An Overview of HTTPS and DNSSEC Services Adoption in Higher Education Institutions in Brazil

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***Abstract*—Cyberattacks are performed against all organizations including Higher Education Institutions (HEIs). When these attacks are successful, they can affect the regular operation of these institutions and may cause the leak of essential or sensitive data that can be misused or become inaccessible. Therefore, the adoption of current security services is important for devices and services exposed to the Internet that should run the latest and secure versions of web-related protocols and comply with the latest security-related guidelines and recommendations.**

This article surveys and analyzes the status of web-related security services, namely the Hyper Text Transfer Protocol Secure (HTTPS) and the Domain Name System Security Extensions (DNSSEC) services, in Brazilian HEIs.

The results of this survey show that regarding HTTPS around 15% do not use any SSL / TLS certificate and of those supporting it, about 14% do not demand its usage. Regarding DNSSEC, the analysis shows that only around 2% of the HEIs are implementing this protocol. These results show that it is important to design an effective and continuous action plan for HEIs regarding the support or discontinuity of versions of these protocols, in order to improve their protection against cyberattacks.

***Index Terms*—DNSSEC, HTTPS, Higher Education Institutions (HEI), Security Headers**

I. Introduction

Cyberattacks are constantly performed against companies and individuals. According to the European Union Agency for Cybersecurity (ENISA) Threat Landscape report [1], the five prime threats identified for 2021 were ransomware, malware, cryptojacking, e-mail-related threats, and threats against data. These threats are aimed at private and public institutions, and the Higher Education Institutions (HEIs) are also targets for these attacks. More recently, the Covid-19 pandemic brought new challenges to HEIs, from migrating to distance learning [2] to configuring and maintaining the infrastructure that supports all the required remote interactions between the academic community. At the same time and according to [3], [4], between 2019 and 2020 more than 1500 educational institutions were attacked by cybercriminals in the USA, which prompted the FBI to issue a warning statement [5]. These attacks can affect the regular functioning of these institutions and important data can be misused or become inaccessible. The impact of these attacks can be strong, as was the case with the Lincoln College in the USA, which is set to close after 157 years of history due to the combined impact of the COVID-19 pandemic and a recent ransomware attack [6], [7].

Given this context, the HEIs must be aware of the risks associated with internet security and take measures to protect their systems and data and ensure safe access to their users. The main page portals, the Learning Management Systems (LMSs), the academic portals, and other services available to the internet should be running the latest versions and comply with the latest guidelines and recommendations. Two of the most important protocols providing services to the internet are the Domain Name System (DNS) and the Hypertext Transfer Protocol (HTTP) and secure versions of these protocols have been released, namely Domain Name System Security Extensions (DNSSEC) [8]–[10] and Hyper Text Transfer Protocol Secure (HTTPS) [11]. In the particular case of Brazil, the HEIs have administrative independence [12] and thus, despite recent guidelines have been released by this country's Ministry of Economy [13], these institutions have different paces towards the adoption of these security standards.

This paper provides an insight into the status of DNSSEC and HTTPS security services in Brazilian HEIs. The results of this study capture the current status of these institutions regarding these two secure protocols and highlight the importance of designing an effective action plan to evolve this status and improve their protection against cyberattacks.

This article is organized as follows. Section II presents the related work. Section III describes the methodology used. Section IV presents and discusses the results. Section V presents the conclusions.

II. Related Work

HTTP and DNS are core protocols in today's internet. Since these protocols are not secure by design, attacks can be performed to disrupt their regular operation. The HTTP Request Smuggling is one of the vulnerabilities that can be performed against HTTP, that takes advantage of different lengths of a single HTTP request to impact web servers and proxies [14]. Regarding DNS several studies demonstrate its exposure to attacks such as string injection [15], and cache poisoning [16].

