Evaluating countries' sovereignty from the point of view of the submarine cable network

Rafael de Oliveira Costa[1], **Daniel Ratton Figueiredo**[1]

[1]System Engineering and Computer Science Program (PESC),
Federal University of Rio de Janeiro (UFRJ)

roc@cos.ufrj.br, daniel@cos.ufrj.br

Abstract. *The submarine cable infrastructure is essential for telecommunications as it is responsible for more than 90% of global Internet traffic. In an increasingly connected world, such infrastructure becomes critical, since failures can disturb or interrupt network traffic, lead to economic loss, and threaten a country's national security. Intuitively, different countries play very different roles in the global submarine cable infrastructure, as well as their sovereignty with respect to network failures (accidental or purposeful). This work provides a detailed study of the sovereignty of countries in terms of their role in the submarine cable network (SCN) over the last 39 years. To this end, the SCN is modeled and characterized as a time-evolving hypergraph of countries where hyperedges represent cables. In order to measure the sovereignty of countries, three metrics are described and evaluated for different countries to show how the role of nations in the information age has changed over time.*

Resumo. *A infraestrutura de cabos submarinos é essencial para o sistema de telecomunicação, pois é responsável por mais de 90% do tráfego global da Internet. Em um mundo cada vez mais conectado, essa infraestrutura torna-se crítica, uma vez que falhas podem perturbar ou interromper o tráfego da rede e levar a perdas economicas e ameaçar a segurança nacional de um país. Intuitivamente, diferentes países desempenham papéis diferentes na infraestrutura global de cabos submarinos assim como a sua soberania no que diz respeito a falhas de rede (acidentais ou propositais). Este trabalho fornece um estudo detalhado da soberania dos países em termos do seu papel na rede de cabos submarinos (SCN) ao longo dos últimos 39 anos. Para este fim, a SCN é modelada e caracterizada como um hipergrafo de países que evolui no tempo, onde as hiperarestas representam os cabos. Para medir a soberania dos países, três métricas são descritas e avaliadas para diferentes países a fim de mostrar como o papel das nações na era da informação mudou ao longo do tempo.*

1. Introduction

Until the mid-1980s, intercontinental data traffic was carried by satellites and submarine cables because at that time their bandwidth was not significantly different. However, the adoption of optical links in submarine cables has drastically changed this scenario (as the bandwidth in optical fibers can be very large and have low errors), and submarine cables have become the main medium for intercontinental data transmission [Chesnoy 2015]. Currently, more than a million kilometers of optical links have been installed at the bottom of the oceans, making the network formed by these links a core and critical infrastructure of today's Internet. Known as the submarine cable network (SCN), it has not received the attention it deserves [Bischof et al. 2018], especially because this network carries approximately 99% of all intercontinental traffic, from email to banking transactions.

The infrastructure of submarine cables consists of devices on the coast (dry plant) and under the sea (wet plant). The dry plant comprises all digital devices that together are responsible for transmitting and receiving optical signals carried by optical links. Here, the set of such devices is simply called a transmission terminal. In addition to optical links, the wet plant is made up of repeaters to extend the signal range, as well as branching units (BUs) to split the signal from a trunk cable into two cables [Chesnoy 2015].

Each submarine cable can be considered a distinct network because it can connect transmission devices located in different cities within one country or across different continents. Note that a single submarine cable can consist of several optical fiber links that are interconnected by repeaters and BUs. To illustrate, Figure 1 shows the Firmina submarine cable that interconnects transmission devices in each of the following countries: Argentina, Brazil, the United States, and Uruguay, using several optical links, which because of the distances between their cities, require 19 repeaters and 2 BUs.

Figure 1. Firmina cable

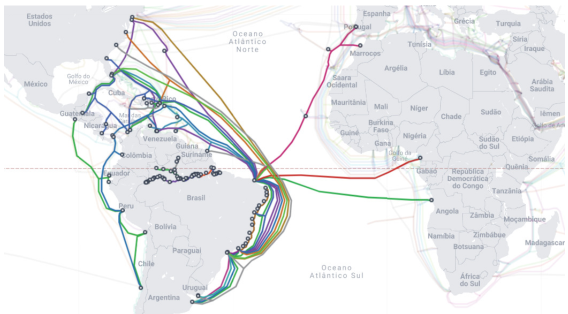


Figure 2. Cables connected to Brazil

Transmission terminals are installed at places known as landing points (LPs). LPs are often cities shared by multiple submarine cables. Thus, two different cables share one or more LPs. We assume that two transmission terminals of two cables that are located in the same LP are connected. While a direct optic cable between the transmission terminals may not exist, it is quite reasonable that they are connected by a local terrestrial network. Lastly, since LPs are often in cities, cities will be used to denote the location of LPs.

