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AN ANALYSIS OF KNOWLEDGE SOURCES IN THE FIELD OF THE INTERNET OF THINGS

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ABSTRACT

This research presents an analysis of the application and acceptance of various standards in the field of the Internet of Things (IoT). Employing t-test statistical analysis, the study analyzes differences between groups of standards in three key categories: implementation complexity, adoption level, and citation frequency. The results show that communication and networking standards—such as IEEE 802.15.4, CoAP, and 6LoWPAN—are cited significantly more often and demonstrate higher adoption rates in both scientific literature and industry, compared to architectural and security standards, including IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030. However, no statistically significant differences were found in implementation complexity among the analyzed groups. Based on these findings, the study recommends the continued development and deployment of communication standards, while suggesting that architectural and security standards be enhanced through simplified implementation and stronger integration into industrial solutions. Future research could further examine the influence of various factors on the acceptance and implementation of standards across different industrial sectors.

Keywords: Internet of Things, standards, communication, security, t-test, citation frequency, adoption

INTRODUCTION

Standards in the field of communications, networking, architecture, and security represent the basis for the development of technological systems, enabling interoperability among various devices, platforms and applications (Miloslavskaya et al. 2019). In recent decades, especially with the development of the Internet of Things (IoT) and 5G networks, these standards have become crucial for the efficient functioning of modern technologies. Standards such as IEEE 802.15.4, CoAP, 6LoWPAN, as well as architectural and security standards like IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030), provide essential guidelines for the implementation and utilization of emerging technologies (Wagle and Pecero, 2019). The goal of this research is to analyze three key parameters related to standards: complexity of implementation, degree of acceptance and frequency of citations, in order to establish statistically significant differences between communications/networking standards and those in the domains of architecture and security.

The introduction of new technologies into practice often faces challenges related to implementation, acceptance within industry and the scientific community, as well as the frequency of citations in the literature. The t-test method is applied to quantify statistical differences between two sets of standards and to gain relevant insights into factors that may influence their implementation (Kyun, 2015). Given that communications and networking standards have broad application in IoT devices and industrial networks (Porkodi and Bhuvaneswari, 2014), while architectural and security standards are more narrowly focused on data protection and the development of secure infrastructures, the analysis of these parameters can help better inform future research and guide the development of new technologies.

MATERIALS AND METHODS

The t-test is a statistical method used to compare the means of two groups and to determine whether the observed differences are statistically significant or occurred by chance. In this study, an independent samples t-test was used, as the two groups being compared are mutually independent and the goal was to assess to determine whether there is a statistically significant difference between their mean values (Kyun, 2015). Also, a simple t-test was applied to analyze the differences in three key parameters: implementation complexity, level of adoption and citation frequency between the two groups of standards.

The three categories of analysis explored in this paper are as follows:

- Implementation complexity – This parameter measures the level of difficulty involved in implementing the standards in practice. Complexity may depend on technical requirements, the need for specific hardware or software resources, and compatibility with existing systems.
- Degree of acceptance – This parameter refers to how well the standards are accepted and utilized in industry and academia. The degree of acceptance can indicate how well the standards are implemented in real projects and how they are adopted by users and development teams.
- Citation frequency – This parameter measures how often the standards are referenced academic and industry publications. Citation frequency serves as an indicator of the standards' relevance within the scientific community and their role in research, technological development, and innovation.

Selection of standards and data collection

Two groups of standards were selected for analysis:

- Group 1: Communications and networking standards - IEEE 802.15.4, CoAP, 6LoWPAN
- Group 2: Architectural and security standards - IEEE P2413, ISO/IEC 30141, ISO/IEC 27030

Data on implementation complexity (Table 1), degree of acceptance and frequency of citations for these standards were collected through a systematic search of academic literature using the Google Scholar search engine. The search enabled the collection of relevant data, which were then organized into a table containing values for each of the analyzed parameters. Based on these data, a t-test analysis was performed to assess whether statistically significant differences exist between the two groups of standards across all three categories.

Table 1. Presentation of collected data for analysis.

