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On IPv6 Slow Adoption; Why We Might Approach it Wrongly?

Mukhammad Andri Setiawan
Universitas Islam Indonesia, Jl. Kaliurang KM 14, Sleman, Yogyakarta 55584, Indonesia.

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ABSTRACT

The slow adoption of IPv6, despite its numerous advantages over IPv4, is a pressing issue in many regions, including Indonesia. This challenge is particularly significant given the increasing demand for Internet of Things (IoT) devices and the need for a sustainable, scalable, and flexible network infrastructure. In response to this issue, our research introduces the Design Thinking-Inspired Technology Adoption (DTITA) model. This innovative approach leverages design thinking principles to facilitate the adoption of new and challenging technologies. DTITA incorporates the five stages of design thinking alongside traditional technology adoption factors, such as perceived usefulness, ease of use, and social influence. The DTITA model aims to create user-centric solutions that address new technologies' unique challenges and barriers. By placing the user at the center of the design process, we were able to develop solutions that are not only technologically advanced but also highly accessible and relevant to users. Through a survey involving individuals from the education industry, Internet Service Providers (ISPs), content providers, government institutions, and the Information and Communication Technology (ICT) industry, we identified key barriers impeding the widespread implementation of IPv6. This study provides valuable insights into the application of design thinking in the context of technology adoption, particularly in the case of IPv6. It contributes to the broader discourse on technology adoption and offers practical recommendations for stakeholders and decision-makers in Indonesia.

Corresponding Author:

Mukhammad Andri Setiawan, Universitas Islam Indonesia, Jl. Kaliurang KM 14, Sleman, Yogyakarta 55584, Indonesia
Email: andri@uii.ac.id

1. INTRODUCTION

As Indonesia continues accelerating its digital transformation, addressing the challenges of limited internet resources, connectivity, and network scalability is at the forefront. This transformation is reshaping the technological landscape and significantly impacting small and medium enterprises and even large enterprises. According to [1] the transformation process from e-government to digital government in Indonesia is underway. This is further developed by the COVID-19 pandemic, which has also led many enterprises to adapt their business models to leverage digital technologies [2].

The widespread adoption of IPv6 can revolutionize the country's landscape, paving the way for inclusive and sustainable growth [3][4][5]. IPv6 is designed to accommodate the growing number of devices connected to the internet, organizing them more efficiently while improving overall network performance and security [6][7][8]. With the increasing demand for Internet of Things (IoT) devices, IPv6 provides virtually unlimited IP addresses, ensuring a sustainable, scalable, and flexible network infrastructure [6][9][10]. Moreover, IPv6 enhances end-to-end connectivity, improving the efficiency of peer-to-peer applications and reducing the reliance on Network Address Translation (NAT) devices [11][12].

Unfortunately, based on the statistics provided by APNIC [13] as shown in Fig. 1, Indonesia still needs to catch up in IPv6 adoption compared to its neighbors. Like many other countries that still need to embrace IPv6 fully, Indonesia shows how disappointing it is when multiple stakeholders are reluctant to implement

IPv6 [14]. One of the major factors hindering the growth and uptake of IPv6 is the need for more technical knowledge and expertise regarding this next-generation Internet Protocol [15]. This situation has created challenges and obstacles for individuals and organizations, which could seriously affect the country's transformation and overall technological progress in the coming years. The lack of training and educational resources on IPv6 can contribute to a skills gap, limiting the capacity of IT professionals and network administrators to implement and maintain the new protocol successfully [2]. As a result, organizations might need help to transition to IPv6, facing potential difficulties in adapting their network infrastructure, troubleshooting issues, and optimizing performance.

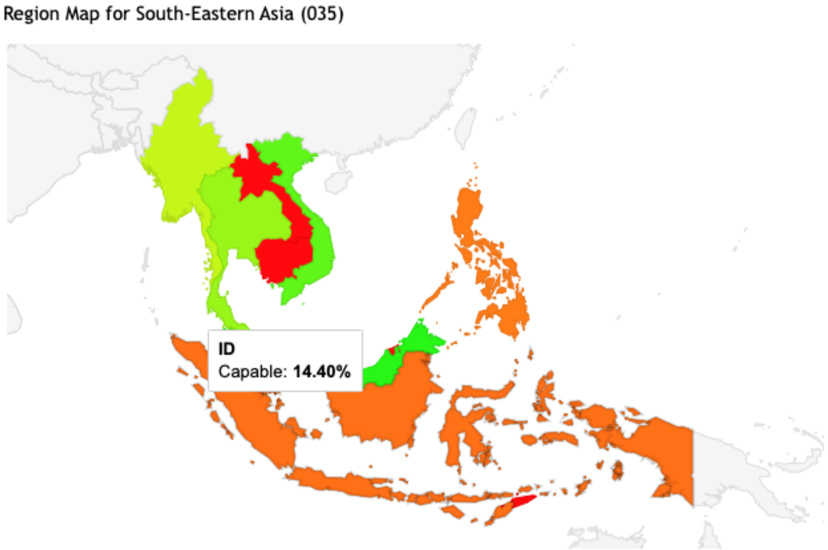

Fig. 1. IPv6 State of Indonesia (as of 1 April 2023)