Hence, we refer to the SCN as the global network that aggregates the networks from each submarine cable. TeleGeography (a telecommunications market research company) provides maps [1] generated from the SCN according to the cables, countries, and years the cables are ready for service. For example, Figure 2 shows the map of submarine cables connected to Brazil (a total of 23 different cables), showing that Brazil has direct connection with cities in the American, European and African continents.

Recent news has reported that geopolitical tensions might be related to the disruption of submarine cables. For instance, political conflicts between the US and China might have induced disruptions in the Asia-Pacific region, and between Russia and NATO

[1] See `https://www.submarinecablemap.com/`

might have induced disruptions in the Baltic Sea [Globo 2025]. Although no investigation has concluded that recent submarine cable disruptions were caused by sabotage, it is important to note that submarine cables are strategic targets of a country's infrastructure, and their security is a core dimension of current and future international governance, as argued by *Bueger and Liebetrau* [Bueger and Liebetrau 2021]. In this context, the sovereignty of a country is posed in terms of its authority to its presence in cyberspace, showing the risks of depending on submarine cables not installed in their own territory. In this sense, "BRICS countries—Brazil, Russia, India, China, and South Africa—declared they would build an undersea BRICS cable system, in order to decrease dependence on the United States and Europe and avoid the risk of surveillance." [Bueger and Liebetrau 2021].

In this context, this work provides a detailed study of the sovereignty of countries in terms of their connectivity in the SCN over time. As each submarine cable has complex connections that interconnect a group of cities from different countries (with repeaters and BUs), we model the SCN as a hypergraph whose nodes are countries, and each submarine cable corresponds to a single hyperedge. The structure of this network is characterized over 39 years using network metrics that capture distinct network properties, such as size and distances. Next, we propose three simple metrics to measure the sovereignty of countries over time from the perspective of the SCN. Our results show how the sovereignty of the countries has evolved, deciding geopolitical players in the information era.

The remainder of this article is organized as follows. Sections 2 and 3 present the fundamental concepts of sovereignty and hypergraphs, respectively. Section 4 presents the evolution over time of the SCN when modeled as a hypergraph of countries. Section 5 describes the metrics to assess the sovereignty of a country and presents the results comparing a few countries. Finally, Section 6 briefly describes recent work, and some final remarks are given in Section 7.

2. Sovereignty

In political relations, sovereignty is a concept concerning the authority that states have over their own territory, implying their ability to govern without external interference. However, in the digital realm, sovereignty represents independence, control and autonomy over digital infrastructures, technologies, and data [Couture and Toupin 2019]. The literature has different terms to cover a range of aspects of digital sovereignty, such as cyber sovereignty, data sovereignty, and technological sovereignty [Azevedo et al. 2025].

Two such terms bring the concept of sovereignty to networks: 'network sovereignty' and 'internet sovereignty'. Although they are part of the same domain, there are different understandings regarding these terms. For example, *Li et al.* [Li et al. 2021] declare that "network sovereignty determines the rationality of the state jurisdiction over the infrastructure and information content of cyberspace and the right of external defense". Meanwhile, *Janardhanan et al.* [Janardhanan et al. 2024] qualitatively define network sovereignty, as "an organization's ability to operate a network while minimizing dependencies on a particular manufacturer". Finally, according to *Zeng et al.* [Zeng et al. 2017], Internet sovereignty is understood as the right of a state to regulate and control cyberspace within its borders, according to its national laws and interests.

In this work, network sovereignty is related to network connectivity in spite of other countries and will be measured quantitatively. In particular, a sovereign country (network node) has alternative network paths to many other countries, depending less on specific countries for its global connectivity. In the extreme case, the most sovereign country has a direct network connection (link) to all other countries, thus fully independent of other countries albeit at a high cost.

3. Hypergraphs

In various real-world systems, relationships are often formed by multiple objects at once. For example, a research paper can have multiple authors. Similarly, a submarine cable can have multiple LPs and connect multiple countries. For example, the Firmina submarine cable in Fig. 1 connects four countries. In such scenarios, it is more appropriate to model the network as a *hypergraph*.

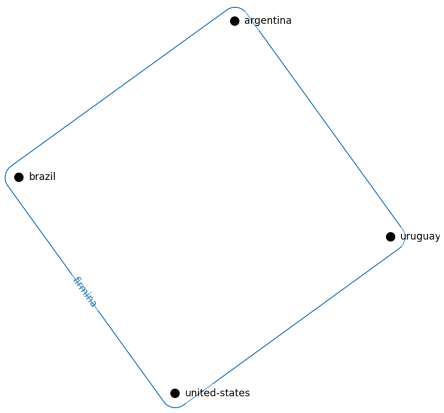


Figure 3. Firmina as a hyperedge.

