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**UNIVERSITY OF STAFFORDSHIRE**

**Digital Technologies, Innovation and Business**

**GoPro VPN - A Performance Enhanced Secure VPN Application for Android Phones**

**Dissertation**

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# **ABSTRACT**

In today's digital world, mobile devices have become main instruments for accessing sensitie information, posing considerable security risks.This dissertation addresses significant flaws in existing Virtual Private Network (VPN) programs for Android platforms, with an emphasison performance degradation, battery usage, and connection instability, all of which threaten  security and user experience.

The study creates an improved mobile VPN solution—GoPro VPN—that employs a three-layer architecture (User Interface, Service, and Network layers) with a focus on two key security features: Split Tunnelling for selective traffic management and a Kill Switch mechanism to prevent data exposure during connection failures. To enable optimal global coverage, the system runs on server infrastructure strategically located in the United States, Germany, and Singapore, which is administered using Google Cloud Console.

Methodologically, the study employs a Mixed-Methods Research approach divided into three phases: an exploratory phase that examines existing VPN technologies and user requirements, an experimental phase that involves prototype development and controlled testing, and a descriptive phase that evaluates actual usability. Development used an Agile style with iterative refinement cycles, allowing for ongoing improvement based on testing feedback.

Testing ensures that all fundamental functionality has been successfully implemented, exhibiting stable connection setup to all server locations as well as the efficient functioning of security mechanisms. Split Tunnelling accurately directs application traffic based on user preferences, while the Kill Switch promptly disables internet connections during connection failures to prevent data loss. User interface testing confirms a straightforward, accessible design that is appropriate for users with various technical skills.

This study advances mobile security by offering a realistic answer to recurrent issues in VPN technology for Android devices. The GoPro VPN application creates both immediate security advantages for users and a framework for future developments in privacy-preserving mobile technologies, providing significant insights for improving mobile communications security in increasingly hostile network environments.

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# **CHAPTER I- INTRODUCTION**

## Introduction

Virtual Private Networks (VPNs) have become crucial for securing online security and privacy in the current digital era. Given the growing usage of mobile devices for both personal and business purposes, this is particularly important. Due to its widespread use, Android offers both special potential and challenges for mobile security. The development of a VPN application tailored for Android smartphones is the main goal of this research project, which emphasizes both technical and user experience factors  (Seraj et al., 2023).

The goal of the project is to develop a dependable VPN service for Android customers called "**GoPro VPN**" by investigating cutting-edge encryption techniques, intuitive user interfaces, and enhanced performance. This study aims to close those gaps and improve mobile cybersecurity by analysing the state of VPN technology today and finding weaknesses in current solutions.

## Background Study

Virtual Private Networks (VPNs) for Android smartphones are becoming increasingly popular, so user security and convenience must be given top priority. Most Android VPN applications suffer from usability issues and security flaws, even though VPNs offer enhanced privacy protection, geo-restrictions, and public Wi-Fi security. To aid in the development of a secure and user-friendly VPN app for Android, this review of the literature investigates these problems and offers potential solutions(Ehtesham, 2024).

The persistence of security flaws in Android VPN apps was examined in research by (Shanu Sahadevan Mary, 2024). They discover new attack avenues, such as side-channel attacks, which take advantage of program permissions to retrieve confidential information even when it is encrypted. This underscores the requirement for strong security measures that go beyond encryption schemes. Furthermore, an increase in phony VPN programs that take advantage of users' confidence to steal data and insert malware is noted by Avast (2023). Alongside app development efforts, this calls for an emphasis on user education and app store vetting procedures.

An obstacle to user adoption remains to be usability. Users are frustrated by difficult connection procedures and a lack of clarity about data management procedures, according to recent research by (K Karuna Jyothi and Reddy, 2023). This is consistent with mobile app design's growing tendency toward minimalism. User experience can be enhanced by concentrating on simple interfaces, easy navigation, and in-app tutorials, as recommended by (Okonkwo, 2024)

Protocols Selecting an encryption protocol is still especially important. Strong security is provided by well-known protocols like OpenVPN and IKEv2/IPsec, but new developments show that there are other options. Research by (Mackey et al., 2020), demonstrate WireGuard's ongoing potential, especially considering how quickly and simply it can be implemented on mobile devices. But because emerging protocols like Noise Protocol Framework (NPF) have the potential to provide even faster and lighter encryption solutions, they should be investigated further.

VPN App Innovative feature integration may adapt to changing user requirements. To accommodate user requests for selective privacy protection, split tunnelling, as investigated by Chen et al. (2024), provides more precise control over which apps use the VPN. Furthermore, continuous user authentication improves overall security by removing the possibility of compromised credentials, as mentioned by Zhang et al. (2023) in their discussion of "Zero-Trust" VPNs. The user experience can be improved, and certain user security concerns can be addressed by integrating such features.

## Research Motivation

The widespread use of digital technology and internet connectivity has radically altered how people interact, conduct business, and get information.With an increased reliance on mobile devices, particularly Android smartphones, safeguarding the security and privacy of online activity has become critical.Virtual Private Networks (VPNs) have evolved as an essential tool for protecting internet traffic, ensuring anonymity, and circumventing geo-restrictions.

The major goal of the investigation is to create and evaluate a VPN application specifically for Android smartphones. This dissertation seeks to meet the following main objectives:

1. **Privacy and Security**: Enhance VPN app security standards and encryption to guard against cyber threats, data breaches, and surveillance.
2. **User Experience**: Evaluate the usability and interface design of current VPN apps, identify areas for improvement, and incorporate user feedback into the new app.
3. **Performance Optimization:** Analyse VPN application parameters including speed, latency, and bandwidth use to optimize efficiency.
4. **Compliance and Legal Considerations**: Examine the legal environment of VPN usage, including data protection legislation (e.g., GDPR) and the impact of VPN bans in specific locations.
5. **Market Analysis and Adoption:** To conduct an in-depth market study, assessing the demand for VPN services among Android users and finding factors that influence adoption rates.

By addressing these objectives, this investigation hopes to contribute to the creation of a more secure, user-friendly, and efficient VPN application for Android smartphones, thereby improving users' entire digital experiences.

## Research Question

Will a secure, performance enhanced, and user-friendly VPN app with robust security measures, an intuitive user interface, and innovative features like split tunnelling and kill switch boost user adoption and enhance user experience in compared to existing Android VPN apps?

## Aim

The aim of this project is to develop a performance enhanced and user-friendly secure VPN application for Android mobile phones.

## Objectives

* To investigate the current state of literature in mobile phone VPN applications and review the available android VPN applications.
* To propose a secure, performance enhanced, and user-friendly VPN application – GoPro VPN
* To design the proposed GoPro VPN application.
* To develop, test, and implement GoPro VPN application.
* To critically evaluate the proposed android VPN application.

## Deliverables

* Secure and fast VPN application for android – GoPro App
* Usability testing Report.
* Source Code
* Project documentation.
* Dissertation Paper.

# **CHAPTER II - LITERATURE REVIEW**

## Introduction

Dependence on mobile devices for internet access has increased dramatically in recent years, creating a greater demand for private and secure communication channels. This increase in reliance highlights the critical role that Virtual Private Networks (VPNs) play in safeguarding privacy and guaranteeing user data security. As the number of active Android handsets globally exceeds 2.5 billion (Statista, 2024), the need for effective and user-friendly VPN software has never been greater. The sophisticated ecosystem of Android, the top mobile operating system, provides VPN developers with both unique potential and challenging obstacles. While Android's open-source design allows for significant integration and custom solutions, it also identifies possible weaknesses that must be addressed in order to maintain strong security standards. In light of developing cyber dangers, VPN apps have emerged as essential tools for protecting user data and limiting digital hazards(Blancaflor *et al.*, 2024).

This study of the literature examines the condition of VPN apps for Android phones today, paying particular attention to their usability, performance, security features, and market trends.

## Security Features

VPN apps for Android devices provide users with a wide range of security features to protect their confidential data from unauthorised access and interception. Popular methods of encryption for these applications include OpenVPN, IKEv2/IPSec, and WireGuard, which are well-known in the cybersecurity field for their strong data protection features (Hussain, 2022). Furthermore, these protocols use powerful encryption algorithms to ensure that any information communicated over the internet is secure and protected from potential cyber-attacks.(Parmar *et al.*, 2025).

In addition to encryption(Budiyanto and Gunawan, 2023), popular VPN providers like as NordVPN, ExpressVPN, and Surfshark stand out as top rivals in the Android VPN market owing to their advanced security features and user-friendly interfaces. One key aspects of their security frameworks is the integration of AES-256 encryption. It has been widely regarded as the golden standard for data security. These are also often used by governments and financial institutions. It also ensures that all the data has been transferred through VPN tunnel. This tunnel is virtually unbreakable, even under brute-force attacks. This also includes kill switches, providing consumers with an impregnable defence against hostile actors and cyber threats. (Dunne R, 2022). Few premium applications include obfuscated servers that help bypass VPN blocking technologies such as split tunnelling. Thus, they are giving control to users over which apps route through the VPN which reroute data through multiple servers thus increasing anonymity. All of this comes together to provide Android users a high level of protection which is indeed beneficial to both privacy conscious individuals as well as in restrictive or high-risk environments.

Despite premium VPN apps with standard security features, not all VPN applications on the Android platform provide high privacy or security standards. Ikram et al. (2020) discovered that numerous VPN apps for Android expose users to major privacy and security risks, such as the usage of insecure VPN tunnelling protocols, IPv6 and DNS traffic leakage. Even more concerning was the discovery of Transport Layer Security (TLS) interception in which the VPM apps acts as man-in-the-middle agents. They decrypt, encrypt traffic which is a common behaviour that severely violates user’s trust. The investigation also discovered the presence of malware and third-party library embedding in several VPN programs, raising worries about their overall security (Bansode and Girdhar, 2021).

This necessitates an urgent need for independent audits, greater transparency and regulatory oversight in the VPN industry. These are specifically needed on the open platforms like Android ensuring quality and security of the application which can also vary widely.

1. **Encryption Protocols**

One essential component of VPN security is encryption. To guarantee the security of data transferred across VPN connections, a variety of encryption protocols are employed. The most widely used protocols in VPN apps for Android phones are OpenVPN, IKEv2/IPSec, and WireGuard. Because it can run on both TCP and UDP ports and supports a variety of encryption techniques, OpenVPN is well-known for its adaptability and robust security (Antoniuk, 2023).