HTTPS and DNSSEC are the secure versions/extensions of HTTP and DNS, respectively. The HTTPS was proposed in 1995 [17] as a secure version of the HTTP that uses the Secure Sockets Layer (SSL) or Transport Layer Security (TLS) protocols for encryption and authentication, which use asymmet-

ric cryptography algorithms such as Rivest–Shamir–Adleman (RSA) or Elliptic-Curve Cryptography (ECC). RSA is still widely used, while ECC provides an equivalent level of encryption with a shorter key length and is ten times faster when compared with RSA [18].

DNSSEC [8] was proposed as an extension that adds security to the DNS protocol and uses digital certificates to validate DNS responses to enable authentication of the origin and integrity of data [19]. Both HTTPS and DNSSEC may rely on SSL and TLS protocols, at the transport layer, to ensure the confidentiality and integrity of data transmitted over the network.

The adoption of HTTPS, DNSSEC, and TLS protocols has been the focus of a set of research studies. According to [20] and regarding HTTPS, despite the increase in the number of sites that adopted the HTTPS protocol to encrypt the communication between users and web servers, many of these sites adopted HTTPS incorrectly, e.g with the lack of redirection from HTTP to HTTPS, leaving users' browsing data exposed. Authors in [21] present HTTPS-Only, an approach attempting to establish a secure connection to a website using HTTPS and only allows a fallback to HTTP if a secure connection cannot be established. In [22] the authors discuss the impact of security headers and reveal that the support of headers is somewhat related to the browser version, the penetration ratio of all headers is less than 17% across all platforms, outdated browser versions may be better supported in terms of headers. In contrast, deprecated headers still enjoy wide implementation.

Regarding DNSSEC and according to [19], this protocol has had a slow adoption rate at a global scale which is at about 24%. In [23] the authors explore the challenges and obstacles towards deployment of post-quantum signatures and explain that smooth adoption towards quantum-safe cyphers can be achieved with cypher-suite negotiation for DNSSEC. In [24] the author proposes and evaluates solutions to replace algorithms in DNSSEC.

A previous survey of the security status of Portuguese HEIs websites was carried out in [25]. The results showed that about 14% of the HEIs do not use SSL, about 81% use the Rivest-Shamir-Adleman (RSA) algorithm, and about 6% of HEIs still negotiate with the vulnerable SSLv3 version. Regarding DNSSEC, only about 12% of HEIs support this service.

This current paper provides an analysis of the adoption of HTTPS and DNSSEC protocols by the HEIs in Brazil.

III. Methodology

The work was developed through quantitative research of an exploratory and descriptive nature [26], which portrays a phenomenon through a representative sample of the target population, investigating properties, characteristics, and conclusions of the relations of this phenomenon.

As an initial step, the methodology included collecting the publicly available information from all higher educations institutions registered in the National Registry of Higher Education Courses and Institutions (CNCIES), of the Ministry of Education and Culture of Brazil (MEC) [27] [28]. This was accomplished using a Web Crawler, which consists of an algorithm developed to inspect the MEC website's source code and collect public domain information regarding the registration of Brazilian HEIs.

After the initial step, a compilation of information regarding the Brazilians HEIs of the 27 federative units of Brazil (26 states and the Federal District) was carried out through the Pentaho Data Integration software to normalize and process the data collected. There are a set of HEIs that do not have an institutional website registered in MEC in their registration form and thus, they were excluded. Among a universe of 3,044 registered Brazilians HEIs, 516 did not have an institutional website in their registry and therefore, 2,528 institutions were used for the current research.

To obtain the web-related security services status, two modules in Python programming language were developed: one for and the other for services statuses. To obtain the status of security services related to the web, two modules were developed in Python programming language: one to collect info regarding DNSSEC service and another to collect info regarding HTTPS service. The multiple items collected by the Python modules were recorded in a Comma-Separated Values (CSV) format file. These research efforts were carried out between April and May of 2022, and all survey data were made available through the GitHub platform [29].

IV. Results and Analysis

Figure 1 presents the output of the initial data collection, i.e. the HEIs collected for the current research, their distribution by states in Brazil, and their category(public or private).