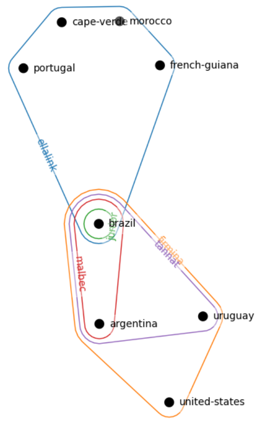


Figure 4. Hypergraph with five hyperedges with Brazil.

A hypergraph $H = \{V, E\}$ is formed by a set of vertices V and a set of hyperedges E where each hyperedge $e \in E$ is a subset of V with any cardinality [Joslyn et al. 2020]. The hyperedge indicates the nodes involved in a single relationship. For example, Fig. 3 shows the Firmina submarine cable (in Fig. 1) modeled as a single hyperedge whose vertices are the countries where the cable has transmission terminals installed. The size of an hyperedge (called width) is the number of vertices it contains. For example, the hyperedge in Fig. 3 has width 4.Real networks are bound to have hyperedges of different sizes. For example, Fig. 4 shows the hypergraph formed by five submarine cables connected to Brazil. Note that they all have different sizes, including size 1 (a cable that interconnects only cities in Brazil).

The number of vertices (denoted by $n = |V|$) and hyperedges (denoted by $m = |E|$) of a hypergraph are called order and size, respectively. Thus, the order and size of the hypergraph in Fig. 4 are 8 (Argentina, Brazil, Cape Verde, French Guiana, Morocco, Portugal, United States and Uruguay) and 5 (Firmina, Malbec, Ellalink, Tannat, and Junior), respectively. Note that the degree of a vertex in a hypergraph is the number of hyperedges that include that node, similar to the definition of degree in a traditional graph. Thus, the degree of the United States, Uruguay, Argentina and Brazil in the hypergraph shown in Figure 4 is 1, 2, 3, and 5, respectively.

Unlike a traditional graph, where the intersection of two edges is at most a single vertex, the intersection of two hyperedges can have multiple vertices. *Aksoy et al*

[Aksoy et al. 2020] propose a framework to generalize graph properties to hypergraphs based on walks (paths). According to them, the hypergraph walk is called a s-walk if the intersection between sequential hyperedges of the walk (path) has at least s vertices in common. Consider a 2-walk as the sequence $W = \langle e_0, e_1, ..., e_N \rangle$. This s-walk has length N and the intersection of all hyperedges e_i and e_{i+1} in W must have at least 2 vertices. Using the concept of s-walk, one can describe s-components, s-diameter, and s-closeness. For example, the s-component is a connected component of the graph where all vertices can reach each other using s-walks.

4. Characterization of HyperSCN over time

The SCN is a global communication network formed by submarine cables that interconnect cities around the world using optical links capable of transporting hundreds of terabytes per second (TB/s). Each submarine cable can be represented by a graph, where vertices represent transmission terminals or repeaters or BUs, and edges represent optical links that connect these vertices (as determined by the cable).

This work models the SCN as a hypergraph. But because we are interested in measuring the sovereignty of countries, vertices are the countries where transmission terminals are installed, and each submarine cable is a hyperedge: a set of countries connected by that cable. Note that submarine cables that interconnect cities in the same country will be transformed into a hyperedge with only one country (known as a singleton). The union of all submarine cables, each modeled as hyperedges, gives rise to a hypergraph that is called HyperSCN. The HyperSCN represents the connectivity between all countries according to the underlying SCN.

TeleGeography provides a rich dataset with submarine cables. For each cable, the dataset contains the geographic coordinates of its LPs (including city names), as well as the year that the cable became operational. For each year from 1989 to 2027, an HyperSCN was built considering submarine cables ready for service that year or before, giving rise to 39 different networks (one per year). Note that the HyperSCN of a given year includes the HyperSCN of the previous year, and thus it only grows over time. The final year is 2027 because TeleGeography reports data on submarine cables not only installed, but also in the process of deployment or planned for future deployment. The data analyzed in this work was extracted TeleGeography on October 2024, and the HyperSCN of year 2027 interconnects 181 countries through 606 submarine cables.

In order to construct the HyperSCN and characterize its structural properties, the Python package HyperNetworkX [Praggastis et al. 2019] was used. This package provides the necessary methods used in this work, including the generalization for s-walk, s-components and s-closeness.

Figure 5 presents how the order and size of HyperSCN evolve over the years. Although at different rates, both increase over the years, indicating that the number of countries and submarine cables increase over the years. Notice that since 2012 the order (n) grew very slowly, whereas the size (m) continues to increase almost linearly over the years. This means that the HyperSCN is densifying, since roughly the same set of countries has seen a large increase in the number of submarine cables in the last 13 years.