Addressing this skills gap requires concerted efforts by various stakeholders, including government, educational institutions, and the private sector, to invest in capacity-building initiatives and develop comprehensive training programs for existing IT professionals and students pursuing careers in the field [16][17]. Furthermore, promoting collaboration and knowledge-sharing among regional and international organizations can help bridge the gap in technical expertise and facilitate the transfer of best practices, such as in IPv6 deployment and management.

As we move forward into a world that is increasingly connected and reliant on the smooth functioning of the internet, it is crucial to identify and address these issues to ensure that Indonesia is included regarding technological advancements and opportunities afforded by IPv6 adoption. Enhancing IPv6 literacy and awareness among policymakers, industry leaders, and the general public can foster a more supportive environment for its adoption, enabling the country to fully capitalize on the next-generation Internet Protocol's benefits [18]. Digital literacy, including knowledge of IPv6, is critical in today's increasingly connected world. However, insufficient emphasis on this subject in Indonesia's educational curricula and professional training programs has led to a significant skills gap [19]. Furthermore, the limited availability of resources, such as textbooks, online materials, and trained instructors, exacerbates the problem and perpetuates the cycle of inadequate IPv6 education [20].

Despite IPv6's introduction at World IPv6 Day 2011 [21], its adoption rate could have been faster, prompting a need for new strategies. This paper proposes a design thinking approach to accelerate IPv6 adoption, focusing on empathy, collaboration, and experimentation. We implemented an IPv6 deployment project across multiple large-scale Indonesian organizations, collecting pre and post-surveys and measuring IPv6 implementation at the network's core through BGP peering data.

The key highlights of our contributions are as follows: we are the pioneers in investigating the phase of advancing large-scale IPv6 network deployment within Indonesian enterprises; our novel approach, i.e., design thinking, explores different views in implementing IPv6 for enterprises. We also offer practical recommendations for stakeholders and decision-makers in Indonesia, contributing to the broader discourse on technology adoption and providing actionable strategies for accelerating IPv6 adoption.

The central research question guiding this study is: "Can the application of a design thinking-inspired approach accelerate the adoption of IPv6 in Indonesia?" A user-centered approach, encapsulated in the DTITA model, can effectively address the unique challenges and barriers associated with IPv6 adoption, thereby facilitating a smoother and more efficient transition to this new technology.

The rest of this paper is structured as follows. In Section 2, we review and examine previous related studies. Section 3 explains our design thinking approach to accelerating the IPv6 adoption. Section 4 provides results and discusses how design thinking has changed the landscape of implementing IPv6 for enterprises scale. Lastly, Section 5 concludes and discusses prospects for IPv6 development in Indonesia.

2. RELATED WORK

2.1. IPv6

The deployment of IPv6 has been a topic of interest among researchers and industry experts for several years, with numerous studies investigating the methods, challenges, and successes of IPv6 implementation. A study by [15] investigated the performance of IPv6 networks compared to IPv4 networks to understand how deployment strategies impacted user experience. The authors discovered that IPv6 networks exhibited similar or even better performance than their IPv4 counterparts, demonstrating the potential benefits of adopting IPv6. The study also highlighted the importance of considering user experience during deployment to ensure a smooth transition.

[22] analyzed IPv6 deployment trends globally, examining the factors that contributed to the rapid adoption of IPv6 in certain regions. The authors found that government policies, industry support, and awareness campaigns significantly drove IPv6 adoption. The study emphasized the need for collaboration among stakeholders, including Internet Service Providers (ISPs), content providers, and end-users, to accelerate IPv6 deployment.

