Web Services Attacks and Security- A Systematic Literature Review

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Abstract

Web Services allow applications to communicate with each other independent of platform and/or language. They are prone to attacks in the form of Denial-Of-Service, XML, XPath, SQL injection and spoofing, making implementation of web service security vital. Though many solutions are proposed for minimizing attacks, there is no single solution for mitigating all the attacks on web services. The objective of this paper is to present a systematic review on the studies of web service security. It is identified that there is lot of research going on in web services, dealing mostly with attack detection as well as identification of vulnerabilities in the services. Denial-of-service attack is found to be the most addressed of all attacks. Solutions were mainly proposed using dynamic analysis, closely followed by static analysis.

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1. Introduction

In the current day, many applications and web pages depend upon web services to seamlessly exchange information among one another. Web services provide a way to transfer dissimilar data over the network helping organizations/individuals reuse functionality across services. There is dynamic relationship between the user and the web service, as there are many scenarios that are user input controlled. This dynamic nature is often a cause of worry. Web services protocols include Simple Object Access Protocol (SOAP), XML-RPC, and JSON-RPC for message communication; Web Service Description Language (WSDL) and Universal Directory and Discovery Integration (UDDI) for web service description and discovery. Frameworks used for creating/developing web services mainly include Apache Axis, .NET and Zend. Due to the variety of protocols and frameworks involved in developing a web service, they become vulnerable and often prone to attacks.

Most web service attacks are XML Injection, XPath Injection, SQL Injection, Spoofing, Denial of Service and Man in the Middle attack. DOS attacks affect the availability of system and its resources to valid requests. Recursive payload takes advantage of extensive XML tag nesting to overload the parsers thus causing XDOS attacks. Coercive payload loads a lengthy XML message into memory that utilizes large amount of CPU resources thus making the server unavailable, contributing to DOS attacks.

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Injection attacks occur when malicious code is inserted through user inputs to gain access to restricted data. SQL, XPath and XML injections are the most occurring in web services. Though parametrized queries, prepared statements and whitelist validations are often stated as countermeasures, these conventional fixes cannot eradicate the attacks completely.

Spoofing is done by masquerading as a valid user and sending requests to bypass any access controls.

The purpose of the paper is in presenting the systematic review we have conducted on the existing state of research on web service security. The rest of the paper is structured as follows: approach taken to review this paper is discussed in Section 2. Section 3 depicts the results obtained. Section 4 answers the research questions raised and Section 5 provides the conclusion.

2. Research Approach

This paper performs a detailed analysis of existing studies on web service security published in journals/conferences.

2.1. Research Questions

Listed below is the set of research questions addressed in this study:

Q1: How much research has happened on web service security since 2005?
Q2: What are the web service security issues that are addressed in the research papers?
Q3: What are the techniques proposed to solve web service security issues?
Q4: Which are the web service security areas focused in the research papers?

To answer Q1, a systematic analysis and review on research spanning from 2005 up to 2016 was done. Regarding Q2, we have tried to identify the attacks that each of the paper focuses on. We wanted to identify the proposed models/algorithms/solutions and Q3 aims to answer that. For Q4, we have differentiated between attacks and vulnerabilities and their detection and prevention techniques.

2.2. Requirement Process

To collect the necessary case papers for the study, data repository search was performed. Relevant articles were obtained from each of the repository.

The search terms used were:
- Web service attacks.
- Web service vulnerability.
- Web service attack mitigation.
- Denial of Service attacks.
- XML injection.
- SQL injection.
- XPath injection.
- Web service attack mitigation.

Combination of above mentioned search terms was done using Boolean AND/OR.

Further search was done on the referenced publications in the obtained papers for topics related to web service security.

2.3. Paper Inclusion Standard

Papers with the following criteria were included:

- Papers that describe solution to address the web service security problem.
- Papers that use testing methodologies for vulnerability detection in web services.
- Papers that address web service attack such as SQL/XML/XPath Injection, Spoofing and Denial of Service.
- Papers that are published before April 2016.
2.4. Data Collection

The following data was collected from every individual paper:

- Title of the paper & Year of publication.
- Summary of Paper.
- Type of Web service attack (XML/SQL/XPath Injection, Spoofing, Denial of Service).
- Area of focus (Attack prevention, Vulnerability detection, Attack detection).

