standards are yet to be defined.

The Tier classification of underwater data centres considers the following factors (arising from the use of the underwater environment).

Location: These are the Epipelagic, Mesopelagic and Bathypelagic and Abyssopelagic zones.

Vessel Category: This describes the class of vessel required to execute all the procedures related to underwater data centres. The vessel or ship classification is done utilizing standards such as that provided by the American Bureau of Shipping (Flis, 2016). The American Bureau of shipping provides information suitable for classifying marine vessels. This can be seen in the marine vessel

and mobile offshore unit rules. Another example of an existing standard is the UK's Merchant ship classification and certification (Maritime and Coastguard Agency, 2018). Research work on marine vessel classification can be found in (Gol et al, 2014).

Number of Computing Platform Service Providers: An underwater data centre can host servers belonging to different computing platform service providers. The number of computing service providers that collectively own the servers aboard the underwater data centre indicates the complexity associated with handling and executing tasks related to the underwater data centre.

Electricity and Power Consumption: The data centre can be deemed grid, renewable or hybrid.

Marine Conservation Interests: In the consideration here, underwater data centres are considered to have varying levels of influence with regard to ensuring marine conservation. Three levels of influence i.e. threat levels have been considered. Each of these threat levels describes the ability of underwater data centre to potentially harm marine life at a given underwater location. The threat levels are least threats, medium threats and high threats. Underwater data centres with least threats are sited in ocean regions where their operation affects the smallest number of marine animals and mammals. This can arise when the underwater location has the smallest population of species (marine life and coral reefs). The underwater data centre has a medium threat when sited in regions where the number of marine animals and mammals are considerable. Medium threat underwater data centres are sited in regions with more marine species than least threat underwater data centres. The high threat underwater data centre is one that is sited in an underwater region with a considerably high number of marine animals and mammals.

Security: Underwater data centres have more physical exposure than terrestrial data centres due to the existence of applications in the ocean. Technological advancements make underwater data centres susceptible to threats from underwater missiles with advanced technology. This is because of the increasing sophistication of underwater missile technology (Karako et al, 2017; NMHB, 2020; Woolf, 2020). From the perspective of the threat potential, underwater data centres are classified as low missile threats (LMTs) and high missile threats (HMTs). LMTs and HMTs are sited in regions belonging to developing nations and developed nations, respectively. The factors of location, vessel category, number of computing platform service providers, electricity and power consumption, marine conservation interests and security are the primary criteria for Tier classification of an underwater data centre.

The secondary criteria for the Tier classification of underwater data centres are design and operational factors that influence the performance of the underwater data centre from a computing and networking perspective. The secondary criteria are:

(1) Computing Payload Architecture – This describes the design architecture of the computing payload used in the servers aboard the underwater data centre. The design architecture can be disaggregated or non-disaggregated.

(2) Computing payload update frequency – The upgrade frequency describes the number of epochs within a given period where the underwater data centre's payload is updated i.e. changed to one of improved technology.

(3) Type of computing payload – The type of computing payload describes the underlying data access and computing architecture used in the computing boards of servers in the underwater data centre. Type of computing payload can be either neuromorphic or non-neuromorphic.

(4) Number of accessible underwater optic cables – The number of accessible underwater optical cables describes the number of locations with access to the underwater data centre. In addition, it indicates the deliverable quality of service (QoS) by the underwater data centre to a given location.

(5) Support for compute intensive deep learning workload – The inclusion of this criterion has been deemed necessary due to the emergence of big data processing and deep learning applications. This criterion indicates the ability of the underwater data centre to support deep learning (big data driven application). In this case, the value can be either a yes or no.

The relation between an underwater data centre's primary and secondary criteria is shown in Figure 1. In Figure 1, the information on data centre availability has been obtained from (Turner et al, 2008). The Tier classification of the underwater data centres reuses some metrics from terrestrial data centre Tier classification. The underwater data centre Tier I classification has the following sub-tiers:

Tier 1a grid: The Tier 1a grid underwater data centre has the similar availability and redundancy with Tier 1 terrestrial data centre. The Tier 1a underwater data centre has the least threat to marine conservation and uses grid-based electricity.

Tier 1a renewable: The Tier 1a renewable is similar to the Tier 1a grid underwater data centre but uses renewable energy being incorporated with marine wave and tidal generators. The onboard generators convert ocean wave energy into electricity used to operate the data centre.