Another important property to be analyzed in the HyperSCN is the width of its hyperedges, as they represent the number of countries connected by a given submarine

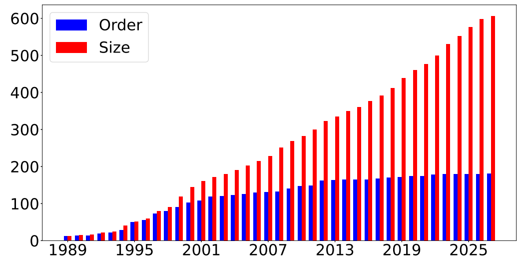


Figure 5. HyperSCN order and size over time.

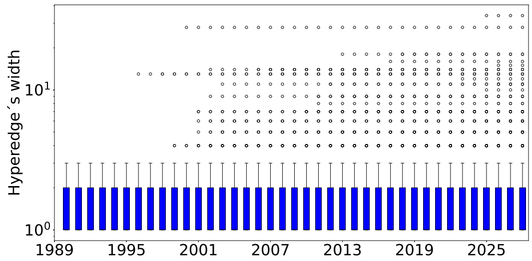


Figure 6. Hyperedge's width over time.

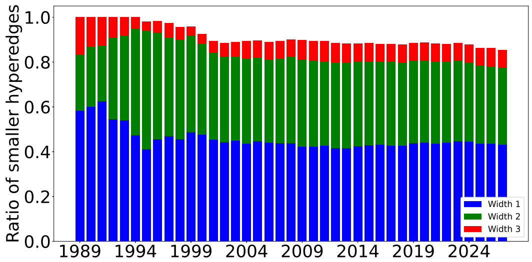


Figure 7. Fraction of hyperedges with width 1, 2, and 3 over time.

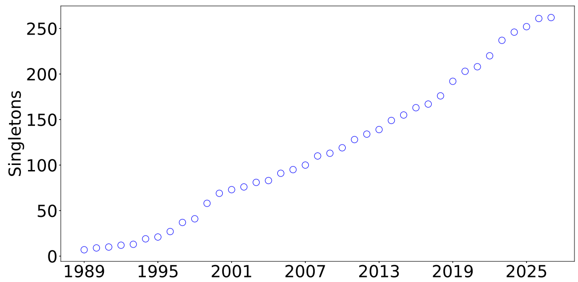


Figure 8. Number of singletons over time.

cable. Figure 6 shows that the width of most hyperedges varies between 1 and 3 over all years. However, note that there are several outliers in the Figure 6, i.e. a few cables capable of interconnecting up to dozens of different countries in the same cable (cables with a larger width). To better understand the evolution of the hyperedge's width, Figure 7 shows the evolution of the fraction of submarine cables with width 1, 2 and 3. Interestingly, despite the growth in order and size, these fractions do not vary significantly over time, and considering data from last year, we can see that only 8% of the cables connect three different countries, 34% are responsible for connecting two different countries, and 43% are singletons. Finally, only 15% of the cables interconnects four or more countries. Given the large fraction of singletons, Figure 8 shows how the number of singletons evolves over time. Note that the number of cables with only one country increases almost linearly over the years, indicating that many submarine cables are being used to connect cities within the same country.

Recall that a hypergraph can have multiple s-components (for each value of s). Each s-component of the hypergraph has a size that is given by its number of vertices, and the largest one is known as the giant connected s-component (GCC). Analyzing the evolution of the relative size of the GCC in the HyperSCN in Figure 9 for $s = 1, 2$ and 3, note that practically all countries have been in the GCC since the beginning of this century considering $s = 1$. This means that today all countries that have at least one submarine cable installed can reach any other country because the HyperSCN is fully connected (for $s = 1$). The relative size of the GCC considering $s = 2$ and $s = 3$ also increased over time, indicating that redundancy is being added by different countries over time. Note

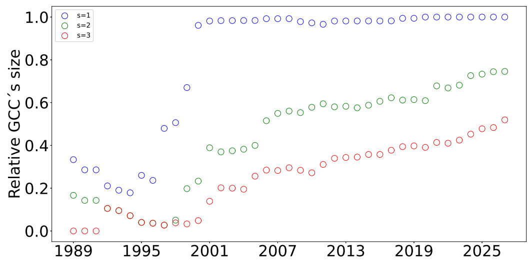


Figure 9. Fraction of vertices in the of s-component over time (for $s = 1, 2, 3$).

Figure 10. Diameter of the largest s-component over time (for $s = 1, 2, 3$).

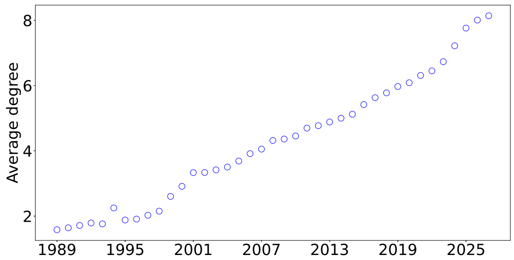


Figure 11. Average degree of the HyperSCN over time.