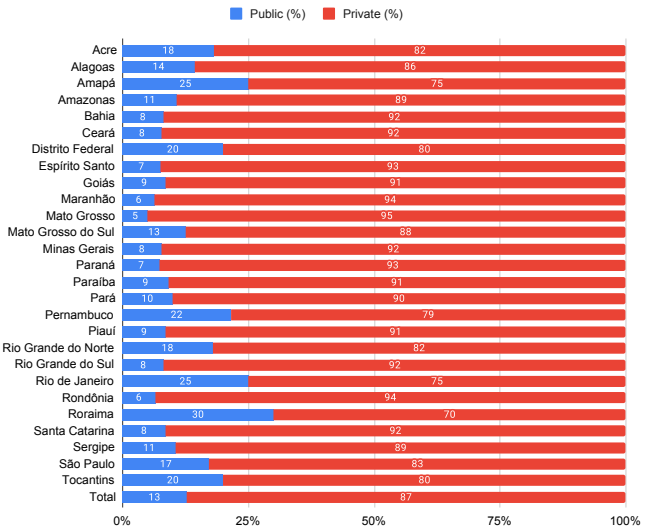

Fig. 1. HEIs by state in Brazil.

The results show a total of 2528 HEIs in Brazil, distributed among the states. Most institutions (87.34%) are private, while 12.66% are public. São Paulo is the state with the highest

number of institutions (604), followed by Minas Gerais (302) and Rio de Janeiro (148). The states with the lowest number of institutions are Amapá (12), Acre (11), and Roraima (10). When analyzing the category of institution, it is possible to verify that the states with the highest percentage of private institutions are Mato Grosso (95%), Maranhão (93.62%), and Rondônia (93.55%). The states with the highest percentage of public institutions are Roraima (30%), Amapá (25%), and Rio de Janeiro (25%). About 16% of Brazilian HEIs did not have their institutional website registered.

A. DNSSEC

Fig 2 presents the results regarding the implementation of DNSSEC in Brazilian Public and Private HEIs. The results show that around 98% of the HEIs in Brazil do not implement DNSSEC. Of the 2528 domains analyzed, only 18 (0.71%) of the public institutions and 34 (1.34%) of the private institutions are configured to use DNSSEC. From these results, it can be concluded that DNSSEC deployment in public and private Brazilian HEIs is still in an early stage, representing a vulnerability for DNS attacks, such as spoofing or cache poisoning.

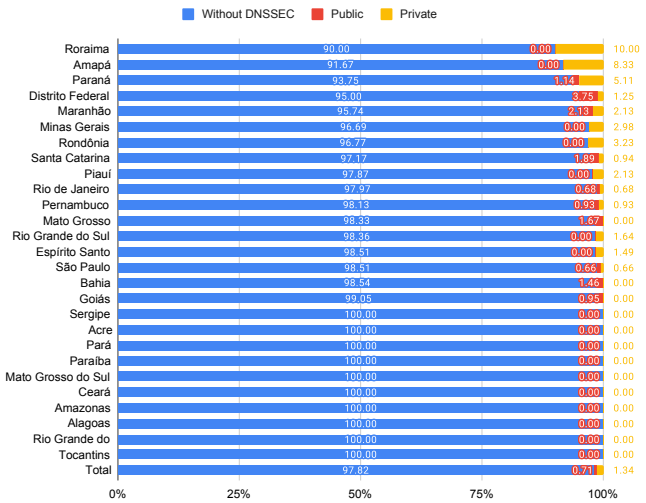

Fig. 2. Distribution of Brazilian HEIs that implemented DNSSEC, according to type (public or private).

B. HTTPS

Fig. 3 presents the analysis of Brazilian HEIs regarding the configuration of the HTTP/HTTPS service. The indicators represent the following conditions:

- HTTP only: The institution website uses only HTTP.
- HTTP & HTTPS: The institution offers both protocols but does not have any redirection to force the use of HTTPS. All institutions in this category have a valid certificate.
- Invalid SSL Configuration: Despite supporting HTTPS, the institution's website, has elements that classify their service as invalid.
- HTTP to HTTPS (other): Institution website that redirects the user to a secure page outside the main domain. All institutions in this category have a valid certificate.
- HTTP to HTTPS (same): Institutions website that redirects the user to a secure page within the main domain, thus ensuring data protection. All institutions in this category have a valid certificate.