Tier 1a Hybrid: This is similar to the Tier 1a grid and Tier 1a renewable except that it uses a combination of electricity obtained from the grid and renewable energy sources.

The underwater data centre has a Tier 2 classification which is similar to Tier 2 terrestrial data centres. The Tier 2 classification of underwater data centres has the Tier classifications of Tier 2a grid, Tier 2a renewable and Tier 2a hybrid. The Tier 2a grid, Tier 2a renewable and Tier 2a hybrid underwater data centre are similar to the Tier 1a grid, Tier 1a renewable and Tier 1a hybrid underwater data centre, respectively. However, Tier 2 underwater data centres have different performance availability and redundancy support from Tier 1 underwater data centres for all sub – classifications described by the suffix of the energy source.

In addition, underwater data centres with a Tier 3 classification are similar to Tier 3 terrestrial data centres. The Tier 3 classification of underwater data centres has Tier classifications of Tier 3a grid, Tier 3a renewable and Tier 3a hybrid. The significant difference between the Tier 3 underwater data centre and Tier 1 underwater data centre lies in the expected performance availability and redundancy. The Tier 3 underwater data centre has a higher expected performance availability and redundancy than a Tier 2 and Tier 1 underwater data centre. This is true for all sub – classifications for a given energy source suffix.

A similar classification pattern holds true for the Tier 4a grid, Tier 4a renewable and Tier 4a hybrid. The Tier 1b grid, Tier 1b renewable and Tier 1b hybrid underwater data centres are similar to the

Tier 1a grid, Tier 1a renewable and Tier 1a hybrid underwater data centres; with the difference being that they pose medium threats to marine conservation interests.

A similar classification pattern is applicable to Tier 2b grid, Tier 2b renewable and Tier 2b hybrid underwater data centres. The Tier 3b grid, Tier 3b renewable and Tier 3b hybrid underwater data centres are similar to the Tier 3a grid, Tier 3a renewable and Tier 3a hybrid underwater data centre. However, the Tier 3b grid, Tier 3b renewable and Tier 3b hybrid underwater data centres pose medium threat to marine conservation in comparison to the Tier 3a grid, Tier 3a renewable and Tier 3a hybrid underwater data centre that pose the least threats to marine conservation.

In the underwater data centre Tier classification, alphabets with an ascending order indicate increasing threats to the realization of marine conservation. For example, the Tier 1a grid underwater data centre has similar availability and redundancy with a Tier 1b grid underwater data centre. However, the latter data centre (i.e. Tier 1b grid underwater data centre) poses a higher threat to marine conservation than the former (i.e. Tier 1a grid underwater data centre). In the proposed classification architecture, the underwater data centre Tier 1a grid is deemed to pose the least threat to marine conservation while the underwater data centre Tier 1b grid poses medium threat to marine conservation. An underwater data centre given as Tier 1c grid is considered to pose the highest threats to marine conservation.

Furthermore, the information on the values of the primary and secondary criteria can be accessed from the metadata of the concerned underwater data centre. The values of primary criteria such as vessel class and location can be accessed from the primary metadata. In a similar manner, the values of secondary criteria such as computing payload architecture and support for compute intensive deep learning workload can be accessed from the underwater data centre's secondary metadata.

A comparison of the different Tiers for underwater data centres is shown in Table I. In Table I, criteria whose parameters can have a wide range of values without loss of performance are specified as variable.

Table I: Criteria values and comparison for Tier 1 classifications for an underwater data centre.

Metric	Tier 1a Grid	Tier 1a-Renewable	Tier 1a Hybrid	Tier 1b Grid	Tier1b Renewable	Tier 1b Hybrid
Grid	Yes	No	Yes	Yes	No	Yes
Renewable	No	Yes	Yes	No	Yes	No
Hybrid	No	No	Yes	No	No	Yes
Conservation threat	Mild	Mild	Mild	Moderate	Moderate	Moderate
Location	Variable	Variable	Variable	Variable	Variable	Variable
Number of Computing Platform Service Providers	Variable	Variable	Variable	Variable	Variable	Variable
Vessel Category	Variable	Variable	Variable	Variable	Variable	Variable
Security and Threat Arising from Physical Exposure	Variable	Variable	Variable	Variable	Variable	Variable
Value of secondary criteria parameters	Variable	Variable	Variable	Variable	Variable	Variable