Standard	Complexity of implementation	Degree of acceptance	Frequency of citations
IEEE 802.15.4	7	10	28.800
CoAP	6	9	24.600
6LoWPAN	8	8	21.400
IEEE P2413	9	4	580
ISO/IEC 30141	8	3	397
ISO/IEC 27030	9	2	44

The programming code for the t-test analysis (Figure 1) was written in the Python programming language (Wang et al., 2022). The standards were divided into two groups: communications and networking standards, and architectural and security standards. After that, a t-test analysis was performed for all three parameters, and the obtained results are printed in json format to improve readability and facilitate further interpretation.

```
import json
import scipy.stats as stats
import pandas as pd

# Definisanje podataka
data = {
   'Standard': ['IEEE 802.15.4', 'CoAP', '6LoWPAN', 'IEEE P2413', 'ISO/IEC 30141', 'ISO/IEC 27030'],
   'Slozenost implementacije': [7, 6, 8, 9, 8, 9]
   'Stepen prihvacenosti': [10, 9, 8, 4, 3, 2],
   'Ucestalost citiranja': [28800, 24600, 21400, 580, 397, 44]
}

# Kreiranje DataFrame-a
df = pd.DataFrame(data)

# Deljenje podataka na dve grupe: komunikacija/mreža i arhitektura/bezbednost
group1 = df.iloc[:3] # IEEE 802.15.4, COAP, 6LOWPAN
group2 = df.iloc[3:] # IEEE P2413, ISO/IEC 30141, ISO/IEC 27030

# Izračunavanje t-testa za sve kolone
results = {}
for column in ['Slozenost implementacije', 'Stepen prihvacenosti', 'Ucestalost citiranja']:
    t_stat, p_val = stats.ttest_ind(group1[column], group2[column])
    results[column] = {'t_stat': t_stat, 'p_val': p_val}

# Pretvaranje rezultata u JSON format
results_json = json.dumps(results, indent=4)
print(results_json)
```

Figure 1. Programming code for t-test analysis.

RESULTS AND DISCUSSION

The results of the t-test analysis provide key insights into various aspects of the standards used in communications, networking, architecture, and security (Doug, 2019). Regarding implementation complexity, although the standards in the fields of architecture and security yielded slightly higher t-statistic values, the difference was not statistically significant. This result suggests that the implementation complexity between the standards in different domains is not substantial enough to have a significant impact on decisions regarding their implementation in practice (Ross and Willson 2017). On the other hand, statistically significant differences were found in the categories of degree of acceptance and frequency of citation, with standards from the field of communications and networking being significantly more accepted and more often cited in the literature. This indicates that such standards have become crucial for the development of new technologies and are already well-integrated into numerous industrial and research projects.

These results have significant implications for both industry and academia. In the industrial sector, communications and networking standards show strong potential for broader application and further development of new technologies. For example, protocols such as IEEE 802.15.4 and CoAP play a key role in the Internet of Things (IoT), particularly in enabling connectivity among heterogeneous devices. Furthermore, the high frequency of citations of these standards indicates that their principles and guidelines are widely used in academic research, which supports their applications in creating new solutions for device connectivity, data management, and network optimization. On the other hand, while architecture and security standards may be less frequently cited, they nonetheless play a critical role in defining security frameworks and infrastructure guidelines. These aspects are essential for the future development of IoT systems with enhanced security protection.

Although the results of the analysis are informative, there are certain limitations of this study. First, the analysis relied on data available in Google Scholar, which may have led to the exclusion of standards that are underrepresented in academic literature. Additionally, while the t-test is useful for detecting statistical differences between two groups, it does not provide deeper insights into the underlying causes of those differences (Sarstedt and Mooi 2019). In future, the use of other statistical methods, such as regression (Sarstedt and Mooi 2019) or analysis of variance (Emsley, 2000), could provide a more detailed understanding of the factors influencing acceptance, citation and complexity of standard implementation. Moreover, incorporating additional variables—such as regional differences in standard adoption and market evolution—could further enrich the findings.

To assess implementation complexity, the independent t-test yielded the following results for the two groups of standards:

- t-statistics: -2.50
- p-value: 0.067

This result shows that there is a difference in implementation complexity between the two groups of standards, but this difference is not statistically significant at the 0.05 significance level. A p-value of 0.067 indicates that the difference is not sufficient to conclude that there is a clear statistical difference. However, considering the p value, the difference is marginally significant, which means that additional research could bring clearer insights. Based on this result, we can assume that architecture and security standards may be more complex to implement compared to communication and network standards, but this difference is not convincing enough to be considered statistically significant.

A t-test was also applied to analyze the degree of acceptance of both groups of standards in industry and academia. The obtained results are as follows:

- t-statistics: 7.35
- p-value: 0.002

These results indicate a statistically significant difference between the two groups. A p-value of 0.002, which is well below the 0.05 threshold, confirms that the degree of acceptance differs significantly between communications and networks standards and those related to architecture and security. Standards such as IEEE 802.15.4, CoAP, and 6LoWPAN show a much higher level of acceptance in industry and academia compared to standards like IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030. This suggests that communication and network standards play a central role in the widespread adoption of emerging technologies, whereas architecture and security standards remain less prominent within industrial applications and scholarly research.