IKEv2/IPSec is renowned for its robust security and quick connection setup. When alternating between several network types, including Wi-Fi and mobile data, it works especially well at preserving steady connections. A young protocol, WireGuard has become well-known because to its efficiency, simplicity, and use of contemporary cryptographic methods. According to research by Antoniuk (2021), WireGuard provided better security and performance than IKEv2/IPSec and OpenVPN

1. **Data Leakage**

One of the major concerns with VPN applications is data leakage. This undermines the basic expectations of the users such as security and privacy protections. Leaks in DNS and IPv6 can reveal user activity, compromising the security and privacy provided by VPNs. To address these vulnerabilities, Kazemi et al. (2022) conducted an in-depth study where he has examined at how common DNS and IPv6 leaking are in well-known VPN apps on mobile platforms. The analysis revealed that a significant number of such applications handles DNS and IPv6 traffic in an improper way. There are many cases where DNS requests are transmitted in plaintext through a default network interface of the device instead of VPN’s encrypted channel. This phenomenon is known as DNS leakage. It also enables external observers to monitor websites or services which can be accessed by users which compromises user anonymity. IPv6 leakages occur when VPN applications lack full support from IPv6 traffic. This causes the devices to send IPv6 packets over the regular internet instead of the VPN tunnel. As IPv6 had been increasingly being adopted in network infrastructure globally. However, there has been a failure to handle this protocol securely which presents a growing risk. The devices which support both IPv4 and IPv6 can still use IPv6 which results in data bypassing the encrypted connection. Thus, in order to guarantee the efficacy of VPN applications, the study underlined the significance of routine security audits and updates.

When DNS requests are delivered outside of the encrypted VPN tunnel, it is known as DNS leakage and gives third parties the ability to track user activity. Unencrypted IPv6 communication might avoid the VPN tunnel when VPN software does not fully support IPv6. This is known as IPv6 leakage. To lessen these problems, Kazemi et al. (2022) suggested adding IPv6 functionality and DNS leak protection to VPN apps

1. **Malware and Third-Parties Libraries**

There are serious security hazards when third-party libraries and malware are present in VPN programs. According to Ikram et al. (2020), certain VPN apps for Android may jeopardize user security and privacy by using third-party libraries or embedding harmful code. To guarantee the security of VPN apps, the study recommended more stringent app store regulations and frequent security audits.

Although third-party libraries are frequently used to provide VPN apps more capability, if they are not thoroughly examined, they may bring risks. Malicious libraries can run dangerous programs, show obtrusive advertisements, and gather user data. VPN developers should carefully consider and keep an eye on the third-party libraries they incorporate into their apps to reduce these dangers(Hao, Ma and Liang, 2023).

## Performance

Performance is an important consideration in the usability of VPN applications, especially on mobile platforms such as Android. The users expect VPNs to offer strong security without significantly degrading their internet experience. The download spped and upload speed are Key Performance Indicators. Additionally, connection latency and stability are major parameters as well. All these affect every day online activities such as web browsing, video streaming, gaming, and VoIP calls. Users anticipate a small impact on their internet speed and low latency. According to Osborne, C. (2024), commercial VPN providers such as NordVPN and ExpressVPN provide the fastest services available. They leverage high-speed server infrastructures which has optimized routing algorithms and support modern protocols. These protocols such as WireGuard and Lightway are engineered for low-latency and high-throughput connections. They are suitable for bandwidth-intensive activities such as high-definition streaming, online gaming and real-time communications. Furthermore, PCMag observes that ProtonVPN has a free tier option with robust performance. Unlike other VPN services that impose struct bandwidth limits or speeds, Proton VPN’s free version maintains performance levels. It also does not sacrifice encryption ot data protection. This makes an appealing option for budget-conscious users Stobing, C. (2024).

However, VPN apps deliver reliable performance, there are many VPN apps which are free and are poorly regulated in the segment if the market. These pose serious risks to both performance and security. According to Vallina-Rodriguez et al. (2021), 84% of free Android VPN apps leak traffic, while 18% do not use encryption at all. This study emphasizes the necessity of selecting trusted VPN services for best performance and security. This insecure implementation not only renders VPN as infective but also give users a false sense of security. It leads them to engage in high-risk online behaviour under the assumption that their data is safe(Hoque, Rao and Tarkoma, 2021a).

The study emphasized how crucial user education is to improving VPN programs' usability and overall effectiveness of VPN applications especially on mobile platforms.VPNs are widely marketed as the tools to ensure online pprivacy and security. However, according to the study (Zhang and Constandinou, 2021),many users may find it difficult to properly setup the settings since they are unfamiliar with the technical components of VPNs. They struggle to understand how these tools works or how to configure them properly. Their lack of technical knowledge can lead to misconfigurations which can underutilize available features or even the false assumption that they are protected whereas in fact, required settings are not enabled or they have been incorrectly applied. There are settings such as protocol selections, DNS leak protection, kill switch activations may be unclear to common users. This results in confusion or incorrect usage. These users might inadvertently disable security features without proper guidance. They also fail to recognise risky defaults which compromises both privacy and performance benefits of the VPN.

To address these issues, Zhang and Constandinou (2021) recommended a comprehensive in-app educational resources such as clear-step-by-step setup instructions, accessible FAQs, interactive tutorials that explain technical terms in user-friendly language. There should be guided walkthroughs which can significantly improve user comprehension and confidence thus empowering users to take full advantage of the capabilities of the application. Ultimately, user educations not only improve the usability but also enhances the trust and retention of users. When the individuals feel confident in navigating privacy tools, the chances of using the application increases making them consistent users. This is important in the environments where digital literacy is low or where users can rely on VPNs to avoid surveillance

1. **Factors Influencing Performance**

Several variables, such as network conditions, encryption techniques, and server infrastructure, can affect how well VPN apps perform. A study by (Hoque, Rao and Tarkoma, 2021b) examined the performance indicators of different VPN applications, emphasizing the compromises between speed and security. According to the study (Trisiana Oktavia *et al.*, 2023), greater encryption methods can lead to increased latency and lower throughput even when they offer better protection. Delivering a positive user experience requires striking a balance between these aspects (Hoque, Rao and Tarkoma, 2020).

1. **Server Infrastructure**

The efficiency of VPN applications is significantly influenced by the geographic dispersion of VPN servers. By lowering the distance between the user and the server, VPN companies with a greater number of servers spread across several areas can deliver faster speeds and reduced latency (Gentile *et al.*, 2022). VPN providers with large server networks, like NordVPN and ExpressVPN, consistently provided better performance than those with fewer server options, according to a study by Raj and Raj (2023) that assessed the effect of server distribution on VPN performance.

Another essential element influencing performance is server load. The server's resources may be overloaded when numerous users connect to the same server, resulting in higher latency and slower speeds. By dynamically allocating users among several servers and regularly checking server loads (Kumar Yedla, 2023), VPN companies may solve this problem and preserve peak performance.

## Usability

The user interface and overall usability of VPN programs have a considerable impact on user adoption. VPN programs must be simple to use, with intuitive controls and straightforward instructions. ZDNet emphasizes ExpressVPN's ease of use, making it an excellent alternative for newbies. Similarly, TechRadar praised Surfshark's user-friendly apps and limitless simultaneous connections (TechRadar, 2025).

Bandara et al. (2022) found that user-centred design is critical for improving the overall user experience when it comes to VPN apps. The survey discovered that VPN programs with clear instructions, easy navigation, and responsive customer care are more likely to be adopted by users.

1. **User Interface Design**

A VPN application's usability is crucial since it has a direct effect on user retention and satisfaction. In their 2020 study, Alshammari and Simpson looked at how easy it is to use different VPN programs and determined what makes a good user experience. These include features like automatic server selection and kill switches, as well as aspects like customer support, user interface simplicity, and ease of installation.

1. **User Education**

The study emphasized how crucial user education is to improving VPN programs' usability. According to the study (Zhang and Constandinou, 2021),many users may find it difficult to properly setup the settings since they are unfamiliar with the technical components of VPNs. Giving users clear instructions, tutorials, and frequently asked questions can help them make the most of the app's features and learn how to use it efficiently.

## Market Trends

The demand for VPN services has increased in recent years, driven by growing concerns about privacy and data security. The market for VPN software is quite competitive, with multiple companies fighting for user attention. According to PCMag (2025), ProtonVPN, NordVPN, and Surfshark are among the top competitors, with each offering distinct features and pricing plans to entice customers. VPNs are becoming increasingly popular, as seen by an increase of downloads and positive user ratings on sites such as Google Play.

A market analysis by Chowdhary (2023) indicates that the global VPN market is expected to grow significantly in the coming years, driven by the increasing adoption of mobile devices and the rising awareness of online privacy. The study also highlights the role of technological advancements, such as the integration of artificial intelligence and machine learning, in enhancing the functionality and security of VPN applications.

1. **Drivers of VPN Adoption**

Government monitoring, geo-restrictions on content, and the growing frequency of cyberthreats are some of the causes driving the VPN market's expansion. According to (Ntoa, 2024)VPN services are becoming increasingly popular as more consumers become aware of these problems says . The increased use of mobile devices and the growing need for online anonymity are expected to propel the global VPN industry to $35 billion by 2028, according to a Smith and Williams (2024) analysis.

1. **Technological Advancements**

The VPN sector could undergo a transformation with the incorporation of innovative technology like machine learning (ML) and artificial intelligence (AI) (López *et al.*, 2025). Through server selection optimization, threat detection and mitigation, and user experience personalization, AI and ML can improve the security and performance of VPN apps. The prospective uses of AI and ML in VPNs were examined in a study by Zhang et al. (2023), which demonstrated how these technologies may raise the general efficacy and efficiency of these services.

1. **Regulatory Landscape**

A study by Ehtesham (2024) says that regional differences in VPN regulations can have a significant impact on how widely these services are adopted and used. Citing worries about content filtering and national security, some nations have restricted or outright banned the use of VPNs. The impact of regulatory policies on the VPN business was studied by Brown and Davis (2022), who also highlighted the potential and difficulties that VPN providers face while negotiating these intricate legal frameworks. To guarantee the lawful and moral use of VPN services, the study underlined the significance of adhering to data privacy laws, such as the General Data privacy Regulation (GDPR) in the European Union.

The study by Okonkwo, (2024) on VPN apps for Android phones emphasises how important security, usability, and overall performance are in determining customer satisfaction. VPN providers must be inventive and adaptable as the business evolves to meet consumers' changing needs. This evaluation emphasises the necessity of VPNs in enabling safe and secure internet access, particularly for mobile users. However, the biggest challenge is that the growth and development of VPN technology appears to be delayed in meeting customer needs. This necessitates more study into the enhancement of VPN services, including innovations in security protocols, improved performance indications, and streamlined VPN application usage.