2. Stratosphere Based Data Centres – Tier Re – Classification

The Tier re-classification of stratosphere-based data centres is done in a similar manner to that of the ocean-based data centres. In addition to availability and redundancy configuration, the primary criteria of classifying stratosphere-based data centres are:

Stratospheric Altitude and Location- The stratosphere has three regions i.e. the lower stratosphere, middle stratosphere and upper stratosphere. The altitude associated with the lower stratosphere can be defined to be in the range 8 km–18 km (Xian et al, 2019). The altitude of the middle stratosphere is in the range of about 20 km to 40 km (Langematz et al, 2019). The upper

stratosphere's altitude can be considered to lie in the range 40 km to 50 km. This is because the stratosphere's maximum altitude is about 50km (Cervany, 2005).

Aerial Vehicle Classification- This is the aviation classification information for the type of aerial vehicle used in realizing the high-altitude platform that serves as the stratosphere data centre. Different types of aerial vehicles such as balloons, airplanes and airships can be used. The airplanes have categories such as A, B1, C, B2, B2L, B3 and L [22]. The L category has subcategories L1C and L1, L2C and L2, L3H and L3G, L4H and L4G and L5. The classification in (European Union Aviation Safety Agency, 2014) considers helicopters, complex motor-powered aircraft, sailplanes, powered sailplanes, balloons and airships.

Communication Capability- The stratosphere-based data centre is expected to communicate with organizations intending to upload and download data. This is essential to derive value from the stratosphere data centre. In this regard, advances in cognitive radio play an important role in classifying stratosphere data centres. The types of stratosphere data centres from the perspective of communications capability are cognitive radio-based stratosphere-based data centres (CRSDC) and non-cognitive radio-based stratosphere-based data centres (NCRSDC). The CRSDC and NCRSDC are capable and incapable of parameter adaptation and dynamic spectrum access, respectively.