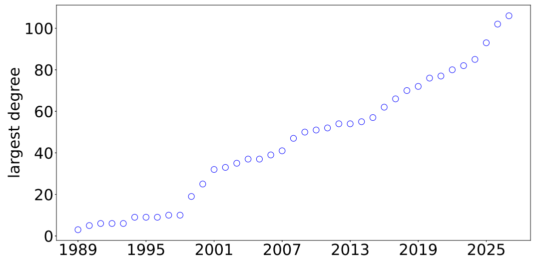


Figure 12. Largest degree of the HyperSCN over time.

that more than half of the countries belong to the GCC for $s = 2$ and 3 in recent years.

Figure 10 reveals that the s-diameter in the GCC has increased and decreased for $s = 1$ and slowly increases for $s = 2$ and $s = 3$. Interestingly, in the last year, the s-diameter is the same (equal to 5). This means that a country in the GCC can reach any other country in the GCC with a sequence of 5 or fewer submarine cables. This is very low considering the number of countries in the GCC. The s-diameter for $s = 2$ and $s = 3$ is smaller than the s-diameter for $s = 1$ for other years. This could be explained because the GCC of the s-components considering $s = 2$ and $s = 3$ is smaller than the GCC considering $s = 1$.

The evolution of node's degrees in the HyperSCN reveals some unique properties of this network. Figure 11 depicts the evolution of the average degree. This figure shows that the average degree increases over the years, supporting the densification of the HyperSCN (more cables are added than countries). Interestingly, the largest degree also increases with time, as shown in Figure 12. Note that since 2010, the largest degree is more than ten times larger than the average degree, suggesting that *hubs* exist in the HyperSCN and its degrees are also increasing over time. Figure 13 shows the fraction of nodes with degrees 1, 2, and 3 in HyperSCN over time. Until 2020, more than 50% of the nodes had degree 1, 2 or 3. However, the fraction of low degree nodes has been decreasing over the last 20 years. This also indicates that countries are building redundancy by participating in more submarine cables.

The complementary cumulative distribution function (CCDF) for node's degree is

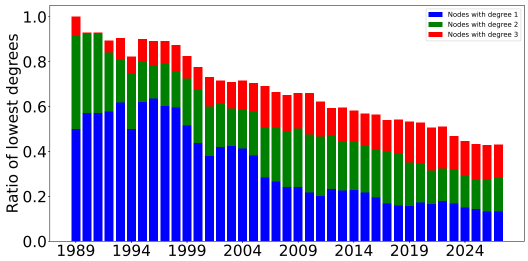


Figure 13. Fraction of vertices with degree 1, 2 and 3 over time.

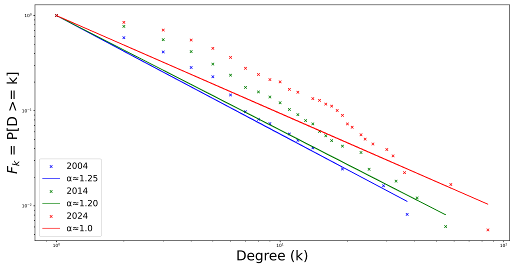


Figure 14. Degree distributions (CCDF) of the HyperSCN for years 2004, 2014, and 2024 (in log-log scale, with line with estimated slope α).

shown in Figure 14 for HyperSCN in the years 2004, 2014 and 2024 (in log-log scale). Note that the three distributions follow a heavy-tailed distribution due to a roughly linear decay of the probability. More strictly, we estimate the exponent (α) for a power law distribution that best fits the data for each year, which was obtained by linear regression using the ordinary least squares method. This suggests that HyperSCN is scale-free (despite the limited range of degrees) and that the *hubs* are growing over time, since α decreases over the three distributions. Figure 14 also shows the lines with slope given by α for each year, indicating its relative agreement with the respective empirical degree distribution.

5. Sovereignty of countries

We assume that countries that belong to a certain hyperedge have mutual dependence, since they belong to the same cable. This is due each must rely on the other for the cable to operate properly. Moreover, countries (vertices) with a larger degree will have a higher chance to reach more countries using a single cable (hyperedge), thus improving its sovereignty by not depending on cables that are not installed in its territory. In this context, we evaluate the sovereignty of countries in the HyperSCN using its structural properties from the point of view of countries (vertices). Section 5.1 presents the proposed metrics to evaluate sovereignty in the HyperSCN, and the results are presented in Section 5.2.

5.1. Metrics for sovereignty in HyperSCN

The sovereignty of a vertex is related to its capacity to reach all other vertices of a network without relying exclusively on intermediate vertices. To evaluate the sovereignty of a given vertex, we consider three metrics: (i) neighborhood size, (ii) s-coverage ratio, and (iii) s-closeness of a vertex.