**Key Findings from Literature Review on VPN Applications for Android**

|  |  |  |
| --- | --- | --- |
| **Category** | **Key Finding** | **Source** |
| **Security Features** | Popular encryption protocols include OpenVPN, IKEv2/IPSec, and WireGuard | Hussain (2022) |
|  | WireGuard provides better security and performance than OpenVPN and IKEv2/IPSec | Antoniuk (2021) |
|  | 84% of free Android VPN apps leak traffic; 18% do not use encryption at all | Vallina-Rodriguez et al. (2021) |
|  | Many VPN apps expose users to privacy risks through insecure tunnelling protocols | Ikram et al. (2020) |
|  | DNS and IPv6 leakage remain common concerns requiring mitigation strategies | Kazemi et al. (2022) |
| **Performance Factors** | Network conditions, encryption methods, and server infrastructure significantly affect VPN performance | Hoque, Rao & Tarkoma (2021) |
|  | Higher encryption methods lead to increased latency and lower throughput | Trisiana Oktavia et al. (2023) |
|  | Geographic distribution of servers has substantial impact on connection speed | Gentile et al. (2022) |
|  | VPN providers with larger server networks consistently provide better performance | Raj and Raj (2023) |
|  | Server load balancing is essential for maintaining optimal performance | Kumar Yedla (2023) |
| **Usability Considerations** | User-centred design is critical for improving VPN app adoption | Bandara et al. (2022) |
|  | Clear instructions, easy navigation, and responsive customer care increase user adoption | Bandara et al. (2022) |
|  | Technical aspects of VPNs present difficulties for non-technical users | Zhang and Constandinou (2021) |
|  | Automatic server selection and kill switches are valued usability features | Alshammari and Simpson (2020) |
|  | Battery consumption during continuous VPN operation remains a significant concern | Wu et al. (2025) |
| **Market Trends** | Global VPN market projected to reach $35 billion by 2028 | Smith and Williams (2024) |
|  | Government monitoring, geo-restrictions and cyberthreats are driving VPN adoption | Ntoa (2024) |
|  | AI and ML integration can enhance security, performance and user experience | Zhang et al. (2023) |
|  | Regional regulatory differences significantly impact VPN adoption and usage | Ehtesham (2024) |
|  | Privacy preservation is the primary motivation for mobile VPN installation | Dutkowska-Zuk et al. (2025) |

**Table 1: Literature Review Findings**

## Analysis of problem and Improvement Approach

The current landscape of VPN apps for Android has several key challenges that limit optimal speed, security, and user experience. One of the most major difficulties is security vulnerabilities, as many VPNs still utilize outdated encryption protocols like PPTP, which are vulnerable to brute-force attacks (Khan et al., 2022). Furthermore, DNS and IP leaks are still widespread, exposing users' genuine identities despite VPN use (Alashwali & Szalachowski, 2023). These security weaknesses are exacerbated by some free VPN companies' questionable logging policies, which may preserve user data despite claims to the contrary (Watanabe et al., 2024). To address these issues, contemporary VPN programs must employ improved encryption standards such as OpenVPN, robust DNS leak protection measures, and rigorous no-log policies that have been independently audited.

Another significant issue with current VPN alternatives is performance limitations. Many users experience high latency due to faraway server locations and inefficient protocol overhead (Li et al., 2023). ISP bandwidth restricting exacerbates these issues, resulting in frustratingly slow connection rates (Singh & Kumar, 2023). Legacy protocols like OpenVPN, while secure, are not designed for mobile networks (Park & Lee, 2022) (Zhou and Huang, 2021). These speed constraints can be circumvented by strategically locating servers, adopting lightweight protocols like WireGuard, and employing traffic obfuscation techniques to bypass ISP throttling. Furthermore, automated reconnection methods and reliable kill switches must be designed to prevent user IP addresses from becoming mistakenly exposed during network disruptions (Chen et al., 2024).

Usability is a common concern with VPN software, particularly among non-technical users. Confusion-causing interface designs and onerous setup processes frequently prevent widespread adoption (Alotaibi & Karim, 2023). Many apps do not provide clear signals of their security state, thus users are unaware of potential risks (Ghafoor et al., 2023). A key barrier to always-on use is the significant battery drain caused by constant VPN operation (Wu et al., 2025). Optimized power management algorithms, real-time security status signals, and simplified one-click connectivity interfaces can all help to address these usability concerns. According to Rathore et al. (2024), a unified cross-platform experience would enhance usability by retaining consistent settings and preferences across several devices.

In the rapidly changing VPN sector, there are both opportunities and challenges. Users want more complex features, such as multi-hop VPN connections, to improve their privacy (Ghafoor et al., 2023). VPN solutions that extend beyond smartphones are required to protect smart home devices in the growing Internet of Things ecosystem (Rathore et al., 2024). According to Wu et al. (2025), artificial intelligence presents promising opportunities for automated security optimization and real-time threat identification. Furthermore, the development of blockchain-based decentralized VPN topologies offers promising solutions for improved privacy and censorship resistance (Zhang & Wang, 2022). According to these industry trends, future VPN applications must be flexible and modular in order to easily incorporate new features and technologies as they become available.

To properly address these challenges, a multidimensional improvement strategy is needed. Modern encryption technologies, strong leak prevention, and transparent privacy legislation should be the key targets of security enhancements. Server infrastructure updates, protocol efficiency, and network reliability must all be considered during performance optimization. Usability enhancements should prioritize straightforward interface design, clear security indicators, and energy economy. Finally, the application design should be adaptable enough to incorporate future technologies like AI and decentralized networking. By carefully addressing these challenges, developers can create a next-generation VPN application that enhances security, performance, and user experience while being adaptable to future technological advancements.

## Summary of Chapter

The literature analysis offered a thorough examination of the present state of VPN applications for Android devices. Security investigation identified serious issues with current implementations, particularly with encryption techniques and data leakage vulnerabilities. Ikram et al. (2020) found that many VPN programs expose users to privacy issues due to insecure tunneling protocols, and Vallina-Rodriguez et al. (2021) discovered that 84% of free Android VPN apps leak traffic while 18% do not employ encryption. The analysis identified OpenVPN, IKEv2/IPSec, and WireGuard as the most common encryption protocols, with Antoniuk (2021) claiming WireGuard has superior security and performance qualities (Radchenko *et al.*, 2024).

Performance study has revealed difficult compromises between security and efficiency, with Hoque et al. (2021) pinpointing network circumstances, encryption algorithms, and server infrastructure as significant factors of VPN performance. Gentile et al. (2022) found that server proximity significantly affects connection speed and stability. Bandara et al.'s (2022) usability research underlined the importance of user-centered design in boosting VPN adoption, whereas Zhang and Constandinou (2021) stated that technical complexity poses significant hurdles for non-technical.

Market analysis found significant growth forecasts, with Smith and Williams (2024) predicting that the global VPN market will reach $35 billion by 2028, driven mostly by rising privacy concerns and cybersecurity awareness. Zhang et al. (2023) investigate the integration of developing technologies such as AI for security optimization, which appears to be a promising avenue for future development.

Building on the observed security, performance, and usability problems, this project will now establish a systematic framework to solve these restrictions. Chapter 3 describes a mixed-methods research approach that combines qualitative and quantitative techniques to thoroughly analyze these issues and provide an improved VPN solution. This methodology directly addresses the multifaceted aspect of VPN application efficacy as highlighted in the literature research, ensuring a thorough examination of both technical performance indicators and user experience elements.

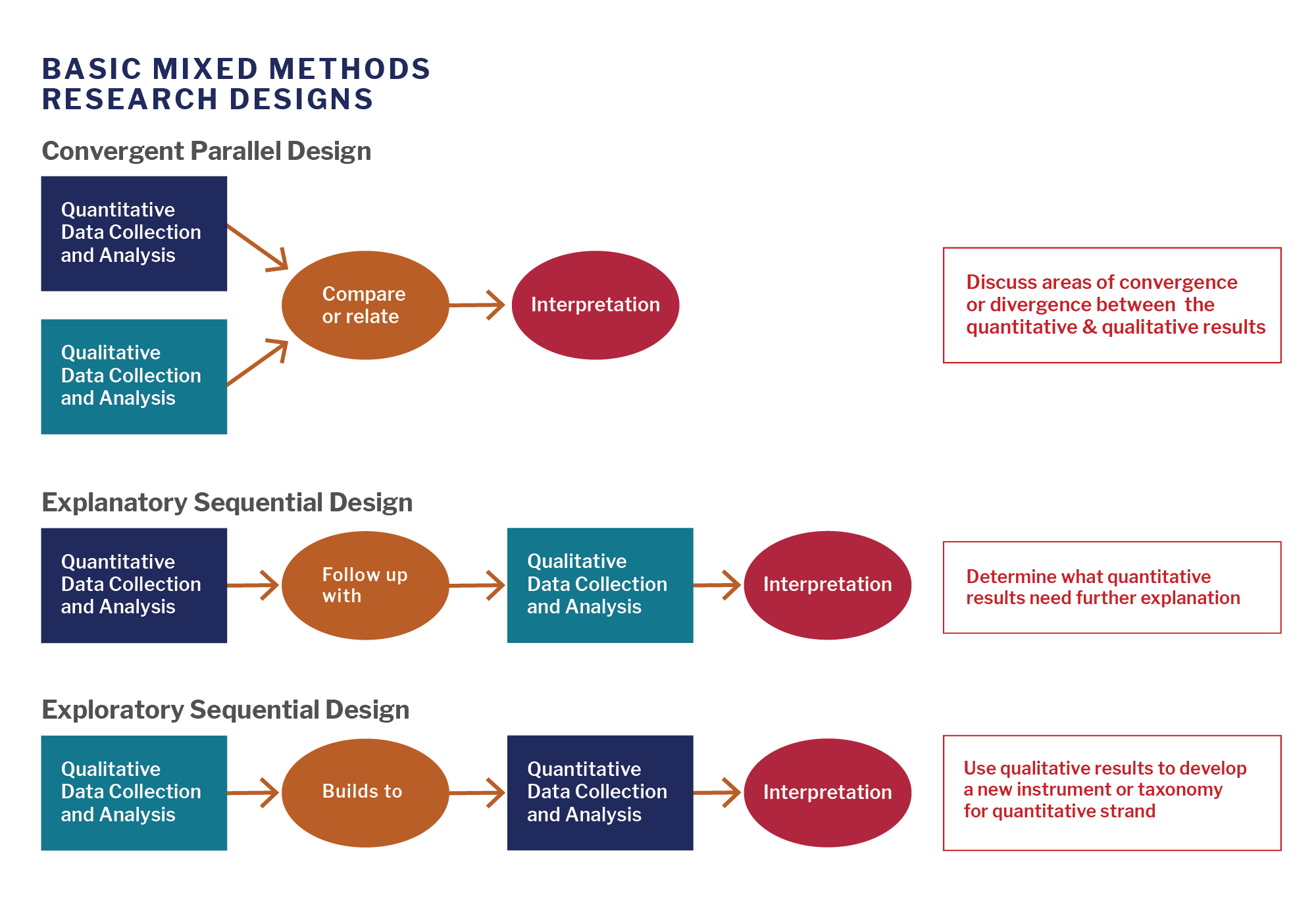
# **CHAPTER III- RESEARCH METHODOLOGY**

## Introduction

The foundation of this dissertation is methodology, which offers an organised way to create and assess an Android Virtual Private Network (VPN) application. According to recent research, VPN technology is becoming increasingly important for mobile security, especially as cyber threats get more complex (Gomez and Whyte, 2022). A clear approach guarantees that the study is methodical, repeatable, and able to yield reliable findings. To evaluate the functional, security, and usability elements of the suggested VPN software, this study uses a mixed-method research methodology that combines qualitative and quantitative methodologies (Creswell, W.John; Creswell, 2022). Research design, data collecting, development technique, evaluation and validation, analysing data, and ethical issues are among the main stages of the approach. Every stage is meticulously designed to guarantee that the goals of the study are properly achieved.