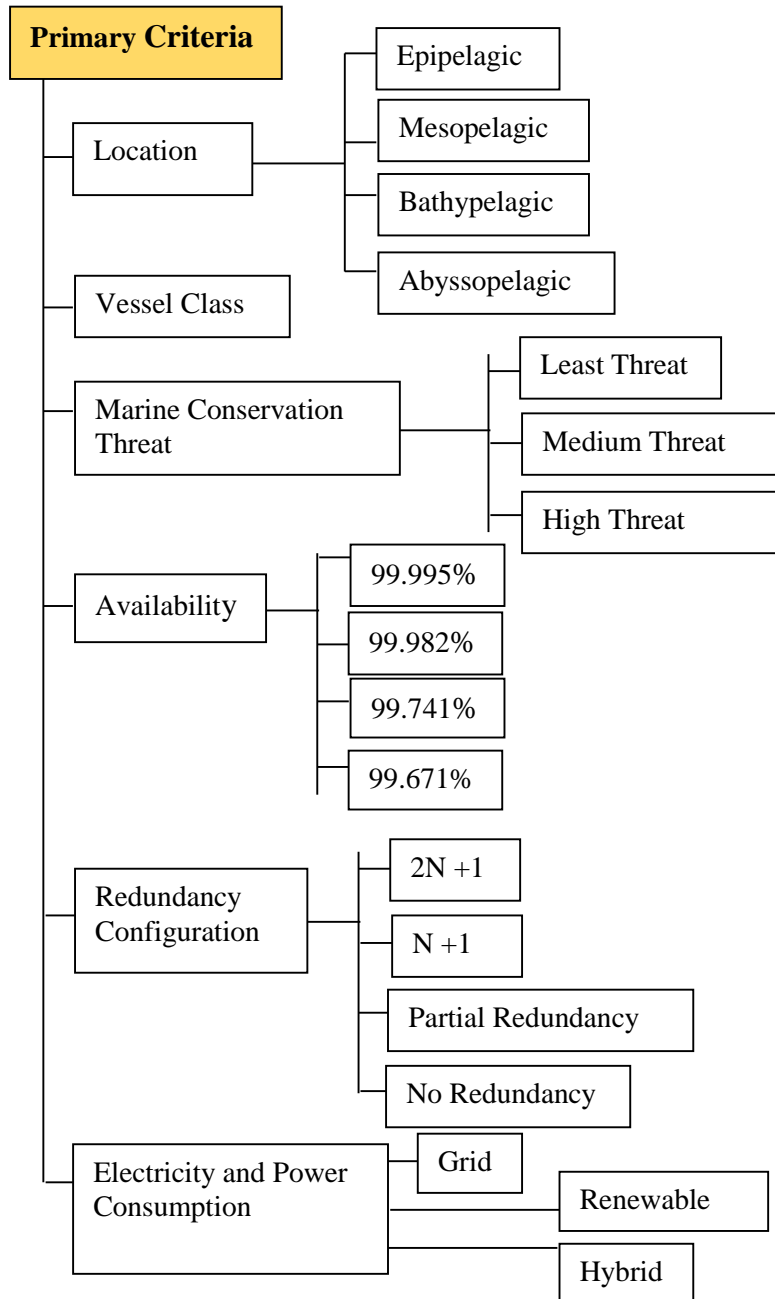


Figure 1: - Organization of Primary Criteria for Tier – Classification of Underwater Data Centres

Physical Security- The stratosphere-based data centre’s security is also deemed a primary criterion. Stratosphere data centres can be sited in regions with varying levels of aerial missile activity from malicious entities. From this perspective, the stratosphere-based data centres can be classified as low security, medium security and high security. Low security stratosphere data

centres are those with poor payload components to mitigate against aerial threats and co-exist with other applications in the stratosphere. They have a low resilience against stratospheric turbulence. Medium security stratosphere data centres host more advanced security payload than low security stratosphere data centres. They have a better resilience to stratospheric turbulence than low security stratospheric data centres. High security stratosphere data centres incorporate the most advanced security payload and have the best resilience against stratospheric turbulence. The realization of low security stratosphere data centres, medium security stratosphere data centres and high security data centres are feasible due to advances in radar technology (Greco et al, 2019).