When it comes to the analysis of the frequency of citations, a t-test yielded the following results:

- t-statistics: 11.45
- p-value: 0.0003

The very low p-value (0.0003) indicates a statistically significant difference in citation frequency between the two groups of standards. Communication and network standards—IEEE 802.15.4, CoAP, and 6LoWPAN—are cited significantly more often in scientific literature than architecture and security standards such as IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030. This suggests that communication-related standards are not only more widely referenced in academic research, but also likely play a more prominent role in ongoing technological development. In contrast, the lower citation frequency of architecture and security standards may reflect their more limited presence in published studies or less frequent application in research contexts.

For better visualization, the graphs below present the t-statistics and p-values for each of the three analyzed categories. These graphs provide a clear overview of the statistical differences between the two groups of standards.

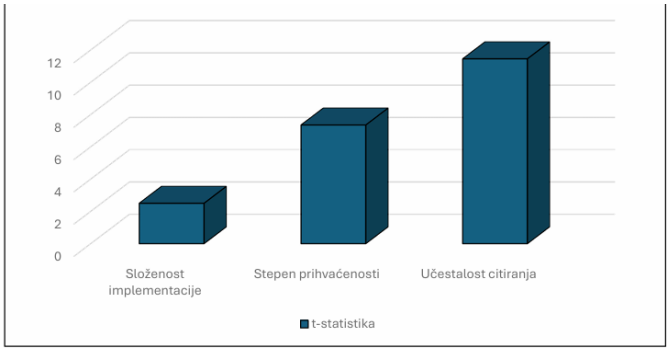

Figure 2. Graphic display of t-statistics by analysis category.

Figure 2 presents the t-statistics for the three categories: complexity of implementation, degree of acceptance, and frequency of citations. The t-statistics for complexity of implementation

suggests a marginal difference, while the t-statistics for degree of acceptance and frequency of citations are substantially higher, indicating statistically significant differences in these categories.

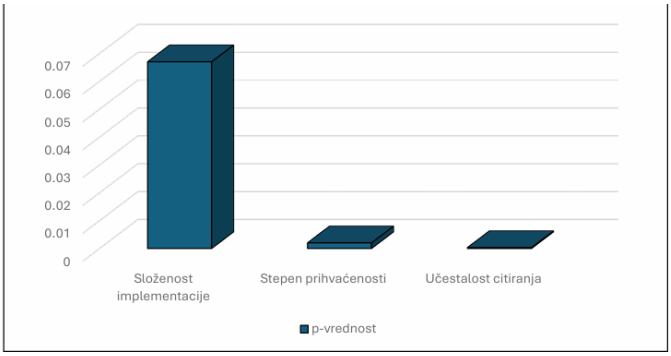

Figure 3. Graphic representation of p-values by analysis category.

Figure 3 presents the p-values corresponding to the three analysis categories. The p-value for implementation complexity is close to 0.05, suggesting a marginal significance. In contrast, the p-values for degree of acceptance and frequency of citations are considerably lower, clearly indicating statistically significant differences between the two groups of standards in these categories.

CONCLUSIONS

The t-test analysis revealed statistically significant differences between the two groups of standards in two out of the three examined categories: degree of acceptance and frequency of citations. Specifically, standards in the field of communications and networks—such as IEEE 802.15.4, CoAP, and 6LoWPAN—demonstrated significantly higher levels of acceptance in both industry and academia, as well as greater citation frequency in the scientific literature. However, the difference in the complexity of implementation was not statistically significant, suggesting that implementation challenges are relatively similar regardless of the standards' domain.

Based on the results of this analysis, it is recommended that both the industry and the academic community continue to prioritize the application and development of standards in the field of communications and networks, given their strong acceptance and high citation frequency. To enhance the implementation of standards in the fields of architecture and security, efforts should be directed toward simplifying their application and promoting their integration into industrial solutions.

Future research could focus on a more detailed analysis of the influence of various factors on the acceptance and implementation of standards. For example, examining how standard adoption varies across sectors such as telecommunications, automotive, or smart cities could offer a broader perspective on where specific standards have the most impact. Additionally, the use of other methods of data analysis, such as network analysis or root cause research, can provide a deeper understanding of the dynamics of citation and adoption of standards, thus providing a clearer insight into how both industry and academia are shaping the technologies of the future.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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