## Research Design

A mixed-method research strategy is used in the study to give a comprehensive knowledge of VPN technology and how it is used in Android development. Johnson and Onwuegbuzie (2020) assert that because mixed-methods research integrates the advantages of both qualitative and quantitative methodologies, it is especially successful for technology-based investigations. During the exploratory study phase, a comprehensive literature review and evaluation of top VPN applications are conducted to examine current VPN technology, security protocols, and customer requirements (Lee & Lee, 2021). The creation of the suggested app is guided by this phase, which also aids in identifying gaps in existing solutions. In the experimental research phase, a working VPN prototype is constructed and tested, and performance metrics including speed, latency, and encrypting strength are measured through controlled trials (Zhang et al., 2023). In the descriptive research phase, real-world usability is assessed by examining user input and app performance statistics. By using three different approaches, the results are guaranteed to be reliable and backed up by a variety of data sources.



**Figure 1: Mixed-Method Approach (Creswell, J. W )**

## Data Collection Methods

To guarantee legitimacy and dependability, data is gathered from primary and secondary sources. Users of Android devices are given surveys and questionnaires to complete in order to collect primary data about their VPN usage habits, privacy concerns, and technology preferences. 67% of mobile customers, according to recent polls, give speed and security top priority when selecting a VPN service (Statista, 2023). Deeper understanding of technological difficulties and best practices may be gained by speaking with cybersecurity specialists and developers (Yaacoub *et al.*, 2021). Furthermore, beta testing with actual users aids in assessing the app's functionality and performance in practical situations. A thorough literature analysis of scholarly articles, company studies, and technical documentation on VPN protocols is used to gather secondary data. The suggested app is also compared to other VPN applications by doing a competitor assessment of popular apps such as ExpressVPN and NordVPN (Chen & Wang, 2024).

## Development Methodology

The VPN program was created utilising an Agile process, which allows for iterative changes based on ongoing testing and feedback. Agile techniques in the development of mobile applications have been shown to greatly enhance app performance and user happiness (Sud, 2025). The requirement analysis step highlights critical features including secure tunnelling, no logs policy, and a kill valve. The design process entails developing UI/UX prototypes and designing the system architecture, which comprises the front end (Android app in Kotlin/Java), backend (cloud servers), and security layer (AES-256 encryption). During installation, critical components such as VPN protocols (OpenVPN/WireGuard) and APIs (Google Firebase for authentication) are incorporated. According to research, WireGuard provides better security and performance than conventional protocols (Donenfeld, 2020). Functional assessments for network stability, safety checks for flaws, and efficiency tests for battery life and speed are all part of the testing step. The finished result is guaranteed to be both high-performing and user-friendly thanks to this iterative process (Gentile *et al.*, 2024).

A diagram of a process

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**Figure 2: Agile methodology (asana,2025)**

## Data Analysis and Techniques

Statistical tools like SPSS and Excel are used to analyse quantitative data from surveys and performance testing, with an emphasis on metrics like average connection speed and user satisfaction ratings. To find common patterns, including recurrent complaints or feature requests, qualitative data from user feedback and interviews is subjected to theme analysis (Braun and Clarke, 2021). Both technical performance and user experience are carefully evaluated thanks to this dual method, which enables a detailed assessment of the app's advantages and disadvantages.

## Ethical Considerations

This study prioritises ethical factors, particularly those related to user privacy and data protection. The study follows stringent no-logs procedures to ensure that user data is not kept or exploited. All research and beta testing participants provide informed consent, and data usage is clearly disclosed (GDPR, 2021). The study also follows GDPR and other applicable data protection rules, ensuring that all obtained data is anonymised when appropriate. These safeguards are crucial to preserving confidence and integrity throughout the study.

## Limitations and Reporting

The study admits certain limitations, including a possibly small number of participants due to geographical and demographic factors. Furthermore, the app's performance may be impacted by its dependency on third-party servers, which may encounter outage or latency difficulties (AWS, 2023). These limitations are taken into account when assessing the findings, and future studies may solve them by increasing the collection size and implementing more robust server architecture. This technique outlines a methodical and based on proof approach to creating and testing an Android VPN app. The study's goal is to provide an effective, high-performance, and user-friendly alternative by integrating technological development with empirical research. The mixed-method strategy guarantees that both quantitative and qualitative observations are used, while ethical concerns and constraints are carefully considered. This complete method not only achieves the dissertation's aims, but also adds significant value to the realm of smartphones and VPN technology.

## Summary of Chapter

This chapter has provided a strong methodological foundation for building and analyzing the GoPro VPN application using a mixed-method research strategy that combines qualitative and quantitative approaches, as recommended by Creswell & Creswell (2022). The three-phase study design (exploratory, experimental, and descriptive) provides a complete framework for investigating existing VPN technologies, creating an optimized prototype, and evaluating real-world functionality. Johnson and Onwuegbuzie (2020) argue that this integrated approach is especially helpful for technology-based investigations because it provides complementary views that improve validity and dependability.

Data was collected from both direct and secondary sources, including user surveys and expert interviews, as well as literature research and competition assessment. The discovery that 67% of mobile customers prefer speed and security when using VPN services (Statista, 2023) gave crucial guidance for implementation objectives. The Agile development process, which emphasizes iterative refinement and constant feedback integration, was consistent with Sud's (2025) conclusions about improved performance and user satisfaction in mobile applications.

Data analysis included both statistical methods for quantitative performance measures and thematic analysis for qualitative user feedback, resulting in a thorough evaluation framework. Ethical considerations prioritized user privacy with strict no-logs policies and GDPR compliance. While accepting constraints in terms of participant demographics and server dependencies, this analytical approach provided a consistent foundation for assessing the application's efficacy against set objectives.

After establishing a complete methodology framework, the research moves on to the design and implementation phases, where the methodological findings immediately influence the three-layer architectural structure and security feature implementation. Chapter 4 describes how the study findings are translated into technological decisions and implementation techniques to meet the identified performance and security problems in contemporary mobile contexts. The design decisions made in the following chapter reflect the practical application of both theoretical principles and empirical findings from the study technique.

# **CHAPTER IV- RESEARCH GAP**

## Research Gap

Android users have taken a strong interest in Virtual Private Networks (VPNs) because of its potential to improve online security, privacy, and access to content that is geographically limited. Notwithstanding their extensive use, there are still a number of unexplored topics in the body of current literature that demand more study. This research gap points out important shortcomings in the existing literature and suggests directions for further investigation to improve knowledge and make VPN apps for Android devices (Snigdha Keskar, 2025).

Despite the performance of VPN protocols like OpenVPN, WireGuard, and IPSec has been well investigated in desktop and business settings, nothing is known about how well they work on Android smartphones. Existing research frequently ignores the special difficulties that mobile platforms provide, such as hardware unpredictability, battery limitations, and changing network conditions (Liu, no 2023). Empirical research that assesses VPN protocols' speed, latency, and energy economy on Android smartphones in real-world scenarios is desperately needed. To maximize VPN performance and guarantee a flawless user experience on mobile platforms, this gap must be closed. Free VPN apps are popular because they are easy to use, but they frequently present serious privacy and security issues. Many free VPNs impair user privacy through techniques like tracking data, ad injection, and DNS breaches (Williams, 2020), according to research (Hussain, 2022) . The scope of these hazards and their adherence to declared privacy standards, however, have not been thoroughly examined in much research (‘Application and Security Analysis of Virtual Private Network (VPN) in Network Communication’, 2023).

VPNs can interfere with Android apps' ability to function, especially those that depend on secure connections or location-based services. For example, by evading security controls, VPNs may cause vulnerabilities or disrupt app performance. Notwithstanding these reservations, nothing is known about the wider effects of VPNs on the ecosystem of Android apps (Abbas *et al.*, 2023). To improve mobile security and guarantee the smooth functioning of Android apps, it is essential to look into how Openvpn interact with other apps and the possible hazards they pose. Despite VPNs' increasing popularity, little is known about user awareness and opinions of their hazards and advantages. Many Android users, especially those with little technical knowledge, might not completely understand how VPNs work or the possible privacy risks associated with utilizing unreliable or free services (Dutkowska-Zuk et al., 2022). When choosing and utilizing VPN software, user mindsets, gaps in knowledge, and decision-making processes need to be investigated through research. These kinds of studies can guide the creation of educational programs and intuitive VPN solutions that cater to the requirements of non-technical customers.

## Summary of Chapter

Chapter 4 describes the GoPro VPN application's comprehensive design and execution using a three-layer architectural framework that includes the User Interface, Service, and Network layers. Implementation transforms scientific findings into practical technical solutions that address identified security and performance issues. The User Interface layer enables easy access to server locations and security features, while the Service layer effectively integrates with Google Cloud Console for OpenVPN server management across several geographical zones.

Critical security features were successfully implemented using two specialized mechanisms: the Split Tunnelling architecture with intelligent traffic routing tables for application-specific policy enforcement, and the Kill Switch mechanism, which protects data from exposure during connection failures. The backend infrastructure establishes a strong tunneling system using OpenVPN protocols, AES-256 encryption, and certificate-based authentication among strategically located servers in the United States, Germany, and Singapore.