The neighborhood of a vertex $N(v)$ in a hypergraph is the set of vertices that share at least one hyperedge with v. This can be determined as follows:

$$N(v) = \bigcup_{e \in E} \{u \mid u \in e \wedge v \in e \wedge u \neq v\} \tag{1}$$

The neighborhood of v is a set resulting from the union of the vertices u belonging to the hyperedge e among all other hyperedges (E) that also contain v and is different of v. The neighborhood size $|N(v)|$ is simply the size of this set.

In the context of the HyperSCN, the neighborhood of a given country will be the set of countries that can be reached with a single hyperedge (submarine cable). The larger the neighborhood size of the country, the more sovereign it becomes. This is due to the possibility of reaching more countries using only cables installed on your own territory.

On the other hand, the s-coverage $C_s(v)$ is the set of vertices that can be reached from a vertex v using s-walks. This is given by

$$C_s(v) = \bigcup_{u \in V} \{u \mid d_s(v,u) \geq 1\}, \tag{2}$$

where $d_s(v,u)$ is the distance between vertices u and v considering an s-walk (for some given s). When $s = 1$, $C_1(v)$ is equivalent to the connected component that has node v and all hyperedges share at least one vertex.

In the context of the HyperSCN, the sovereignty of a country is related to its s-coverage. For any s, the larger the s-coverage of a country v, the more countries it can reach, which means that its connectivity is not limited.

The s-closeness is a generalization of closeness centrality for hypergraphs [Aksoy et al. 2020]. It measures the proximity of a given vertex to all other vertices, taking into account that hyperedges can have different width s. In particular, it is the inverse of the sum of the s-distance between a given vertex and all other vertices in the same s-component, multiplied by number of vertices minus 1, given as follows:

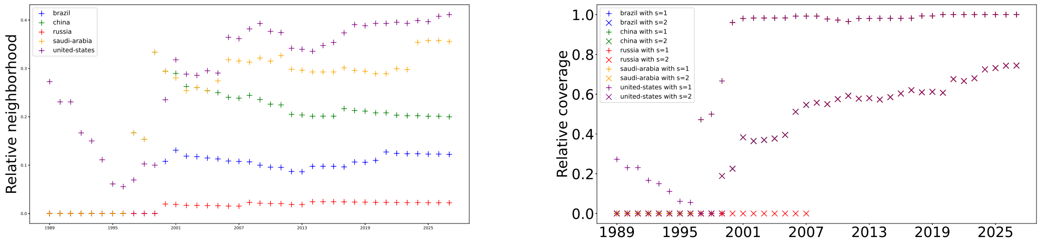
$$S_s(v) = \frac{|V| - 1}{\sum_{u \neq v \in V} d_s(v,u)} \tag{3}$$

The closer $S_s(v)$ is to 1, the closer the vertex v is to all other vertices considering s-walks. This measure is related to sovereignty in the following way: sovereign vertices are those that have the highest s-closeness values, allowing such a vertex reach any many vertices through a few hyperedges, reducing the number of vertices along the paths that can disrupt connectivity. On the other hand, low values for s-closeness indicate that the distance between v and other vertices depends on many hyperedges (and many intermediate vertices). So, less sovereign countries are those with lower s-closeness.

5.2. Results on sovereignty

The sovereignty of the following countries will be discussed: Brazil, China, Russia, Saudi Arabia and United States. These five countries were chosen for different reasons. China, Russia, and United States were due to tensions between them in terms of submarine cable incidents. Brazil and Saudi Arabia are a possible victim of surveillance, as their territory is valuable from a geopolitical point of view.

Figure 15a shows the relative neighborhood size of the countries over time. Among them, the United States could be considered the most sovereign because every year its relative neighborhood is larger than that of other countries. Currently, the United States shares submarine cables with more than 40% of other countries. In this regard, China's sovereignty has been slightly declining over the years, but keeping at least 20% of the countries in its neighborhood. Russia is the least sovereign country according to this metric, as only 2% of the countries are reachable by submarine cables installed in its



(a) **(b)**

Figure 15. Relative neighborhood size of countries (15a) and s-coverage of countries with $s = 1$ and $s = 2$ (15b) over time.