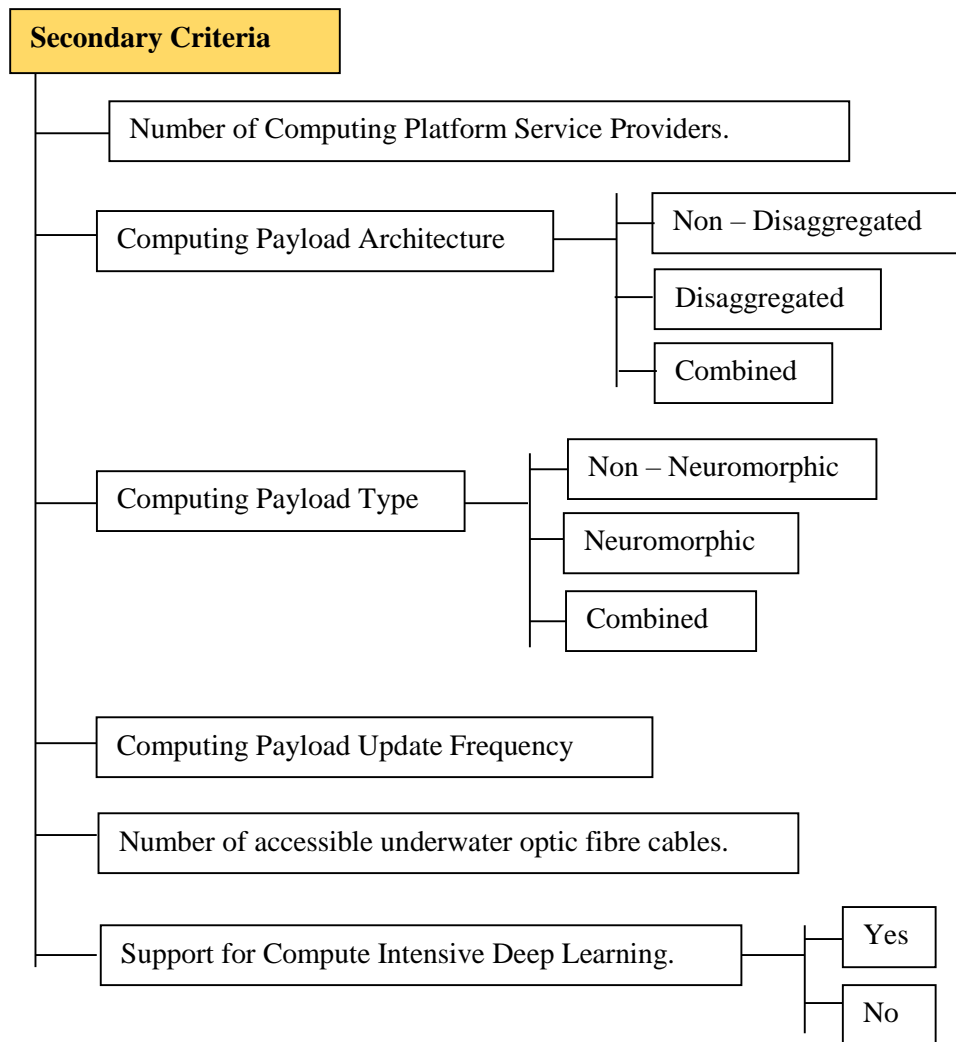


Figure 2: Organization of Secondary Criteria for Tier-Classification of Underwater Data Centres.

Radar systems have evolved from using non-dynamic spectrum access to dynamic spectrum access technologies. Conventional radars have evolved to incorporating phase scanning arrays (Wiesback et al, 2015). Future radar systems also benefit from multiple input and multiple output technologies, digital beamforming, array imaging and intelligent signal coding (Wiesback et al, 2015). In addition, improved radar system technology can be realized via the incorporation of artificial neural networks (Wan et al, 2019; Wang et al, 2019). High security stratosphere data centres incorporate artificial intelligence driven electronic radar systems. Medium security

stratosphere-based data centres incorporate advanced electronic signal processing systems but without artificial intelligence-based solutions. Low security stratosphere data centres do not incorporate advanced signal processing systems.

Influence on Avian Habitat: The deployment of data centres into the stratosphere should not endanger avian diversity at high altitudes. This is because some aves have been found to reside or migrate at high altitudes. For example, bar headed geese has been observed to fly at altitudes exceeding 8 km (Harrison, 2019) corresponding to the lower stratosphere region. The vulture and Whooper swan are noted to fly at an altitude of 11.278 km and 8.29 km, respectively. The influence on avian habitat is important due to biological conservation interests. Avian species that fly at high altitudes are mapped prior to deploying stratosphere data centres. This enables the development of a map for high altitude stratosphere avian habitats. An example of such a map is presented in (Parr et al, 2019). Stratosphere data centres are not located in stratospheric regions that support avian life. In addition, areas where stratospheric data centres disrupt bird's migration are not used as a long-term site for hosting stratosphere data centres. The information on avian life disruption is obtained from data on disturbance to the altitude and flight mechanism in stratosphere data centres.

The secondary criteria associated with the classification of stratosphere-based data centres are:

Number of Existing Aerial Applications: This is the number of applications with which stratosphere data centres share the aerial space. Examples of applications that utilize aerial vehicles in the stratosphere are: (1) Military (Harrison, 2019; Parr et al, 2019), (2) Wireless networks (Scott, 2017) and (3) Scientific Investigations (Massie, 2019).

Aviation Policy: The aviation policy describes the support by a country/sovereign region for the use of stratosphere aerial vehicles for data storage and access applications. The aviation policy also considers the compliance of the stratosphere data centre to data sovereignty policies.

Number of Service Providers: This is the number of service providers that own the servers aboard the deployed stratosphere data centre. The number of service providers influences the mobility requirements of a stratosphere data centre. A stratosphere data centre hosting computing payload belonging to a large number of service providers should be highly mobile to provide service to multiple subscribers.

Support for Open Computing: The information on the support for open computing indicates if the computing payload is non disaggregated, disaggregated or hybrid. A hybrid open computing payload supports non disaggregated and disaggregated servers. This factor has been considered to indicate the extent to which the stratosphere data centres embraces initiatives such as the open compute project. This is because disaggregated hardware and software play an important role in the open compute project (Dorn et al, 2018; ETSI, 2019).

Computing Payload Technology: The computing payload technology can be classified as non-neuromorphic, neuromorphic or hybrid computing payload (neuromorphic and non-neuromorphic).

Operational Stratosphere Temperature: The operational stratosphere temperature describes the stratospheric environmental temperature at the data centre location. A low and high temperature

indicates that the stratosphere data centre benefits and does not benefit from stratospheric cooling, respectively. Benefitting from low temperature reduces cooling energy and enhances the PUE.