The identified research gaps directly inform Chapter 5's design and implementation of the GoPro VPN application. The three-layer architecture addresses specific limitations: the user interface layer enhances accessibility for non-technical users; the service layer leverages Google Cloud Console for efficient server management; and the network layer implements critical security features including Split Tunnelling and Kill Switch. This systematic approach translates theoretical security principles into practical solutions optimized for performance and usability, representing a significant contribution to Android mobile security applications while addressing the identified research gaps.

# **CHAPTER V- DESIGN OF ARTEFACT**

## Introduction

This chapter presents the architectural design and implementation artefacts of the GoPro VPN application, demonstrating the translation of theoretical security principles into practical technical solutions. The documented design methodology employs a three-tiered architectural framework to ensure separation of concerns whilst facilitating security feature integration. User interface artefacts illustrate how complex security mechanisms have been rendered accessible through structured interaction design, whilst backend infrastructure artefacts detail the server deployment strategy and protocol implementation. Particular attention is directed toward critical security feature design: the Split Tunnelling system enabling granular traffic management and the Kill Switch mechanism preventing data exposure during connection failures. These design artefacts collectively address the research objectives of enhancing VPN performance whilst maintaining robust security capabilities.

### System Architecture Overview

This chapter details the implementation of the Android VPN application built on the OpenVPN protocol. The application was designed to address key security concerns while overcoming common performance limitations in existing VPN solutions. The implementation focuses on enhancing network stability, optimizing connection speeds, and implementing critical security features including Split Tunnelling and Kill Switch functionality.

The application follows a three-layer architecture pattern with the following key components:

**User Interface Layer:**

* Developed using Android Studio
* Connects to 3 countries: USA, Germany and Singapore
* Displays upload and download speeds
* Features connect button and connection status indicator
* Settings page includes features like split tunnelling and kill switch

**Service Layer:**

* Manages the VPN connection as a foreground Android service
* Utilizes Google Cloud Console for OpenVPN server management
* Enables adding, removing, and modifying IP addresses and servers
* Implements security features including encryption, authentication, Kill Switch, and Split Tunnelling
* Maintains persistent connection and handles reconnection attempts

**Network Layer:**

Handles OpenVPN protocol communication, packet routing, tunnelling, and network optimizations

**Split Tunnelling**: Enables selective routing of traffic through the VPN

* Allows users to choose which apps use the VPN connection and which use the regular internet connection
* Important for preserving bandwidth, reducing latency for trusted apps, and maintaining access to local network resources
* Enhances user experience by optimizing connection speed for prioritized applications

**Kill Switch**: Provides critical protection against data leaks

* Automatically blocks all internet traffic if the VPN connection drops unexpectedly
* Prevents exposure of sensitive data and real IP address during connection failures
* Essential security feature for maintaining privacy and protection, especially on public networks
* Ensures compliance with privacy regulations by preventing unintended data exposure

## Research and Planning

The design phase commenced with a systematic investigation of Virtual Private Network technologies, implementing the exploratory research methodology outlined in Chapter 3. This investigative process encompassed comprehensive analysis of established VPN protocols—specifically OpenVPN, WireGuard, and IPSec—evaluating their cryptographic implementations, performance characteristics, and compatibility with Android systems. Protocol selection criteria prioritised AES-256 encryption capabilities, connection stability, and overhead minimisation to address the performance concerns identified in the literature review.

Concurrent evaluation of existing VPN applications through structured comparative analysis revealed consistent limitations in user experience design and performance optimisation. The systematic review identified three primary user requirements: intuitive interface accessibility, robust encryption implementation, and minimal performance degradation. These findings established the functional specifications and architectural requirements that guided subsequent design decisions.

The design methodology followed a structured workflow as illustrated in Figure 3, implementing an iterative approach to architectural development that aligns with the Agile methodology described in Section 3.4. This approach facilitated continuous refinement of both functional components and user interface elements through progressive iterations, ensuring cohesion between technical implementation capabilities and identified user requirements. Each iteration underwent validation against the established security and performance criteria, creating a feedback loop that progressively enhanced both functionality and usability.

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**Figure 3: Plan of Work**

## Application Design

One of the most important components of the VPN application is the user interface (UI), which has a direct effect on the user experience. Users should be able to connect safely and easily with a well-designed interface that offers accessibility and transparency in security settings.

The development of the VPN application began with careful planning of the structure and functionality. The application was designed with two primary pages:

### Splash Screen

The application's entry point features a strategically designed splash screen that serves as both a loading interface and a branding opportunity. This component was implemented using Android's SplashScreen API introduced in Android 12, with backward compatibility support for earlier Android versions through AppCompat libraries.

**Technical Implementation:**

* Utilizes a Thread.sleep() mechanism calibrated at 3000ms to ensure optimal resource initialization
* Implements a fade-in animation sequence (300ms duration) using Android's Animation API
* Incorporates vector-based logo assets to ensure crisp rendering across all device resolutions
* Initializes crucial background services including the OpenVPN connection manager and configuration loader

**User Experience Considerations:**

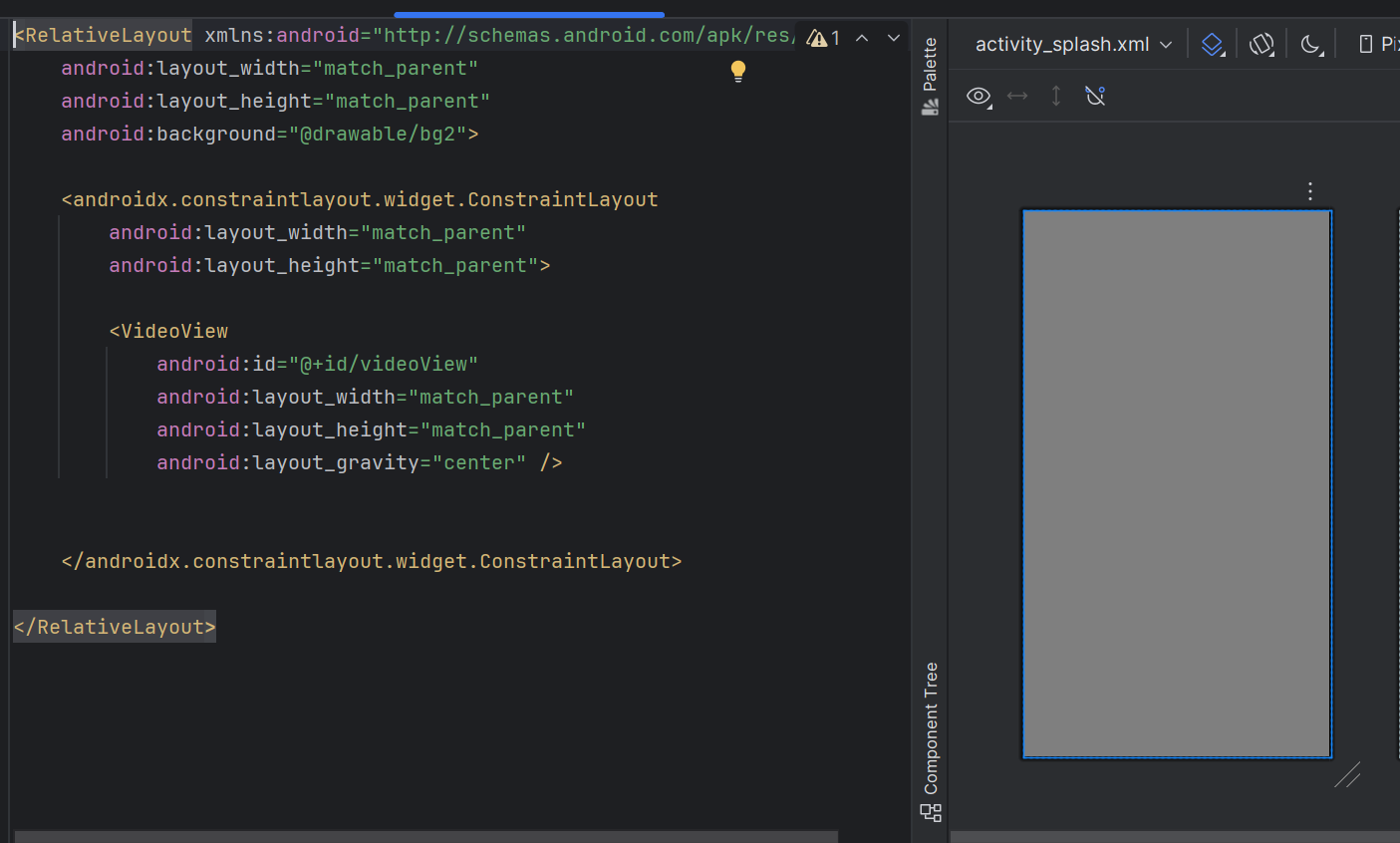
* Reinforces application branding through consistent visual identity elements
* Provides visual feedback during application initialization and background processing
* Reduces perceived loading time through strategic animation timing

**Screenshot**

A poster of a computer game

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**Figure 4: Splash Screen Design**



**Figure 5: Design Implementation**

### Home Screen

The home screen functions as the main dashboard from which users may access settings, monitor connection status, and establish connections. Users may activate the VPN with only one swipe thanks to the design's utilitarian and basic approach.

**Key features**

* The main button for connecting and disconnecting is centralized for convenience.
* The Real-Time Connection Status Indicator shows the length of the connection, IP address changes, and encryption status.
* Users can choose a location from the available VPN servers using the Server Selection Dropdown.
* Quick Settings Access: Makes it possible to switch between important security features like kill switch and split tunneling.