A study performed by [23] explains how the IPv6 deployment is maturing though there are still some raised concerns, i.e., the deceleration of IPv6 growth from an exponential rate to a linear one between 2012 and the end of 2016. The research discovered that, up until the end of 2016, IPv6 adoption exhibited apparent irregularities in terms of topology and geography. Regarding topology, the network core experienced more robust IPv6 deployment, primarily led by transit and content providers. Meanwhile, the network edges, comprised of enterprise clients, saw slower adoption rates. The study also suggested that the lagging in network edges might be attributed to the absence of strong incentives for implementing IPv6, as alternative solutions, such as Network Address Translation (NAT), are available.

[24] conducted a study highlighting the factors that could potentially influence the ongoing rapid progress of IPv6 adoption, either positively or negatively. The study presents several models that encapsulate the relationships among different Internet stakeholders and consider various connectivity options. The research also highlights a different scenario where ISPs maintain multiple connectivities, but they unanimously agree to include IPv6 as one of the choices. Although this alone is not enough to sustain the acceleration of IPv6 adoption, it allows for a more reliable analysis of how different elements can impact its progress.

Studies from [25] and [26] presented the performance of IPv6 transition mechanisms, comparing techniques such as Dual-Stack, 6to4, and Manual Tunnel. Both studies found that the choice of transition mechanism significantly impacted network performance and end-user experience. The studies recommended that organizations carefully evaluate the suitability of different transition mechanisms for their specific network requirements and invest in monitoring and measurement tools to optimize performance during the transition process. Another study from [27] also recorded similar results in the IPv6 transition.

[28] explored the impact of IPv6 deployment on Content Delivery Networks (CDNs). Even though the study did not focus on how IPv6 affects performance, it shows that the depletion of ports in IPv4 NAT is hastened, resulting in a greater impetus toward transitioning to IPv6. Hence, an immediate action of migrating to IPv6 for CDNs is necessary. Another study from [29] further corroborates the notion that implementing IPv6 in cellular networks leads to superior performance compared to legacy IPv4 networks within Akamai's infrastructure.

The studies discussed above to reveal the importance of deploying IPv6 in both the core and edge networks to ensure a robust network infrastructure for the future. Failure to do so may result in inadequate network performance and reduced end-user experience. The depletion of ports in IPv4 NAT is hastening, and the need for migration to IPv6 is becoming increasingly urgent. The success of IPv6 deployment depends on the collaboration of various stakeholders, including government policymakers, ISPs, content providers, and end-users. Industry support and awareness campaigns are also significant drivers of adoption. It is essential to carefully evaluate different transition mechanisms for network requirements, invest in monitoring and measurement tools, and consider user experience during deployment to ensure a smooth and successful transition. In summary, it is no longer an option for enterprises to ignore the importance of deploying IPv6 in both core and edge networks if they want to maintain a robust network infrastructure in the future.

However, it is also to be noted that even though the necessity for having IPv6 is inevitable, multiple studies confirmed that some hesitance persists, with reasons cited ranging from a lack of technical expertise to concerns about the potential costs and complexity of the migration process [30]. It then begs the question, is the current approach, not enough? Could the presented reasons in multiple studies not be enough to convince enterprises to implement IPv6?

2.2. Design Thinking

Design thinking has gained considerable attention as a practical approach for addressing complex enterprise problems, focusing on empathy, ideation, and experimentation [31]. This user-oriented methodology allows organizations to comprehend better and anticipate their customers' needs, leading to more creative and efficient solutions [31]. Through iterative prototyping and testing, design thinking fosters a culture of continuous learning and improvement [32]. Moreover, its collaborative nature promotes the formation of cross-functional teams, dismantling organizational silos and facilitating integrated problem-solving [33]. Consequently, enterprises that adopt design thinking experience higher customer satisfaction levels and enhanced operational performance [34].

Design thinking employs a systematic framework to discover people's wishes, unaddressed necessities, and the sentiments that emerge from their encounters with products or services. The fundamental objective of this approach is to elevate the quality of life by giving prominence to customers in the design process [35]. As the designer navigates through the design journey, they undergo a reflective process that weaves together internal thought patterns and their external expression. By amalgamating and illustrating these ideas, the designer generates a comprehensive and well-rounded concept that considers various aspects of the user experience, ultimately resulting in more meaningful and user-centric solutions.

The design thinking process has five fundamental principles: human-centered, observation, visualization, prototyping, and experimentation [36]. These stages form a non-linear, iterative framework that enables the development of innovative and user-centric solutions.