The primary and secondary criteria and the categories associated with the Tier classification of stratosphere data centres are shown in Figure 3 and Figure 4, respectively. In Figure 3, the primary criterion of the influence on avian habitat has two subcategories i.e. low environment threat (LETh) and high environment threat (HETh). LETh and HETH indicates that the stratosphere data centre does not and does pose any risks of avian extinction, respectively. The classification of stratosphere data centres hinges around aerial vehicle class and stratosphere temperature. The Tier classifications for stratosphere data centres are:

Tier 1a class A: The classification of stratosphere data centres also re-uses the terrestrial data centre's performance metrics of availability and redundancy. In addition, stratosphere data centre considers the choice of aerial vehicle and the threats posed to avian life. The availability and redundancy of a Tier 1 stratosphere data centre is similar to that of a Tier 1 terrestrial data centre. The general specification for the classification of a Tier 1 stratosphere data centre is given as Tier 1 *Alphabet Class Capital Alphabet*. A stratosphere data centre with Tier 1a Class A classification poses the least environment threat i.e. LETh (due to small letter 'a') to avian life and uses the category A plane (as specified in capital letter 'A'). The additional stratosphere data centres with a Tier 1a classification are: Tier 1a class A, Tier 1a class B1, Tier 1a class B2, Tier 1a class C, Tier 1a class B2L, Tier 1a class B3 and Tier 1a class L (considering all sub-categories in class L). All the stratosphere-based data centres with the Tier 1a prefix have the same availability and redundancy, and a low environment threat for a given aerial vehicle class.

Tier 1b class A: The Tier 1b class A stratosphere data centre utilizes the class A plane with HETH to avian life. The availability and redundancy configurations are the same as that of the Tier 1 terrestrial data centre. Information on values of associated with primary and secondary criteria are specified as metadata. Additional categories in Tier 1b are Tier 1b class A, Tier 1b class B1, Tier 1a class B2, Tier 1b class C, Tier 1b class B2L, Tier 1b class B3 and Tier 1a class L (considering categories in class L).

The stratosphere data centre with availability and redundancy similar to Tier 2 terrestrial data centre (LETh) is given as Tier 2a class A, Tier 2a class B1, Tier 2a class B2, Tier 2a class C, Tier 2a class B2L, Tier 2a class B3 and Tier 2a class L (considering sub-categories in class L). In addition, the Tier 2b class A data centre (HETh) is similar to the Tier 2a class A data centre. In this case, the stratosphere data centre classifications are Tier 2b class A, Tier 2b class B1, Tier 2b class B2, Tier 2b class C, Tier 2b class B2L, Tier 2b class B3 and Tier 2b class L (considering categories in class L).

The proposed architecture uses a similar classification approach that recognizes the threat to avian life and class of aerial vehicles for the Tier 3a class A stratosphere-based data centre. In addition, the proposed Tier re-classification architecture for Tier 4 stratosphere data centres. The classification approach considers the Tier 4 classification (indicating the level of availability and redundancy which is similar to terrestrial data centres), small alphabet (to indicate the level of threat to avian life) – with letter a being the least and indicating low environmental threats; and letter c being the last alphabet (in the classification consideration) and showing high environmental

threats to avian life. The capital letter with possible values of A, B1, B2, C, B2L, B3 and L indicates the class of the aerial vehicle used to realize the stratosphere-based data centre.

A comparison of the different Tiers for stratosphere-based data centres is shown in Table II. In Table II, criteria whose parameters can have a wide range of values without loss of performance have their variables specified as variable.

Metric	Tier 1a Class A	Tier 1a- Class B	Tier 1a Class C	Tier 1b Class A	Tier1b Class B	Tier 1b Class C
Aerial Vehicle Class	A	B	C	A	B	C
Renewable	Yes (Solar)	Yes (Solar)	Yes (Solar)	Yes (Solar)	Yes (Solar)	Yes (Solar)
Threat to Aves	Mild	Mild	Mild	Moderate	Moderate	Moderate
Stratospheric Location	Variable	Variable	Variable	Variable	Variable	Variable
Number of Computing Platform Service Providers	Variable	Variable	Variable	Variable	Variable	Variable
Security and Threat Arising from Physical Exposure	Variable	Variable	Variable	Variable	Variable	Variable
Value of secondary criteria parameters	Variable	Variable	Variable	Variable	Variable	Variable

Table II: Criteria values and comparison for Tier 1 stratosphere-based data centre.