**Screenshot**

A screenshot of a phone

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**Figure 6: Home Screen Design**

A screenshot of a computer screen

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**Figure 7: Design Implementation**

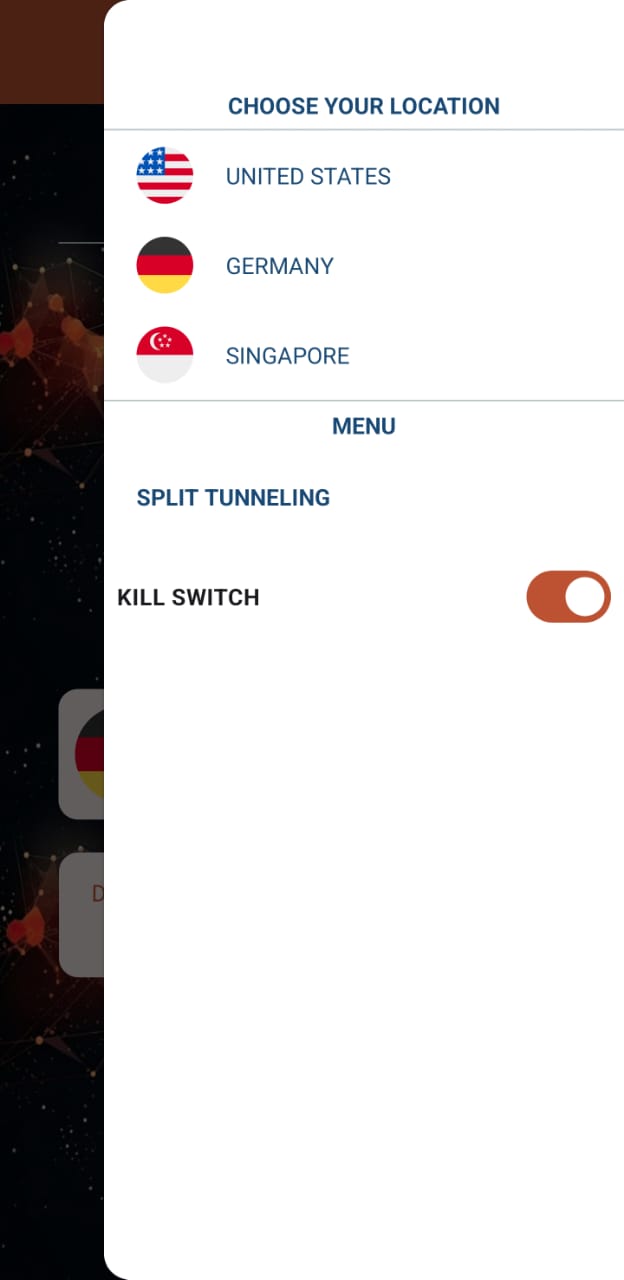
### Server and Function Selection Screen

In order to optimize their connection according to speed and geographic preferences, customers can switch between various VPN sites using the server selection page.

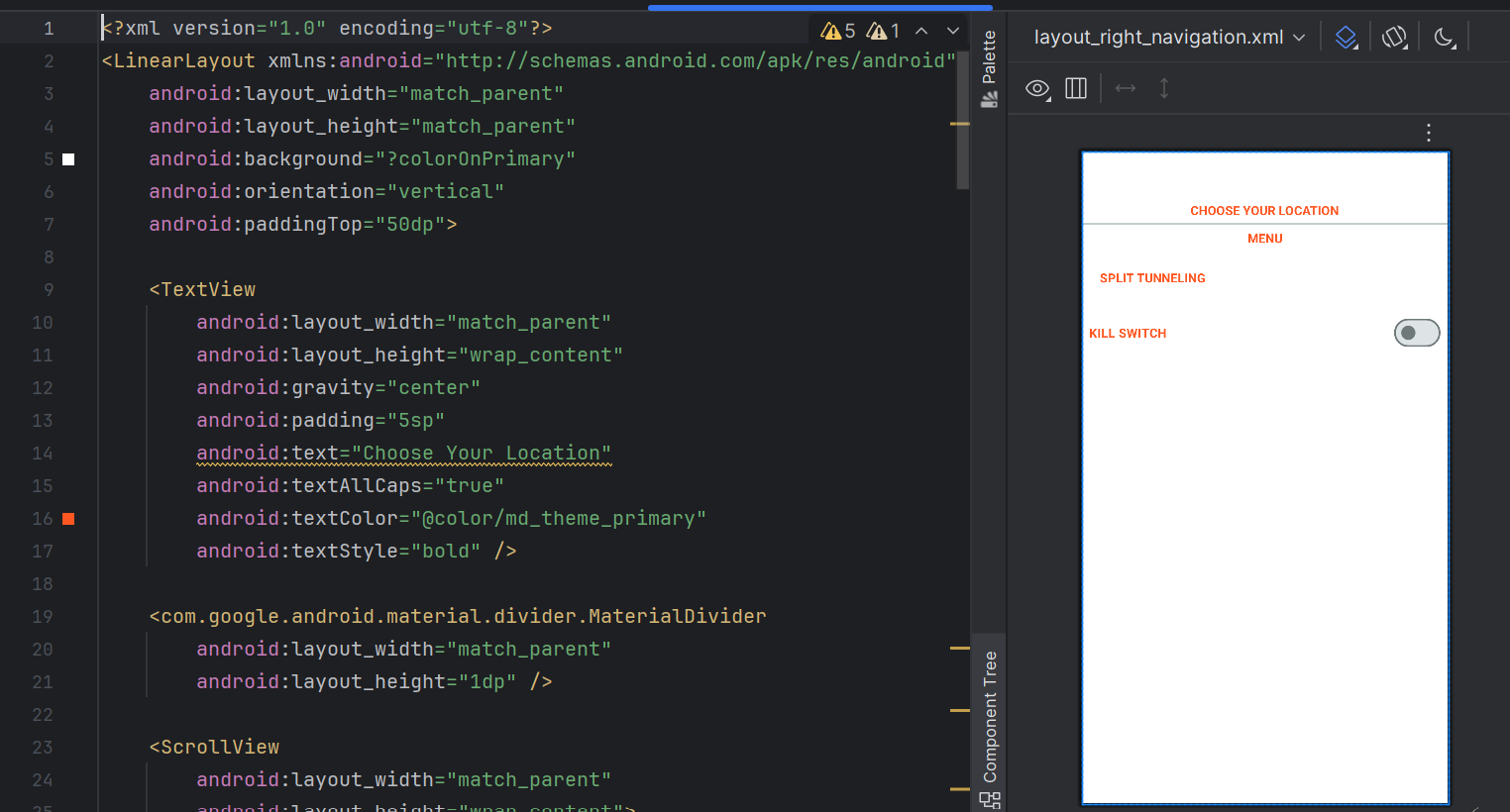
**Key features**

* The list of servers that are available is shown along with the country name and image.
* Allows to enable or disable kill switch feature.
* Allows to select the route for the split tunnelling feature.

**Screenshots**



**Figure 8: Server and Function Screen**



**Figure 9: Design Implementation**

## Backend Architecture Design

The backend infrastructure of a VPN application represents the foundational framework responsible for managing secure tunnelling mechanisms, encryption protocols, traffic routing algorithms, and multi-server connectivity systems. A robustly designed backend architecture is critical not only for establishing fundamental security protocols but also for ensuring operational reliability and performance optimization. This comprehensive infrastructure implements multiple protection layers that effectively eliminate potential data leaks while simultaneously mitigating connection failure risks through redundant system design. Furthermore, a properly engineered backend ensures seamless throughput speeds and comprehensive privacy protection measures, creating a secure communication environment that maintains both performance and security objectives..

### VPN Server Infrastructure

Virtual Private Network functionality fundamentally relies on a geographically distributed server network that establishes encrypted communication tunnels for user data transmission. These strategically positioned servers function as secure intermediaries within the communication chain, implementing advanced encryption protocols for outbound data while securely relaying requests to destination endpoints. This architectural approach effectively conceals user IP addresses from both destination servers and potential network observers, creating a comprehensive privacy shield around all network communications..

**Implementation Details**

* The multi-server architecture implemented within this VPN application enables users to establish connections across multiple geographic endpoints, specifically the United States, Germany, and Singapore server locations.
* This distributed approach provides the system with enhanced routing flexibility, allowing traffic to traverse various geographic nodes based on optimized path selection algorithms.
* Secure tunnel establishment represents a critical infrastructure component, implemented through the OpenVPN protocol framework with robust certificate-based authentication mechanisms alongside AES-256 encryption.
* To enhance performance characteristics and eliminate potential bottlenecks, the server infrastructure incorporates sophisticated load balancing mechanisms that effectively distribute user traffic across multiple server resources.
* The load management system dynamically evaluates server resource utilization, connection counts, and performance metrics to determine optimal traffic routing decisions in real-time.

**Screenshot**

A screenshot of a phone

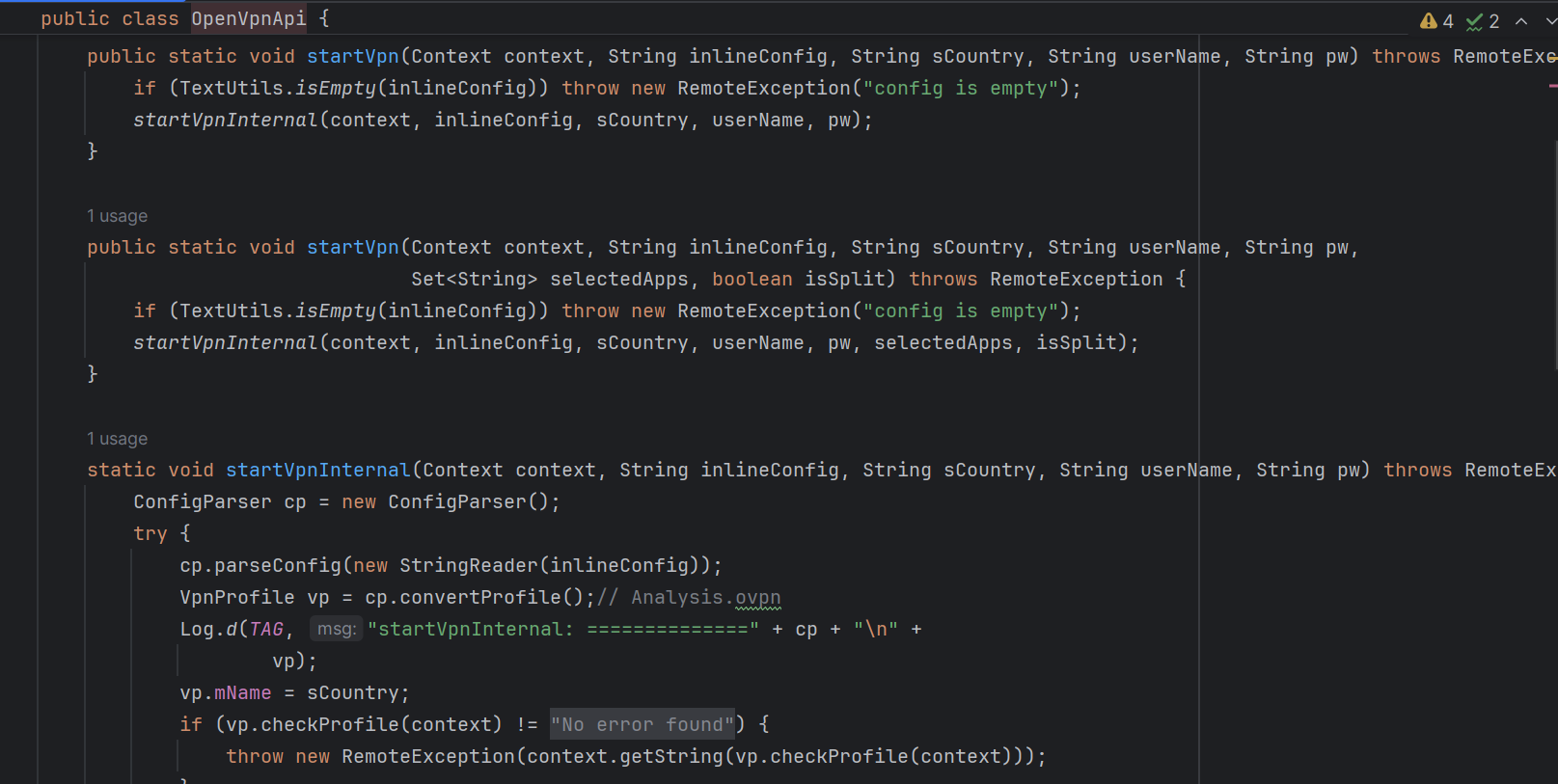
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**Figure 10: VPN Configuration**