1. *Human-centered*: The first stage involves understanding the users' needs, motivations, and challenges by deeply immersing in their experiences [31]. This stage emphasizes an empathetic approach crucial for gaining insights into the users' perspectives and identifying their problems [37].
2. *Observation*: In this stage, the insights gathered during the human-centered phase are synthesized to articulate the users' needs and challenges [38]. This definition serves as a foundation for the subsequent stages, ensuring that the design process focuses on addressing the users' concerns.
3. *Visualization*: The visualization stage generates many potential solutions to the defined problem, drawing on creativity and out-of-the-box thinking. The goal is to explore diverse possibilities, encouraging innovation and collaboration within the team [31].
4. *Prototyping*: This stage involves creating tangible representations of the selected ideas to visualize and evaluate their feasibility [38]. Prototyping allows designers to refine their concepts, identify potential issues, and gather user feedback, ultimately leading to a more robust solution.
5. *Experimentation*: The final stage focuses on the investigation to test the refined prototypes with users to validate their effectiveness in addressing the initial problem. Feedback from this phase informs further iterations and refinements, ensuring that the final solution meets the users' needs and expectations.

Through iterative ideation, prototyping, and testing, design thinking encourages the development of user-centric, innovative solutions that are not only technologically advanced but also highly accessible and relevant to users.

2.3. Technology Acceptance

Perceived usefulness and perceived ease of use are two of the most widely studied constructs in the literature on user acceptance of information technology, as explained in the Technology Acceptance Model (TAM) [39]. Perceived usefulness refers to the extent to which users believe that a particular technology will enhance their job performance or productivity, while perceived ease of use refers to the degree to which users believe the technology is easy to use [40].

Empirical research has consistently shown that these two constructs strongly predict user acceptance of information technology [41]. Moreover, recent studies have explored the interplay between perceived usefulness and ease of use in shaping user acceptance of information technology. Research has suggested that the impact of perceived ease of use on user acceptance is mediated by perceived usefulness [40]. This implies that users are more likely to adopt a technology if they perceive it to be helpful and that the ease of use of the technology influences the perceived usefulness.

Recent studies have also extended TAM by considering additional factors impacting user acceptance, such as social influence, trust, and perceived risk [42]. Moreover, researchers have also explored the role of emotions in shaping user acceptance of IT. Emotions, such as enjoyment and anxiety, have been found to influence users' perceptions of usefulness and ease of use, impacting their adoption behavior [43][44].

3. METHODS

Drawing upon the literature review, we proposed the *Design Thinking-Inspired Technology Adoption* (DTITA) stages to address the slow IPv6 adoption that draws the concepts from the design thinking approach and technology acceptance. DTITA leverages the principles of design thinking to facilitate the adoption of new and challenging technologies. This model incorporates the five stages of design thinking alongside the traditional technology adoption factors, such as perceived usefulness, ease of use, and social influence. The DTITA aims to create user-centric solutions that address new technologies' unique challenges and barriers. The proposed framework operates through a five-stage process within the context of design thinking and upholds prescribed principles to ensure alignment with the underlying concept. DTITA stages shown in Table 1.

To implement a design thinking-inspired approach for accelerating IPv6 adoption, we began our investigation by distributing a questionnaire to a diverse group of 106 respondents. The survey was conducted online utilizing Google Forms. It was strategically disseminated across a diverse range of internet communities, encompassing the likes of APJII (The Indonesia ISP Association), a pivotal organization in the realm of internet service providers in Indonesia. Additionally, the survey was propagated through IDNIC (Indonesia Network Information Center), a key player in the management of internet resources in Indonesia. The distribution network was extended to IdREN (Indonesia Research and Education Network), a powerful platform for research and education networking in Indonesia. Lastly, the survey was circulated within various IT Engineer communities, ensuring a comprehensive and diverse respondent base. This methodical approach to distribution provided a broad spectrum of perspectives and insights, thereby enhancing the robustness and validity of the survey results. The outcomes derived from the survey served as critical input, shaping the agenda and discussions for the subsequent IPv6 workshop. This workshop, conducted after the study, utilized these insights to address critical issues, develop strategies, and foster a deeper understanding of the subject matter among the participants.

Table 1. DTITA stages

Stage	Principles	Action
Empathy (Human-centered)	Through the empathy stage, understand the needs and concerns of the users, network administrators, and stakeholders involved in the transition to IPv6	- Interview - Survey
Define (Observation)	Analyze the information gathered during the empathize stage to identify the fundamental problems, challenges, and opportunities related to the adoption of IPv6	- Formulate clear problem statements - Develop objectives
Ideate (Visualization)	Brainstorm solutions for addressing the identified problems and challenges. Encourage input from stakeholders and users to generate innovative ideas. Start to consider the perceived usefulness and perceived ease of use of IPv6	- Focus Group Discussion - Choosing implementation strategy
Prototype	Develop a model within the lab for the proposed IPv6 implementation solutions	- Prepares technical documentation - Draw network architectures
Experimentation (Test)	Evaluate the effectiveness of the prototypes by soliciting feedback from users and stakeholders	- Measures usefulness and ease of use