The results of Fig. 3 show that of the 2528 websites analyzed, 390 institutions (15.43%) only offer the HTTP protocol, and 359 institutions (14.20%) offer both protocols but do not have any redirection to force the use of HTTPS. In addition, 726 institutions (28.72%) have an invalid SSL configuration which means that, despite having HTTPS, there are errors in their certificate or settings. Finally, 1021 institutions (40.39%) offer the HTTPS protocol properly, thus ensuring data protection. The states that lead the ranking of institutions that only offer the HTTP protocol are Amazonas (28.57%), Acre (27.27%), and Mato Grosso (25.00%). The states with the highest percentage of institutions that offer HTTPS properly are Sergipe (63.16%), Espírito Santo (53.73%), and the Rio Grande do Norte (53.57%).

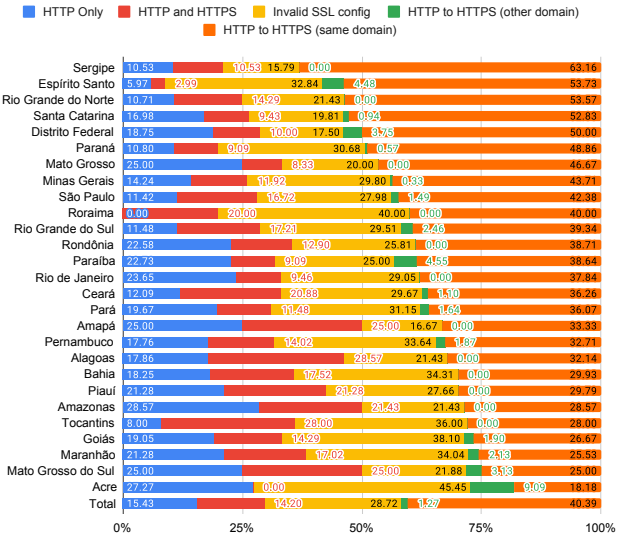

Fig. 3. Distribution of the use of the HTTP/HTTPS service.

1) Certification Authority: Certification Authoritys (CAs) are responsible for issuing and managing the digital certificates that ensure the identity of the parties in an online transaction. Fig. 4 and Fig. 5 present the certification authorities of public and private Brazilian HEIs, respectively. The results show that the R3 CA is the most used by public institutions, representing 24.7% of the CAs, followed by Cloudflare Inc ECC CA-3 (4.4%) and AlphaSSL CA-SHA256-G2 (3.8%). Other CAs account for the other 12.2% certifications. Regarding the private institutions, R3 is responsible for 31.6% of certifications, followed by AlphaSSL CA-SHA256-G2 (8.2%) and Cloudflare Inc ECC CA-3 (7.3%) and where other CAs account for 15.3% of the total. From these results it can be

concluded that, although R3 CA is used more frequently by private and public HEIs, there is a greater variety of CAs being used by public institutions, as can be seen by almost 40% regarding the spectrum of other CAs. Also, Cloudflare Inc ECC CA-3 and AlphaSSL CA-SHA256-G2 manage to double their market share in the private institution sector, when compared to the public sector.

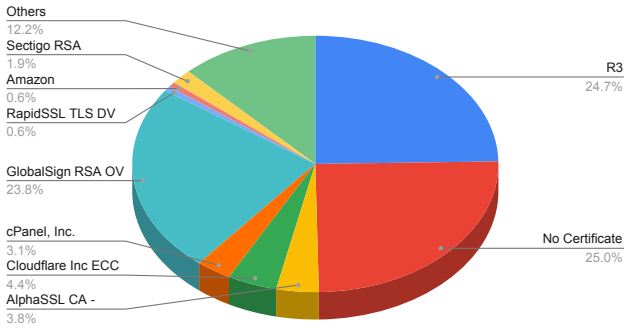

Fig. 4. Certification authorities of public Brazilian HEIs.