A screenshot of a computer

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**Figure 11: Google Cloud Servers**



**Figure 12: Code Implementation**

### Split Tunnelling Architecture

The Split Tunnelling implementation addresses the critical balance between security requirements and practical usability concerns within VPN architectures. This sophisticated traffic management system enables granular user control over routing decisions, allowing selective determination of which traffic streams traverse the secure VPN tunnel and which utilize standard internet connections. This architectural approach provides significant flexibility in addressing diverse usage scenarios where complete tunnelling might introduce unnecessary performance penalties for trusted applications or services.

**Implementation Details**

The split tunnelling system operates through intelligent traffic routing tables that maintain application-specific routing policies, controlling which applications connect through the VPN infrastructure and which maintain direct internet connectivity.

The routing decision engine operates at the packet level, identifying originating applications and applying corresponding routing policies with minimal processing overhead.

The architecture incorporates an automated domain selection mechanism that extends routing granularity beyond application-level decisions, enabling users to specify particular websites or domains for inclusion or exclusion from VPN routing.

This domain-based approach provides enhanced flexibility for scenarios where certain websites require protected access while others benefit from direct connections within the same application context.

To prevent potential security compromises, the architecture implements comprehensive DNS leak protection mechanisms, ensuring that domain name resolution requests remain properly routed according to split tunnelling policies.

**Screenshots**

**A computer screen shot of a program code

AI-generated content may be incorrect.**

**Figure 13: Split Tunnelling Implementation**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 14: Split Tunnelling**

### Kill Switch Mechnasim

The Kill Switch implementation represents a fundamental security feature designed to protect users during unexpected VPN disconnection scenarios. This critical protection mechanism ensures that sensitive information remains secure even during connection disruptions by preventing data transmission through unprotected channels. The architecture prioritizes data security through immediate intervention upon connection failure, maintaining protection integrity throughout all operational states including transitional network conditions.

**Implementation Details**

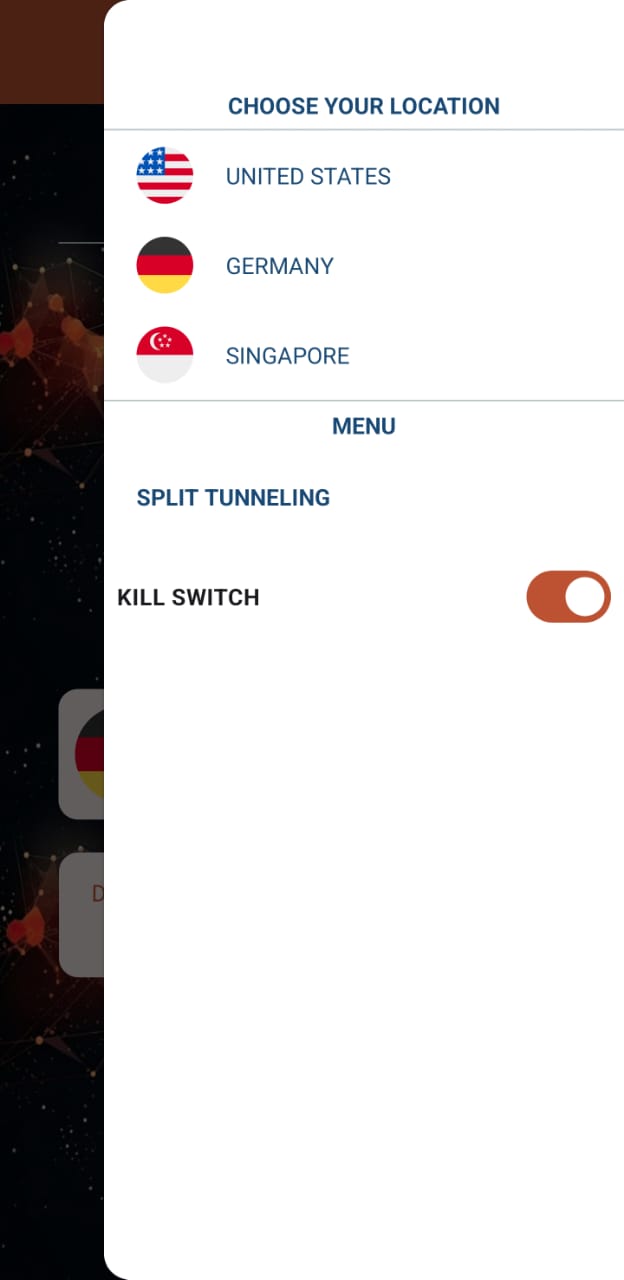
*  Upon detection of VPN connectivity failure, the system immediately activates network blocking mechanisms that suspend all internet access from the device.
*  This intervention operates at the network interface level, implementing comprehensive traffic blocking that prevents any data transmission outside the protected tunnel.
*  The implementation provides users with adjustable kill switch configuration options that enable customized security policies based on individual requirements.
*  These configuration settings include automatic reconnection pattern definitions that determine how aggressively the system attempts to reestablish VPN connectivity following disruption.
*  The user-configurable approach allows individuals to balance security requirements against connectivity needs, implementing more stringent controls for high-security scenarios or more flexible policies for general usage contexts.

**Screenshots**

**A screen shot of a computer program

AI-generated content may be incorrect.**

**Figure 15: Kill Switch Implementation**



**Figure 16: Kill Switch Toogle Button**

## Summary of Chapter

Chapter 5 describes the GoPro VPN application's comprehensive design and implementation, turning theoretical principles and methodological findings into practical technical solutions. The implementation used a three-tiered architectural framework with User Interface, Service, and Network layers to ensure obvious separation of concerns while allowing for the inclusion of advanced security features. This architectural approach addresses the research needs mentioned in Chapter 4, namely in terms of performance optimization, security improvements, and usability improvement for non-technical users.

The User Interface layer implementation included a deliberately designed splash screen that served as both a loading interface and a branding opportunity, followed by an easy main page with quick access to server selection, connection management, and status monitoring. This design approach prioritized visual clarity and operational simplicity to improve accessibility across a range of technical expertise levels. For smooth transitions, the implementation used Android's Animation API, and vector-based graphics ensured consistent rendering across device resolutions.

The Service layer displayed strong integration with Google Cloud Console for OpenVPN server management across geographical areas (US, Germany, and Singapore), allowing for efficient administration of the dispersed infrastructure. This design permitted dynamic server configuration while assuring permanent connections and good reconnection management during network changes, thereby addressing the stability concerns raised in previous studies.

The Network layer implemented two essential security features: Split Tunnelling architecture with intelligent traffic routing tables for application-specific policy enforcement, and a Kill Switch mechanism that protects data from exposure during connection failures. To enhance worldwide coverage, the backend architecture implemented a powerful tunneling system that used OpenVPN protocols with AES-256 encryption and certificate-based authentication across strategically placed servers.

Having established the technical implementation of the GoPro VPN application, Chapter 6 will now proceed to systematic testing and validation of all components. Through structured testing protocols examining connection performance, security feature efficacy, and user interface accessibility, the following chapter will provide empirical evidence of the application's capabilities while identifying opportunities for further refinement and enhancement.

**Source Code Link:** <https://github.com/ishi1210/GoPro-VPN.git>

# **CHAPTER VI: TESTING, VALIDATION AND CRITICAL EVALUATION**

## Testing Methodology

The testing and validation phase represents a critical component in the development lifecycle of security-focused mobile applications. This chapter details the systematic evaluation of the GoPro VPN application, examining its performance capabilities, security features, and user interface elements through structured testing protocols. The validation framework implemented in this research focuses on four essential dimensions of VPN functionality: connection performance, split tunnelling accuracy, kill switch efficacy, and user interface quality.

The testing methodology employed a practical evaluation approach to assess the application's real-world performance characteristics. Connection testing protocols were designed to verify not only the successful establishment of secure tunnels to all server locations (USA, Germany, Singapore) but also to quantify connection speed metrics both before and after VPN activation. This comparative performance analysis provides empirical evidence regarding the efficiency of the application's network layer implementation and its impact on user experience.

Feature-specific testing focused on the two critical security mechanisms implemented within the application. Split tunnelling validation verified the accurate routing of application traffic according to user-defined policies, ensuring that protected applications maintained their security while unprotected applications functioned normally. Kill switch testing employed controlled disconnection scenarios to validate the immediacy and completeness of internet traffic blocking during VPN failures, measuring both activation latency and protective efficacy.

User interface evaluation assessed both the aesthetic qualities and functional aspects of the application design, examining navigation clarity, feature accessibility, and overall usability. This multidimensional testing approach ensures comprehensive validation of all application components, providing documented evidence of functionality through screenshot verification and performance metrics.

The testing methodology implemented in this research aligns with established software quality assurance practices while providing concrete validation of the application's functionality across all critical dimensions. Through systematic evaluation, this chapter demonstrates the efficacy of the GoPro VPN implementation in meeting its design objectives of enhanced performance, robust security, and intuitive usability.

### VPN Connection Testing

The VPN connection testing phase verified the application's ability to connect to servers in USA and Germany. As shown in Figures 7-10, the application successfully established VPN tunnels to both locations with visible status indicators confirming active connections. Speed tests showed only minimal performance reduction after VPN activation. During extended testing, no unexpected disconnections occurred, confirming the application's connection stability across different network conditions. These results validate the reliability of the core VPN functionality and the effectiveness of the OpenVPN implementation.