The proposed Tier classification architecture differs from the Tier classification of terrestrial data centres. This is because the Tier classification of terrestrial data centres essentially focuses on data centre facility performance without necessarily considering the facility housing the data centre as seen in (OPNFV & OCP, 2018). This is because buildings do not pose significant threats to marine and avian diversity. This is because existing terrestrial data centre Tier classification does not consider factors such as security, use of renewable energy and networking ability. Newer tier classifications of terrestrial data centres consider the ability to support new networking standards and technologies such as open networking and computing described in (OPNFV & OCP, 2018; Khan, 2019).

In addition, the Tier rating of ocean and stratosphere data centres consider environmental friendliness (sustainability) as a criterion. Environmental friendliness is also recognized in the Tier 5 data centre classification which is presented in (Switch, 2020). However, these factors are considered in the novel Tier 5 terrestrial data centre classification. Table III presents a criterion-based comparison for the classification of the novel Tier 5 terrestrial data centre classification with that of ocean and stratosphere-based data centres.

Table III: Comparison of feature-based criteria for Tier 5 Terrestrial, Ocean and Stratosphere Data Centres.

Criteria	Tier 5 Terrestrial data centre	Ocean data centre	Stratosphere data centre
Availability	Yes	Yes	Yes
Redundancy Configuration	Yes	Yes	Yes
Vessel Class	No	Yes	No
Aerial Vehicle Class	No	No	Yes
Security	Yes	Yes	Yes
Missile threats	No	Yes	Yes
Marine Diversity	No	Yes	No
Avian Diversity	No	No	Yes
Renewable energy	Yes	Yes	Yes
Networking	Yes	Yes	Yes
Computing Payload Consideration	No	Yes	Yes