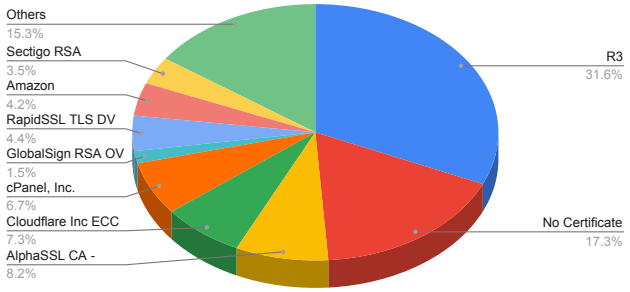

Fig. 5. Certification authorities of private Brazilian HEIs.

2) TLS Protocol: Fig. 6 presents the length of TLS keys used by Brazilian HEIs and their supported asymmetric encryption algorithms, i.e. RSA or ECC. The results show that most HEIs use 2048-bit RSA (65.23%) and 256-bit ECC (9.69%) keys. The 3072-bit RSA key (3.20%) and the 384-bit ECC key (0.44%) are the least used. The results seem to support that the Brazilian HEIs using an HTTPS service generally uses secure and high-quality TLS keys. Only one institution uses a 1024-bit RSA key, which can be considered insecure.

Fig. 7 presents the algorithms used by institutions. The results show that most Brazilian HEIs (74.45%) use the RSA algorithm, followed by the ones using ECC algorithm (10.13%). The results also show that the state of Roraima (90%) is the leader in the use of the RSA algorithm, followed by the Rio Grande do Norte (85.71%) and Ceará (80.22%). In

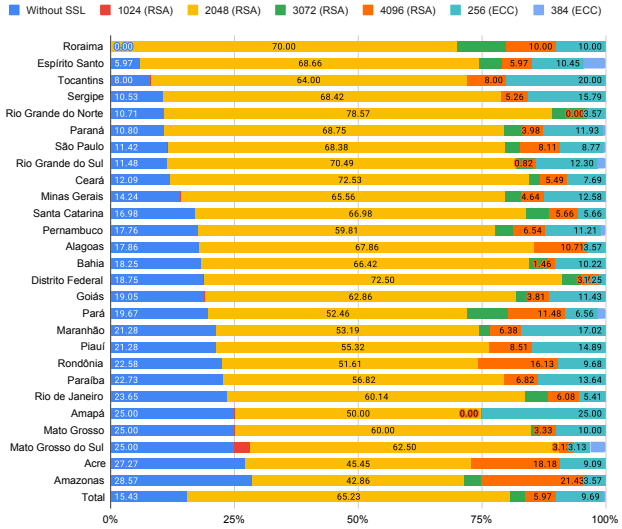

Fig. 6. Length of TLS keys used by Brazilian HEIs.

the ECC category, the state that leads the use of this algorithm is Amapá (25%), followed by Tocantins (20%) and Maranhão (17.02%).