4. RESULTS AND DISCUSSION

From the distributed questionnaire, the demographic profile of our participants consisted of 97% males, with 50% aged between 36-45 years. In terms of occupational backgrounds, 69% of respondents were from the education industry, 20% from Internet Service Providers (ISPs), 2% from content providers, 3% from government institutions, 3% from Information and Communication Technology (ICT) industries, and the remaining respondents represented various other sectors. Upon examining the roles from the survey, it is observed that a majority, 65%, hold engineering positions. Those in managerial roles constitute 32%, while a small fraction, just 3%, are staff members. Moreover, half of these participants worked within enterprise-scale organizations, catering to between 1,000 and 9,999 customers.

This preliminary survey aimed to develop a foundational understanding of the challenges and perspectives encountered by these diverse stakeholders. This enables us to tailor our strategies for accelerating IPv6 adoption to the specific needs and constraints of the target user base. By capturing a representative snapshot of the professionals involved in the IPv6 transition, our research aims to identify and address the unique obstacles these varied groups face, ultimately promoting a more seamless and efficient adoption process.

Upon collecting the responses from our diverse participants, we employed the design thinking methodology to accurately identify the challenges and barriers impeding IPv6 implementation and the reasons behind its sluggish adoption rate. By leveraging the design thinking approach, we aim to address the identified challenges and create user-centered solutions that facilitate a smoother and more efficient transition to IPv6 across diverse sectors.

4.1. Empathize

The empathy phase is a crucial part of the design thinking process, which emphasizes understanding the target audience's needs, challenges, and feelings to create effective and user-centered solutions. Empathy is a critical component of the human-centered approach in design thinking, as it involves understanding the user's needs, desires, and pain points. Empathy helps designers gain a deep understanding of the users' perspectives and design solutions that are tailored to their specific needs. The human-centered approach puts the user at the center of the design process and aims to create products and services that meet their needs and preferences.

By placing ourselves in the shoes of the workshop participants during the empathy stage, we could gain a deeper insight into their experiences and identify the pain points they encountered while trying to implement IPv6. In this stage, we sought to uncover the root causes of their struggles, primarily from misconceptions about IPv6 and a fear of its perceived complexity. By empathizing with the engineers and acknowledging their concerns, we were able to develop a clearer understanding of the barriers they faced, which in turn informed the subsequent stages of the design thinking process. Some critical finding that becomes empathy artifacts are found as presented in Table 2.

Table 2. Empathy artifacts

No	Pain Points
1.	No client/customer is requesting IPv6
2.	IPv6 is too complex to understand (due to its length)
3.	Implementing IPv6 is harder than IPv4
4.	Lack of engineer who understand IPv6
5.	Can't afford to fund IPv6 implementation

Table 2 highlights several critical challenges in the adoption of IPv6. These challenges include the perception of IPv6 as complex, lack of demand from clients or customers, difficulty implementing IPv6 compared to IPv4, scarcity of skilled engineers, and financial constraints.

These insights suggest several areas for action to accelerate IPv6 adoption. Firstly, there is a need to raise awareness about the benefits and necessity of IPv6 among potential clients and customers. This could be achieved through targeted educational campaigns or workshops. Secondly, efforts should be made to demystify IPv6 and present it in a more accessible and less intimidating manner. This could involve the development of educational resources or tools that simplify the technical aspects of IPv6.

Furthermore, the scarcity of skilled engineers underscores the need for more focused training and education in IPv6. This could involve incorporating IPv6 into relevant educational curricula or providing specialized training programs for existing engineers. Lastly, the financial constraints faced by some organizations suggest the need for more cost-effective strategies for IPv6 implementation or the exploration of financial support mechanisms for organizations transitioning to IPv6.

4.2. Define

In the second phase of the design thinking process, the define stage, we aim to analyze the information gathered during the empathize stage, establish clear problem statements, and develop objectives to resolve the identified issues. The primary pain points identified include the perceived lack of demand for IPv6, complexity due to address length, challenges in implementation, scarcity of skilled engineers, and financial constraints. We then define the problem statement and objectives.

Table 3 outlines the problem statements and objectives identified. The problem statements reflect the pain points identified during the Empathy stage, which include the perceived lack of demand for IPv6, complexity due to address length, challenges in implementation, scarcity of skilled engineers, and financial constraints.