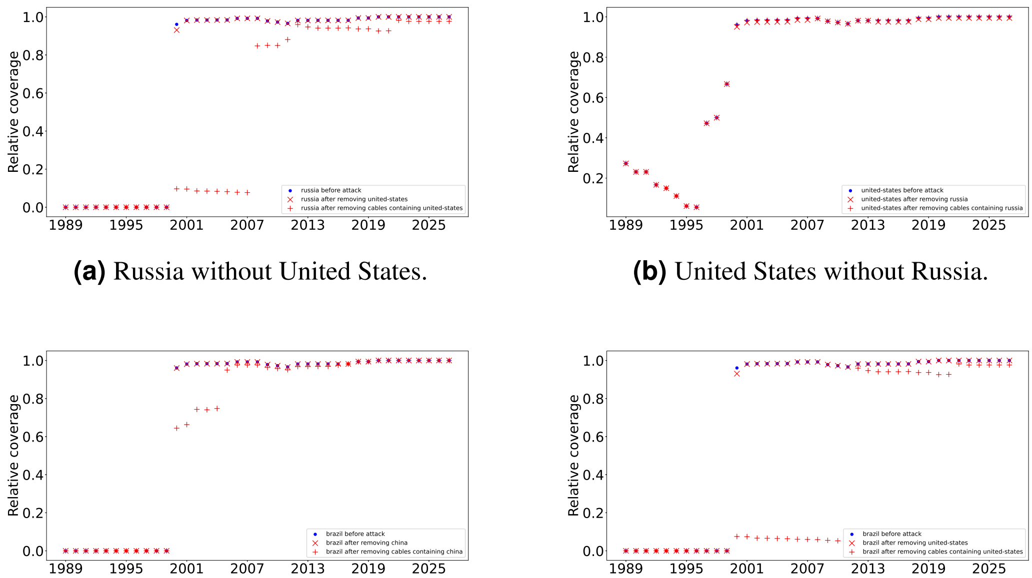
cities. The neighborhoods of Brazil and Saudi Arabia were inexistent in the early years because they did not have any submarine cables. But over the years, this changed significantly and both countries had an increase in their neighborhood, with Saudi Arabia having a much higher increase compared to Brazil. Currently, Brazil and Saudi Arabia have a relative neighborhood size of 12% and 35%, respectively. Note that Saudi Arabia and United States have a similar neighborhood size, indicating its geopolitical influence.

Figure 15b presents the relative s-coverage over time. Note that in the early years, only the United States had non-zero s-coverage. But from 2000 onward and for $s = 1$, all countries have a very similar 1-coverage that is equal to 1 (or almost 1), meaning that they all reach all (or almost all) other countries. For $s = 2$, the 2-coverage has not reached 100% for any country, but has been growing over the years. Interestingly, Russia had zero 2-coverage until 2008, when a new cable was installed, and its 2-coverage became identical to the other countries. Thus, under the s-coverage metric, these different countries currently have identical sovereignty in recent years.

Since all countries depend to some extent on submarine cables that are not installed in their territory, it is interesting to consider what happens if a country denies routing traffic to another. Will this significantly reduce its s-coverage? In order to address this question two denial models are considered: (i) the denial country is removed from all hyperedges (namely, the denial country refuses to route traffic); (ii) all hyperedges with the denial country are removed (namely, the denial country has control and removes the cable where it participates). Clearly, the second denial model is more aggressive than the first.

Figure 16 shows the relative s-coverage over time of the United States and Russia when the other denies the first, and also Brazil when denied by China and the United States, for both denial models considering $s = 1$. As expected, the second denial model has a larger effect on the s-coverage. Note that Russia was very dependent on the United States until 2008, when a new cable provided a larger s-coverage without the United States (see Fig. 16a). In contrast, the s-coverage of the United States when Russia denies its traffic is not affected at all throughout the period (see Fig. 16b).

Considering Brazil, note that its s-coverage has little dependence on China since 2005, even for the more aggressive denial model (see Fig. 16c). However, Brazil's s-coverage was strongly influenced by denial of the United States until 2010. Today, Bra-



(a) Russia without United States.

(b) United States without Russia.

(c) Brazil without China.

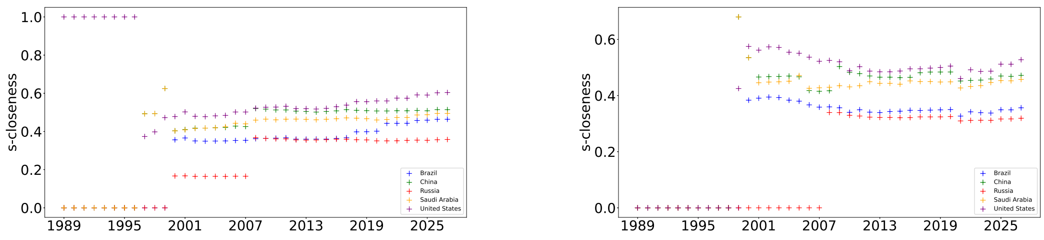
(d) Brazil without United States.

Figure 16. s-coverage of countries without the presence of another country.

zil's s-coverage is little influenced by a denial of the United States, indicating that it has built redundancy using submarine cables with other nations (16d). Last, considering the HyperSCN in the most recent year, a given country is unlikely to be impacted by the denial of another country, since removing a specific country or a subset of submarine cables containing the denial country is not capable of significantly reducing the s-coverage of a given country, regardless of its degree of sovereignty.