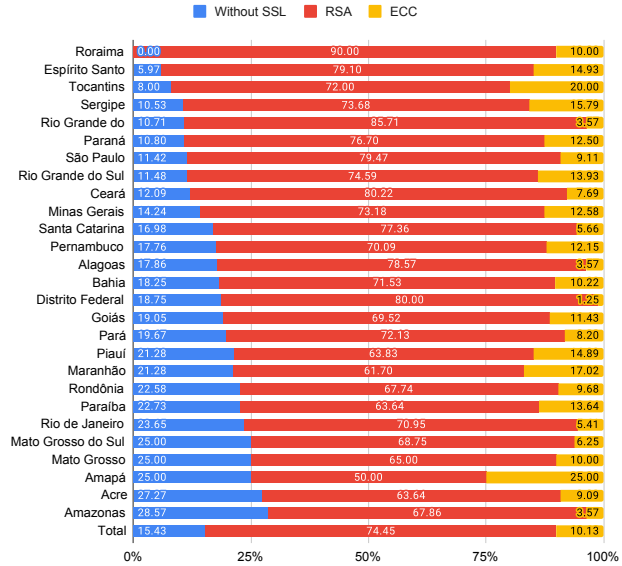

Fig. 7. TLS Algorithms Used by Brazilian HEIs

Fig. 8 presents the best version of TLS protocol used in HTTPS connections established with institutional websites of Brazilian HEIs distributed by states. The results show that the TLSv1.3 version is used by 43.24% of Brazilian HEIs, while 41.34% use the TLSv1.2 version. The states that lead in the implementation of the TLSv1.3 version are Amapá (66.67%), Roraima (60%), and Ceará (57.14%). Rio Grande do Sul (55.74%), Rondônia (48.39%), and Sergipe (47.37%)

states lead the use of the TLSv1.2 version.

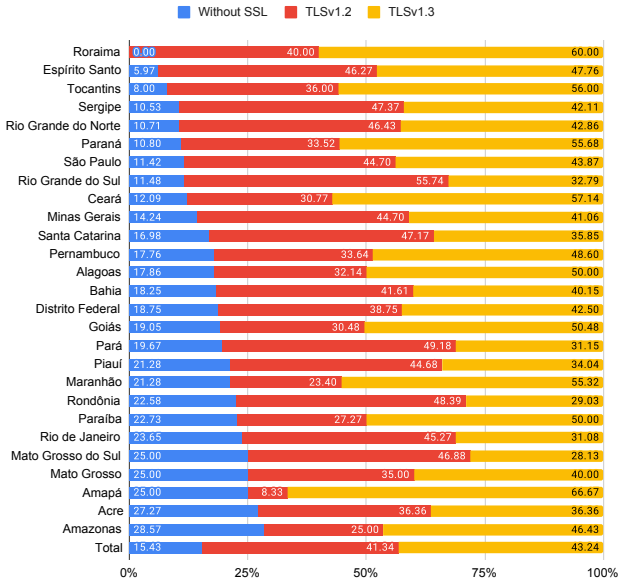

Fig. 8. Best version of the TLS protocol by the Brazilian HEIs.

Fig. 9 presents the worst version of SSL/TLS protocol used in HTTPS connections established with institutional websites of Brazilian HEIs distributed by states. These results are presented in order from top (worst) to bottom (better). The results show that the SSLv2 version is used by 0.20% of Brazilian HEIs, while 1.58% use the SSLv3 version, and TLSv1.0 is used by 38.29%. The states that lead in the use of the SSLv2 version are Santa Catarina (0.94%), and São Paulo (0.66%). Already in the lead in the use of the SSLv3 version, the Mato Grosso do Sul (6.25%), Rio de Janeiro (4.05%), and Amazonas (3.57%). Finally, the states that lead the use of the TLSv1.0 version are Amapa and Roraima (50%), Rondônia (48.39%), and Minas Gerais (46.03%).

3) Security Headers: Fig. 10 evaluates the implementation of the following security headers: X-Content-Type-Options, X-Frame-Options, and X-XSS-Protection. The results show that, of the 2528 institutional websites, 80.02% (2023) do not implement security headers, while only 19.98% (505) do. Among those that use security headers, private institutions lead with 16.81% of use, against 3.16% of public institutions. The states that lead in the use of security headers by public institutions are Roraima (20%), Sergipe (10.53%), and Acre (9.09%). The states with the lowest use of security headers are Mato Grosso (1.67%), Paraná (1.70%), and Bahia (2.18%). The states of Alagoas, Amapá, Maranhão, Tocantins, and Piauí do not have any public institution that uses security headers. Among private institutions, states that lead in the use of security headers are: Rio Grande do Norte (32.14%), Rio Grande do Sul (24.59%) and Sergipe (21.05%). The states with the lowest use of security headers are: Mato Grosso do Sul (6.25%), Amapá (8.33%) and Mato Grosso (10%).