The objectives outlined in the table provide a roadmap for addressing these pain points. They include increasing awareness and understanding of the advantages of IPv6 among potential clients and customers, simplifying the experience of IPv6, providing more focused training and education in IPv6, and exploring more cost-effective strategies for IPv6 implementation. Based on these findings, future efforts to accelerate IPv6 adoption should focus on these critical areas. This could involve developing targeted educational campaigns or workshops, creating resources or tools that simplify the technical aspects of IPv6, incorporating IPv6 into relevant educational curricula or providing specialized training programs for existing engineers, and exploring financial support mechanisms for organizations transitioning to IPv6.

Table 3. Problem Statements and Objectives of Define Stage

No	Problem Statements	Objectives
1.	Perceived lack of demand for IPv6: Organizations have not observed significant client or customer requests for IPv6, leading to a perception that the technology may not be necessary. This could potentially be due to a lack of awareness or understanding of the benefits of IPv6 among clients and customers.	Increase awareness and understanding of the advantages of IPv6 among potential clients and customers, emphasizing its long-term benefits and the growing need for a more extensive address space.
2.	Complexity due to increased address length: The length and structure of IPv6 addresses are seen as a barrier to understanding, which may discourage organizations from adopting the technology.	Develop educational materials and training programs to simplify the understanding of IPv6 addressing and demonstrate the benefits of its larger address space.
3.	Challenges in IPv6 implementation: Implementing IPv6 is perceived as more complex than IPv4, possibly due to the differences in technology, compatibility issues, and a lack of experience in managing IPv6 networks.	Create comprehensive guidelines and best practices for IPv6 implementation, focusing on minimizing compatibility issues and offering support during the transition process.
4.	Scarcity of skilled engineers: The limited availability of engineers with sufficient knowledge of IPv6 presents a significant challenge for organizations seeking to implement the technology. This knowledge gap may slow down the adoption rate of IPv6 and create implementation bottlenecks.	Develop and promote comprehensive training programs and certification courses for engineers to acquire the necessary skills and knowledge to effectively implement and manage IPv6 networks.
5.	Financial constraints: Organizations may be deterred from adopting IPv6 due to the costs associated with implementation, such as upgrading hardware and software, employee training, and potential downtime during the transition.	Identify cost-effective strategies for IPv6 implementation, including phased approaches and leveraging existing resources. Additionally, emphasize the long-term cost savings and strategic benefits of IPv6 to help organizations justify the investment.

4.3. Ideate

In response to the identified problem statements that impede the acceleration of IPv6 adoption and identified objectives, we have devised several strategies to achieve the expected goals. Firstly, we address the issue of limited client demand for IPv6. It is crucial to increase awareness and understanding of the advantages of IPv6 over IPv4. To achieve this, we propose targeted marketing campaigns and educational initiatives that emphasize the long-term benefits of IPv6 adoption, such as its vast address space, improved routing efficiency, and enhanced security features. The transition to IPv6 has gained considerable momentum in recent years, primarily driven by the adoption of this protocol by major content providers such as Google, Meta, Microsoft, and numerous other platforms. As these industry leaders embrace IPv6, the longstanding "chicken and egg" problem that has hindered its widespread adoption is gradually being resolved. These efforts should focus on articulating the potential return on investment (ROI) and long-term strategic value, encouraging clients to request and adopt IPv6. Consequently, users can expect a more seamless and responsive online experience as the prevalence of IPv6 grows. The widespread adoption of IPv6 by significant content providers not only alleviates the "chicken and egg" issue but also reinforces the perceived usefulness of the protocol. By demonstrating the tangible benefits of IPv6 adoption, these industry leaders contribute to a more favorable attitude towards the protocol, ultimately promoting its broader adoption across the internet ecosystem.

Secondly, to tackle the perceived complexity of IPv6, it is essential to develop comprehensive educational resources that simplify and demystify its technical aspects. These resources can enhance understanding and facilitate adoption by utilizing virtual labs, analogies, and real-world examples from industries. Additionally, establishing workshops and seminars aimed at decision-makers and technical teams can further address this issue. These educational programs should provide hands-on experience and practical knowledge, enabling stakeholders to develop a solid understanding of IPv6 implementation, management, and optimization.

Thirdly, by implementing workshops and seminars, participants were exposed to this targeted approach to IPv6 address management. By highlighting the ease of identifying subnets within IPv6 addresses, as opposed to the more cumbersome process of analyzing subnet masks and referencing spreadsheets in IPv4, the training sessions aimed to demonstrate the comparative ease of working with IPv6 in enterprise settings. The workshops and seminars aim to alleviate the mental block associated with the perceived complexity of IPv6. This approach simplifies the interpretation of IPv6 addresses, allowing for more efficient network management and administration.