Figure 17 shows the s-closeness for Brazil, China, Russia, Saudi Arabia, and the United States over time. Again, the most and least sovereign countries throughout the period are the United States and Russia, respectively. Unlike the results obtained through the previous metrics, China increased its s-closeness and appeared as the second most sovereign country, a place occupied by Saudi Arabia before. The main changes between the s-closeness results considering $s = 1$ (1-closeness in Figure 17a) and $s = 2$ (2-closeness in Figure 17b) are: (i) lower absolute values in each year of 2-closeness compared to 1-closeness and (ii) in the early years, all countries have 2-closeness equal to zero. Recall that 2-closeness requires at least two vertices in common when considering two hyperedges, making it harder to find short paths among the vertices and also reducing the number of vertices that can be reached.

Table 1 shows a ranking of the five most sovereign countries (across all countries in the network) considering the relative neighborhood size and s-closeness for $s = 1$ in the last year. Note that United States is the first in both metrics. Interestingly, France, Portugal and United Kingdom also appear in both rankings (in different positions). Last, Saudi Arabia and Spain also appear in the ranking, indicating their privileges position with respect to these sovereign metrics. Note that the s-coverage of all countries in the last year is identical and maximum (all in the same connected component), with the exception of Uganda, Azerbaijan, Kazakhstan, Marshall Islands and Tuvalu since they have submarine



(a) s=1 **(b)** s=2

Figure 17. s-closeness of different countries over time (for $s = 1, 2$).

cables that connect only their own cities.

	Relat. neighborhood size		s-closeness	
1st	United States	0.411	United States	0.604
2nd	France	0.400	United Kingdom	0.576
3rd	Portugal	0.394	France	0.575
4th	United Kingdom	0.361	Portugal	0.573
5th	Saudi Arabia	0.355	Spain	0.540

Table 1. Ranking of the most sovereign countries.

6. Related Work

Despite previous analysis and characterization of the SCN [Beaufils 2000, Malecki and Wei 2009, Bischof et al. 2018], given its crucial role in the global communication infrastructure, understanding its characteristics and evolution remains a research agenda.

Our previous recent work indicates that the SCN is composed of many connected components from which a large fraction are simple paths, while it also has a GCC containing approximately 80% nodes [Costa and Figueiredo 2023]. In contrast, this work models the SCN as a hypergraph of countries instead of a graph of landing points.

Prior works have used hypergraphs to model telecommunication networks. In 1998, *Sarkar and Sivarajan* [Sarkar and Sivarajan 1998] used hypergraphs to model cellular mobile communication systems. A similar approach was also taken by *Ganesan et al.* in recent works [Ganesan 2021, Ganesan 2023, Ganesan 2025]. However, to the best of our knowledge, no prior work has modeled and characterized the SCN as a hypergraph of countries that evolves over time.

Recent works in the literature discuss network sovereignty in the context of the SCN. In particular, *Ganz et al.* [Ganz et al. 2024] explore the challenges submarine cables face to digital sovereignty, which are their ownership structure, cross-jurisdictional nature, and vulnerabilities to malicious actors. On the other hand, *Buerger and Liebetrau* [Bueger and Liebetrau 2021] argue that states should protect their submarine cables in order to assert their authority over such a vital communication infrastructure as the SCN. Last, [Rai 2025] presents a discussion on sovereignty and India's role on protecting submarine cables in the Indo-Pacific region given the recent rise of geopolitical tensions. Unlike them, this work presents a quantitative assessment of the sovereignty of network nodes induced by the SCN.

7. Conclusion

This work presented and characterized the HyperSCN, a hypergraph created from public data on submarine cables where each vertex corresponds to a country, and each submarine cable is represented by a hyperedge with the countries that have a LP in the cable. The evolution of HyperSCN has been analyzed using various structural metrics, such as degree and distance. For instance, the number of singletons has increased over the years, which shows that submarine cables are increasingly being used to connect cities in the same country, as evidenced by the *Norte Conectado* project in Brazil [Ministério das Comunicações, Brasil 2025]. Furthermore, our results indicate that HyperSCN exhibits a heavy-tailed degree distribution that indicates the presence of *hubs*. Thus, a few countries (the *hubs*) have a direct connection to a large fraction of other countries, while most countries have few connections.

Another contribution is the quantitative assessment of the sovereignty of countries from the point of view of the SCN. In this sense, we measure neighborhood size, s-coverage ratio, and s-closeness to evaluate the sovereignty of a few countries over time. Results indicated that with respect to neighborhood size and s-closeness the United States and Russia are the most and least sovereign countries, respectively. Moreover, when considering possible political embargo, Brazil is more dependent on United States than on China in terms of s-coverage.

For future work, other metrics to evaluate sovereignty will be designed in order to capture the dependence in terms of cable ownership (as opposed to countries), as several submarine cables belong to the same company (or same consortium).

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