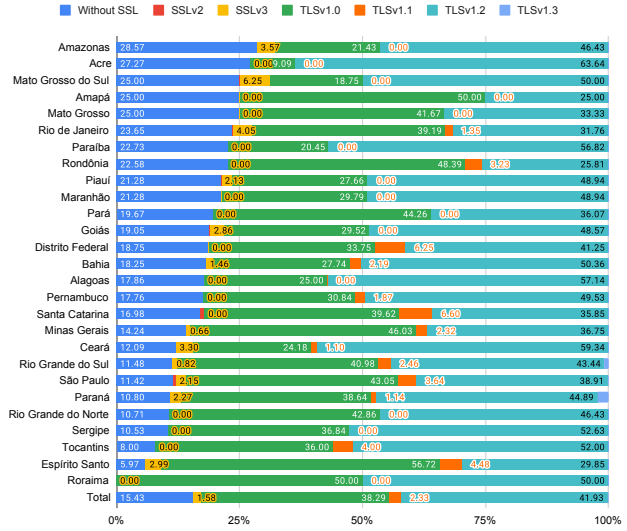

Fig. 9. Worst version of the SSL/TLS protocol by the Brazilian states.

The state of Sergipe leads the use of security headers, while Mato Grosso follows as the one that least implements this technology. From these results, it can be concluded that the security headers support stills in an early stage, particularly in public institutions.

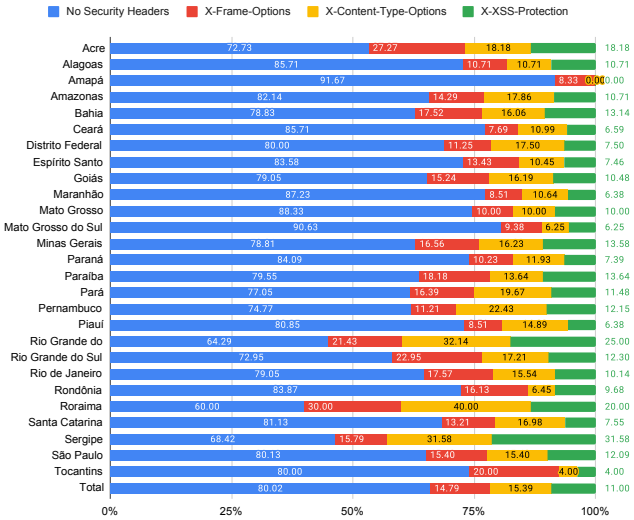

Fig. 10. Security Headers by Brazilian states

V. Conclusions

To protect their systems and data, and ensure safe access to their users, HEIs should implement the desired security levels in their web-related services, supporting services such as HTTPS and DNSSEC.

This article surveys and analyzes the status of web-related security services, namely the HTTPS and the DNSSEC services, in Brazilian HEIs.

All Brazilian HEIs that had an institutional website registered in the MEC of Brazil had their public domain data collected and 2,528 records were analyzed by scripts to collect specific data on DNSSEC adoption, HTTPS redirection, security header usage, and SSL/TLS certificate information.

The obtained results show that, regarding DNSSEC, only about 2% of the HEIs are implementing this protocol. Regarding HTTPS around 15% do not use SSL/TLS certificates and from those supporting it, about 14% do not demand its usage. Additionally, about 43% of Brazilian HEIs already negotiate with the latest version of TLS (TLSv1.3), while about 2% still negotiate with a vulnerable SSL version (SSLv3). Regarding TLS cyphers and algorithms, 65.23% of public and private institutions with HTTPS use a 2048-bit encryption key, and 71.64% use the RSA algorithm. Regarding negotiations under the TLS protocol, 43.24% of Brazilian public and private HEIs already negotiate with the latest version of TLS: TLSv1.3, while 1.58% of HEIs still negotiate with the vulnerable SSL version: SSLv3. There are still 0.20% of HEIs that negotiate with the oldest version of SSL: SSLv2.

These results show that it is fundamental to design an effective and continuous action plan for HEIs to support the most up-to-date version of these protocols and end support for obsolete versions, to improve their protection against cyber attacks.

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