The management of Internet prefixes plays a critical role in effectively implementing and optimizing IPv6 within enterprise environments. One aspect of this management involves the selection of the appropriate IPv6 address allocation size from Regional or National Internet Registries (RIRs) such as APNIC or IDNIC. In this context, utilizing a /32 prefix allocation instead of a /48 allocation offers several advantages in routing engineering and traffic management.

A /32 IPv6 allocation provides a larger address space than a /48 allocation, offering enterprises greater flexibility in designing and modifying their routing architecture. By leveraging the increased address space available with a /32 prefix, organizations can implement more granular traffic engineering techniques, optimizing network performance, enhancing reliability, and improving overall efficiency. Consequently, understanding the implications of different IPv6 allocation sizes and their potential impact on routing engineering is essential for enterprises seeking to harness the capabilities of IPv6 fully.

Post-training evaluations revealed that participants experienced a shift in their perception of IPv6 complexity. After being exposed to this focused approach, they reported a greater appreciation for the simplicity of managing Virtual Local Area Networks (VLANs) and subnets using IPv6, noting that it was, in fact, more accessible than working with IPv4. This finding is consistent with the TAM, suggesting that by enhancing the perceived ease of use of IPv6, we can contribute to a more favorable attitude toward its adoption. By redirecting the focus from the extended length of IPv6 addresses to the ease of managing VLANs and subnets within enterprise environments, we can dispel the mental block regarding IPv6 complexity.

Fourthly, to maintain participant engagement with IPv6-related topics and facilitate continuous learning, we have established a knowledge-sharing community through WhatsApp or Telegram group designed to foster collaboration and exchange best practices. By nurturing a culture of cooperation and shared expertise, we aim to facilitate the ongoing professional growth of engineers, promoting a deeper understanding of IPv6 and its applications. The knowledge-sharing community is a valuable resource for participants, enabling them to access a wealth of information, practical insights, and real-world experiences from their peers. Engineers can seek guidance on specific challenges through this collaborative environment, share their experiences, and engage in meaningful discussions on various aspects of IPv6 adoption and implementation. This process enhances personal understanding and contributes to the collective knowledge base, driving innovation and progress in the field of IPv6 technology.

Fifthly, the cost of implementing IPv6 is a significant deterrent for some organizations. To mitigate this concern, we emphasize the importance of IT governance and management in optimizing resource allocation, reducing the overall cost of implementation, and ensuring a smooth transition. By adopting a phased approach to implementation, organizations can minimize the risks associated with the change and better manage costs. Furthermore, leveraging existing resources, such as open-source tools and shared infrastructure, can significantly reduce capital expenditures.

Further, to mitigate the financial burden associated with the implementation of IPv6 and instill confidence in organizations contemplating a larger-scale deployment, we propose the introduction of a pilot stage as part of the IPv6 adoption process for that type of organization. This pilot stage serves as a strategic approach to IPv6 implementation, allowing enterprises to evaluate the protocol's feasibility, benefits, and potential challenges within a controlled and limited environment before committing to a full-scale transition. By implementing IPv6 within this controlled environment, organizations can assess the protocol's compatibility with existing network components, identify potential bottlenecks or issues, and evaluate the required changes in network management practices. This process enables organizations to gather valuable insights and develop best practices, which can be applied to the broader IPv6 deployment.

In addition to providing a comprehensive understanding of the technical aspects of IPv6 implementation, the pilot stage also allows organizations to assess the financial implications of the transition. By conducting a cost-benefit analysis within the pilot environment, enterprises can better understand the required investments and anticipated ROI, facilitating informed decision-making and resource allocation for the larger-scale deployment.

4.4. Prototype and Test

Adopting IPv6 during the pilot stage can be facilitated by implementing prototypes, diagrams, and automation tools. These elements streamline the process, enabling a more efficient and effective transition to the new protocol.

Prototypes play a pivotal role in the pilot stage deployment of IPv6, as they provide a tangible representation of the proposed solution. By simulating network conditions and configurations, prototypes allow enterprises to test the feasibility and functionality of IPv6 integration in a controlled environment. This testing phase enables organizations to identify potential issues, optimize configurations, and refine the deployment process before initiating the full-scale implementation. As a result, enterprises can mitigate risks and ensure a more successful IPv6 adoption.