3. Results Obtained

Table 1. Summary of review findings.

| Ref | Type of Attack | Summary of the Paper | Area of focus          |
|-----|----------------|----------------------|------------------------|
| [1] | XPath injection| An architecture that uses a run-time monitoring mechanism to identify malicious queries thus preventing XPath Injection. | Attack prevention      |
| [2] | SQL injection  | SQL vulnerabilities in web services is detected based on mutation operator related automated testing approach. | Vulnerability detection|
| [3] | DOS attack     | An adaptable algorithm for testing web services by parsing incoming XML messages for DOS attack. | Attack detection       |
| [4] | SQL,XPath injection | A comparison of existing vulnerability scanners against 300 public web services to identify security flaws. | Vulnerability detection|
| [5] | SQL,XPath injection | An automated approach for XPath/SQL injection vulnerability detection in web services. | Vulnerability detection|
| [6] | SQL injection  | A systematic approach for web services to detect SQL injection vulnerabilities using penetration testing tool. | Vulnerability detection|
| [7] | DOS attack     | Model an architecture to apply on web services and create a filter defense system to protect against XML based DOS. | Attack detection/Attack prevention |
| [8] | XML injection attack | An approach is proposed with pluggable API as well as security services in the middleware to detect and overcome XML Injection attacks. | Attack detection       |
| [9] | Spoofing, DOS  | An automated pluggable API Model for network level threat detection was proposed. | Attack detection       |
| [10]| DOS attack     | A proposed real time agent based classification mechanism for detecting and preventing DOS attacks on web services. | Attack detection/Attack prevention |
| [11]| SQL,XML, XPath injection | A novel approach to complement existing vulnerability detection by forming sound and precise slices thus identifying false and true positives. | Other                  |
| [12]| Spoofing       | Proposed a misuse pattern called Spoofing web services to prevent the same attack on web services. | Attack prevention     |
| [13]| XML injection  | A hybrid learning, universal approximator model is proposed to detect XML SOAP based attacks on web services. | Attack detection/Attack prevention |
| [14]| SQL,XMl injection | An intrusion detection systems based on fuzzy rules is suggested to prevent Injection as well as Denial-of-service attacks. | Attack prevention     |
| [15]| DOS attack     | A content introspection framework is suggested to prevent XML based Denial-of-service attack on web services. | Attack prevention   |
| [16]| DOS attack     | Effectiveness of a cryptographic authentication technique for access grant to prevent DOS attacks on web services is studied. | Other                  |
| [17]| DOS attack     | Deploy known DOS vulnerabilities on web services to identify the effect on resources and performance. | Other                  |
4. Exploration

4.1. How much research has happened on web service attacks since 2005?

In this systematic study, we identified relevant papers as shown in Table 1. Fig. 1. (a) depicts the research on web service attacks per year. The research is active and still going on as per Fig. 1. (a). Paper publications is spread across journals and conference proceedings. Out of the 36 papers, 6 has been published in journals, covering areas such as...
Computer Science, Network and Information security as well as system engineering. The remaining 30 has been published in various international conferences.

Table 2. Web service attacks vs Area of focus.

| Web service attacks                  | Attack detection | Attack prevention | Vulnerability detection | Vulnerability prevention | Combination |
|--------------------------------------|------------------|-------------------|-------------------------|--------------------------|-------------|
| XML injection                        | 4                | 1                 | 1                       | 1                        | 1           |
| SQL injection                        |                  | 2                 |                         |                          |             |
| XPath injection                      |                  | 1                 |                         |                          |             |
| Spoofing                             |                  | 1                 |                         |                          |             |
| Denial-Of-Service                    | 6                | 3                 | 7                       |                          |             |
| SQL,XML injection and DOS            |                  | 1                 |                         |                          |             |
| SQL and XPath injection              | 2                | 2                 |                         |                          |             |
| SQL, XML and XPath injections        |                  |                  |                         |                          |             |
| SQL and XML injections               | 1                |                  |                         |                          |             |
| Spoofing,DOS                         |                  | 1                 |                         |                          |             |

4.2. What are the web service security issues that are addressed in the research papers?

There are varied attacks on web services, ranging from injection attacks to Denial of service attacks. The following sections elaborates on them.

4.2.1. SQL Injection Attack

SQL injection attacks are very common in a web service environment. Most of the web services have improperly coded blocks that fail to filter non-validated user inputs. This inject and embed themselves as a parameter in a SQL statement trying to run non-administrative commands. As per Table 2, we can identify that 25% (9) of papers address SQL injection attacks. Among the 9 papers, 77.78% of them (7) discuss on other attacks such as XPath and XML injection as well.

4.2.2. XML Injection Attack

When any service fails to validate malicious XML content, XML injection vulnerability arises. The injection of malicious XML content into any service can alter the working logic. 30.55% of papers (11) discuss XML injection attack along with other attacks. 7 papers out of 11 (63.63%) address XML injection attacks alone.

4.2.3 XPath Injection Attack

XPath injection attack targets services/applications that use XPath as a language to convert user provided input to query XML documents. By sending a malformed user input, unauthorized information such as structure of XML document is obtained. 1,4,5,11,28,29 are the papers published that discuss on XPath based injection attacks. This constitutes 16.67% of the total papers analyzed.