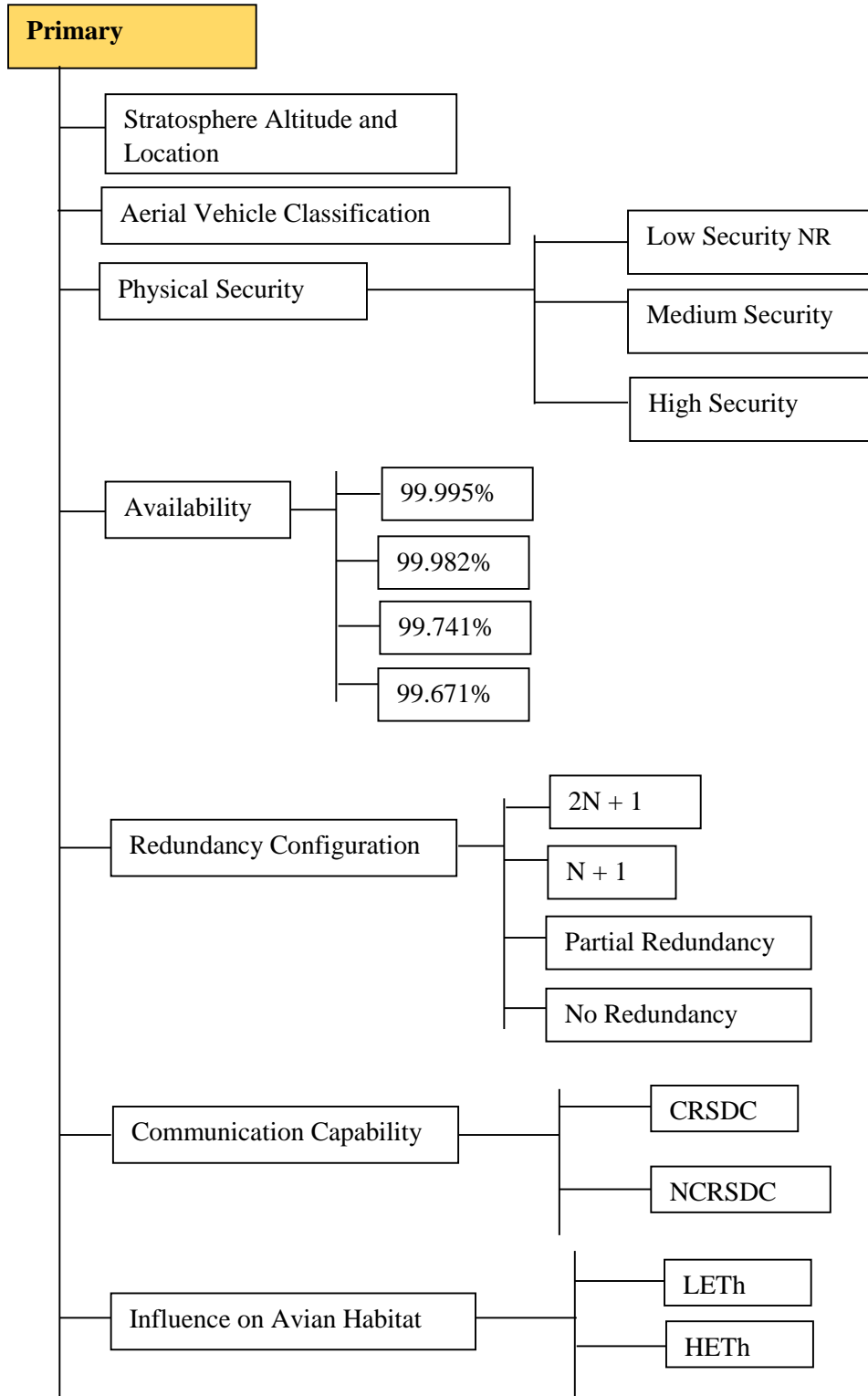


Figure 3: Primary Criteria for the Tier Classification of Stratosphere based data centres.

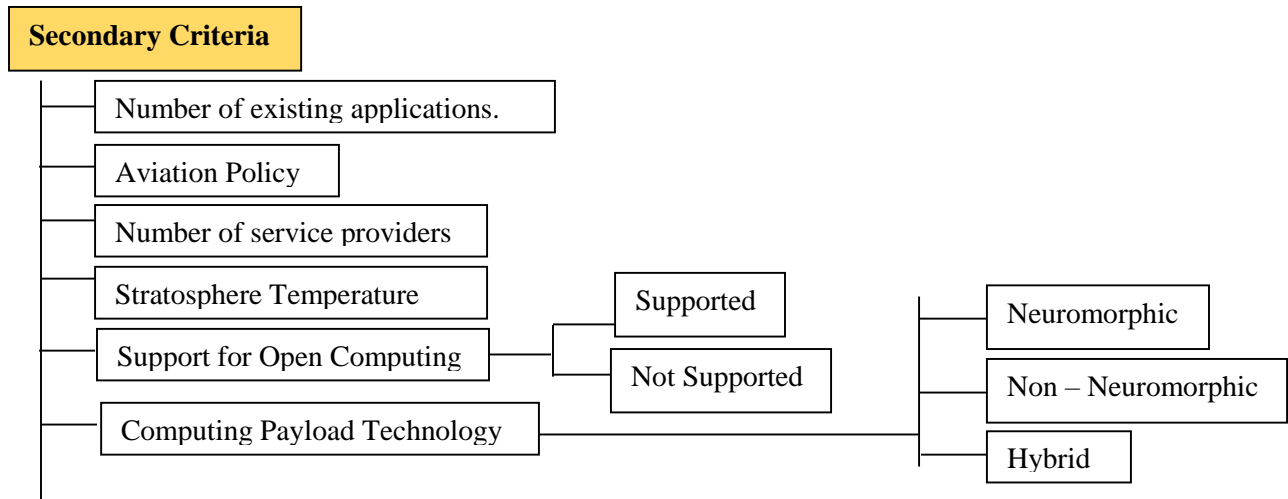


Figure 4: Secondary Criteria for the Tier Classification of Stratosphere based data centres.

Conclusion

This article proposes a novel Tier re-classification architecture for non-terrestrial data centres. The proposed re-classifications consider future non-terrestrial data centres located in the ocean and stratosphere. It classifies criteria to be used in the novel tier re-classification as either primary criteria or secondary criteria. The discussion in the paper identifies the primary criteria and secondary criteria for ocean-based data centres and stratosphere-based data centres. In addition, Tier classifications for data centres sited in the stratosphere and ocean have been presented and the roles of different criteria are also discussed. Furthermore, the proposed tier re-classification is compared with the existing Tier 5 terrestrial data centre and it is shown that the proposed classification architecture identifies the role of previously unconsidered factors. Additional work aims to further investigate the feasibility of non-terrestrial data centres with the proposed tier re-classification architecture.

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