Diagrams serve as visual aids to help teams better understand the complexities of the network infrastructure during the IPv6 deployment process. These graphical representations illustrate the connections and relationships between various network components, such as VLANs, switches, and routers. By providing a clear overview of the network topology, diagrams facilitate communication and collaboration among team members, ensuring that everyone is on the same page. This clarity contributes to a smoother and more efficient pilot stage, as potential issues can be identified and addressed more readily.

Automation tools, such as Ansible, significantly enhance the pilot stage deployment of IPv6 by automating repetitive tasks and reducing the potential for human error. This is particularly beneficial when implementing IPv6 across a variety of hardware platforms. For instance, in a Cisco environment, Ansible can automate the configuration of network devices, while in a CommScope setup, it can streamline network infrastructure management. Similarly, in a MikroTik setting, Ansible can simplify the deployment and configuration of network services. By leveraging Ansible's automation capabilities, network administrators can ensure consistent and error-free deployment of IPv6 across diverse hardware environments, thereby enhancing network performance and reliability. By automating tasks such as configuration management, application deployment, and network automation, enterprises can ensure a more consistent and accurate implementation process. Automation also accelerates the deployment timeline, allowing organizations to realize the benefits of IPv6 more quickly. This increased efficiency is particularly valuable during the pilot stage, as it enables teams to iterate and refine their deployment strategies more rapidly.

In conclusion, using prototypes from virtual labs, diagrams, and automation tools during the prototype stage of IPv6 deployment dramatically improves the efficiency and effectiveness of the implementation process. By enabling thorough testing, clear communication, and streamlined operations, these elements contribute to a more successful IPv6 adoption and facilitate a smooth transition to the new protocol.

5. CONCLUSION

Indonesia's digital transformation faces challenges such as limited resources, slow IPv6 adoption, skill gaps, and insufficient technical knowledge. To address these issues and accelerate IPv6 adoption in enterprises, a design thinking-inspired approach that emphasizes empathy, collaboration, and experimentation is proposed. The study investigates enterprise-scale IPv6 deployment in Indonesia and introduces the Design Thinking-Inspired Technology Adoption (DTITA) model to create user-centric solutions.

Targeted solutions such as awareness campaigns, educational initiatives, and comprehensive guidelines can be developed by understanding stakeholders' challenges. A good engagement in active dialogue with all relevant parties, including government agencies, businesses, and end-users, is necessary to understand their needs and concerns, as stated in the first approach of design thinking, i.e., empathize. Subsequently, decision-makers should invest in comprehensive education and training programs to increase awareness and technical understanding of IPv6. Also, the organization should consider implementing supportive policies and regulations. Furthermore, leveraging prototypes, diagrams, and automation tools during the pilot stage can contribute to a smoother IPv6 transition. Future research can focus on cross-industry comparisons of IPv6 deployment, providing a comprehensive understanding of the challenges and opportunities in implementing IPv6 across different settings.

While this study provides valuable insights into applying a design thinking approach to accelerate IPv6 adoption, it has limitations. The proposed Design Thinking-Inspired Technology Adoption (DTITA) model is primarily based on a literature review and has yet to be empirically tested or validated. This limits its ability to provide evidence-based results, and its effectiveness in a real-world context still needs to be seen. On the other side, while the study provides valuable insights into stakeholder challenges, potential limitations include sample bias due to its specific distribution, response bias from the self-selection of respondents, and potential inaccuracies from self-reported data. The survey design also influences the results, and the lack of qualitative data could limit the depth of insights. Lastly, language and comprehension barriers could affect the accuracy of responses. These limitations should be considered when interpreting the results and planning future initiatives. Another area for further investigation is the economic impact of IPv6 implementation. Examining both short-term and long-term financial benefits for organizations can help stakeholders understand the value of investing in IPv6 and address concerns about costs and complexity. By capitalizing on these opportunities, Indonesia can ensure a more seamless digital transformation and foster a robust and sustainable network infrastructure by utilizing IPv6.

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BIOGRAPHY OF AUTHOR

Mukhammad Andri Setiawan is an assistant professor at Universitas Islam Indonesia. He received his Ph.D. from the University of Queensland, Australia. Currently, he serves as Chief Information Officer at Universitas Islam Indonesia and as head of training and human resources development at Indonesia Network Information Center (IDNIC), the National Internet Registry of the Republic of Indonesia. His main research interests are in the area of Information Systems, such as business process management and improvement, organizational change through the information system, IT governance, IT security, and research area in the development of the Internet of Things. Email: andri@uii.ac.id; ORCID: 0000-0002-2461-6104.