4.2.4 Denial of Service Attack

DOS attack renders the target machine unresponsive by depriving the service of resources. DOS Attacks is addressed in 52.77% of papers (19), amongst which 15.78 % (3) deal with multiple attacks. Papers addressing DOS attacks alone are 3,7,9,10,14,18,20-23,25,27,30,32,33,35.
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Fig. 1. (a) Publication year vs Publication count; (b) List of techniques used.

Table 3. Comparison between year and attacks.

| Year | SQL Injection | XML Injection | XPath Injection | DOS | Others/Combinations |
|------|---------------|---------------|-----------------|-----|---------------------|
| 2005 |               |               |                 | 33  |                     |
| 2006 |               |               |                 |     |                     |
| 2007 |               |               |                 |     |                     |
| 2008 |               |               |                 |     |                     |
| 2009 |               |               |                 |     |                     |
| 2010 |               |               |                 |     |                     |
| 2011 |               |               |                 |     |                     |
| 2012 |               |               |                 |     |                     |
| 2013 |               |               |                 | 3   |                     |
| 2014 |               |               |                 | 3   |                     |
| 2015 |               |               |                 | 3   |                     |
| 2016 |               |               |                 | 3   |                     |

4.3. What are the techniques proposed to solve web service security issues?

4.3.1. Dynamic Analysis

Dynamic analysis technique focuses on identifying output consistency w.r.t to input given in runtime. It is the most suggested technique with 36.11% of articles (13) proposing as a solution technique as per Table 4. It compromises black box testing, learning based and schema hardening. Other dynamic techniques are discussed in.

4.3.2. Static Analysis

Static analysis deals with the code and does not focus on execution. Discrepancies are identified in the code to check for vulnerabilities. Static analysis can be done during the development phase itself. 11 deals with slicing techniques; code analysis in. Flow analysis is discussed in. As seen in table 30.55% of articles (10) focus on static analysis. Static and dynamic analysis study are done in.

Table 4. Summary of techniques in the studies.

| Techniques            | References               | No of Papers (% ) |
|-----------------------|--------------------------|-------------------|
| Dynamic Analysis      | [2-4,6,17-19,21,29,30,32,33,36] | 13 (36.11%)       |
| Static Analysis       | [1,5,9,11,15,20,23,28,31,34] | 10 (27.78%)       |
| Model Based           | [7,10,13,14,22,26]        | 6 (16.67%)        |
| Secure programming    | [8,16,24,35]              | 4 (11.11%)        |
| Others                | [12,25,27]                | 3 (8.33%)         |
4.3.3. Model Based

As per Fig. 1. (b), in another 6 studies (16.67%), models are used as solving techniques. 10 uses a case based reasoning model. Fuzzy logic is dealt with in 14. Intrusion model is used in 26. Web services attack model is discussed in 26. Other models are proposed in 7, 13.

4.3.4. Secure Programming

Techniques to secure the web service using filters, libraries or secure coding are discussed in 4 papers as per Table 4 (11.11%). Filtering policy is discussed in 24. Defense system integration into web services for authentication and verification is used in 25. Hash-based cryptography measure is included in web service in 16. Pluggable API based security is discussed in 8.

4.3.5. Others

Other approaches like pattern based 12, vector quantization 25 and adaptive rule 27 solutions are discussed in 3 papers as per Table 4.

4.4. Which are the web service security areas focused in the research papers?

This study mainly focuses on two areas: web service attacks and web service vulnerabilities. 20 studies (55.56%) focus on web service attacks and 6 (16.67%) focus on web service vulnerabilities. 10 papers (27.78%) focus on various combination techniques or attack implementation to test out web service strength as well as evaluate the web service contingency measures. To elaborate further the techniques are further classified into Attack Detection/Prevention, Vulnerability detection/prevention.

Table 2 indicates how the techniques are divided into six groups. Attack detection is the highest individual area with 30.55%, followed by Attack prevention that has papers contributing 25%. This is a positive approach as not only should contingency measures be taken after an attack has occurred, but enough research needs to be done on how to prevent the attack themselves.

Vulnerability detection and prevention is also important and 6 studies (16.67%) focus on the vulnerabilities. Vulnerability prevention is discussed in 26.

5. Conclusion

Web services have become the primary way in which key information is seamlessly exchanged between applications. This makes web service security an essential component and web service attack a serious threat to the integrity and availability of data. We have systematically analyzed 36 papers on web service attacks. Most addressed attacks are Denial-of-Service attacks followed by XML injection attacks. Techniques to deal with attacks predominantly focus on attack detection measures. Since web service attacks cannot be completely eliminated, penetration and automation testing should be done as part of every development. This will guarantee added protection as well as lower attacks on web services.

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