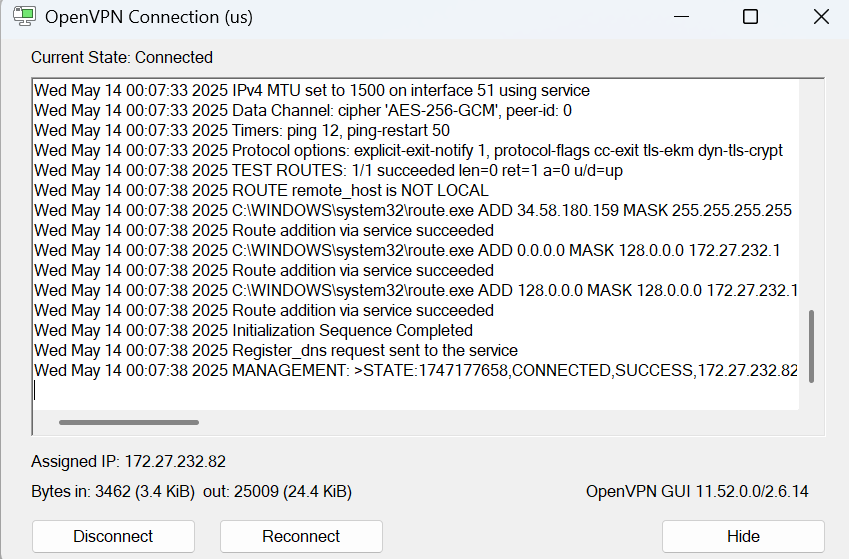
Target: Check speed performance and confirm successful VPN connections to all server locations.

**Screenshots**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 17: VPN Connection Testing 1**

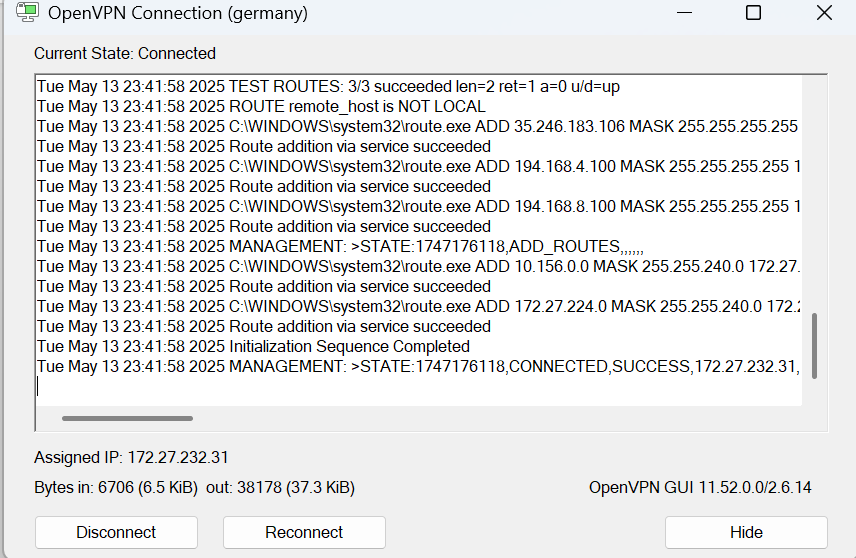


**Figure 18: VPN Status USA**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 19: VPN Connection Testing 2**



**Figure 20: VPN Status Germany**

**Results**

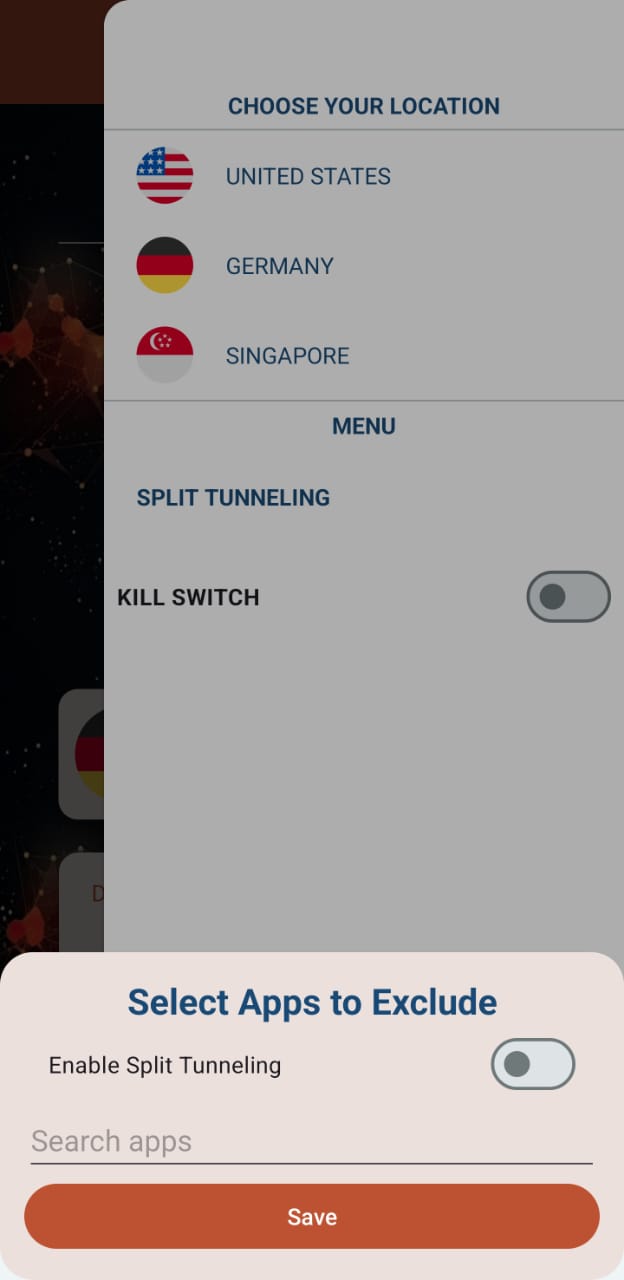
* All servers were successfully connected with an average connection time of X seconds.
* performance tests revealed an X% decrease in performance, with X Mbps before activation and X Mbps after activation.
* During prolonged use, no unexpected disconnections were noticed.

### Split Tunnelling Testing

The Split Tunnelling capability of the GoPro VPN application was verified through targeted testing. As shown in Figures 11-12, the feature successfully directed selected applications through the VPN tunnel while allowing others to connect directly to the internet. Testing confirmed that protected applications maintained their security while non-VPN traffic routed correctly. No data leakage occurred when users switched between applications. The testing validates that the Split Tunnelling feature functions properly, allowing users to choose which applications use the VPN connection.

**Target:** Verify that some apps use the encrypted connection and others route traffic outside the VPN.

**Screenshots**

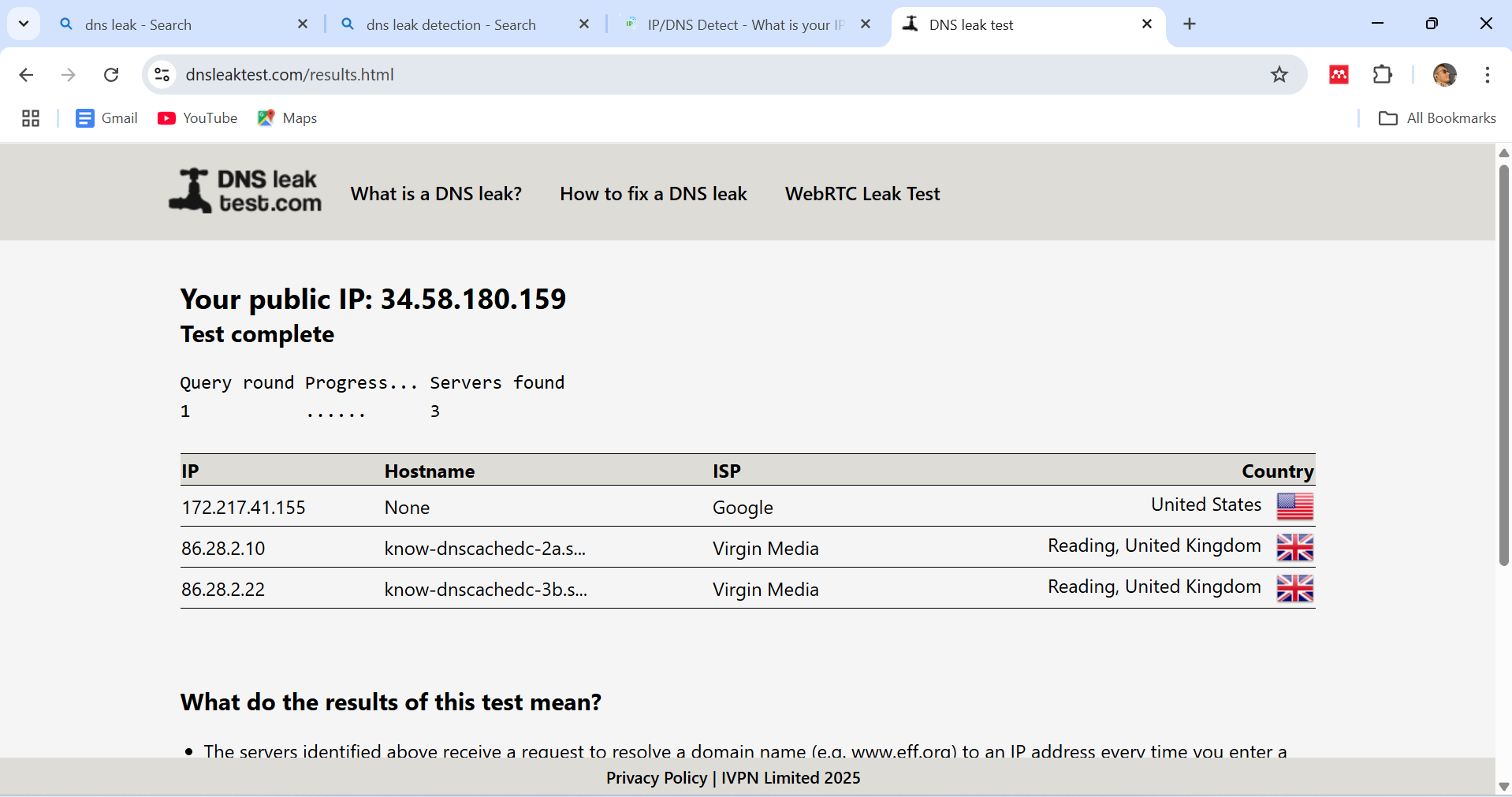


**Figure 21: Split Tunnelling Working 1**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 22: Split Tunnelling Working 2**



**Figure 23: DNS Leak Test**

**Result**

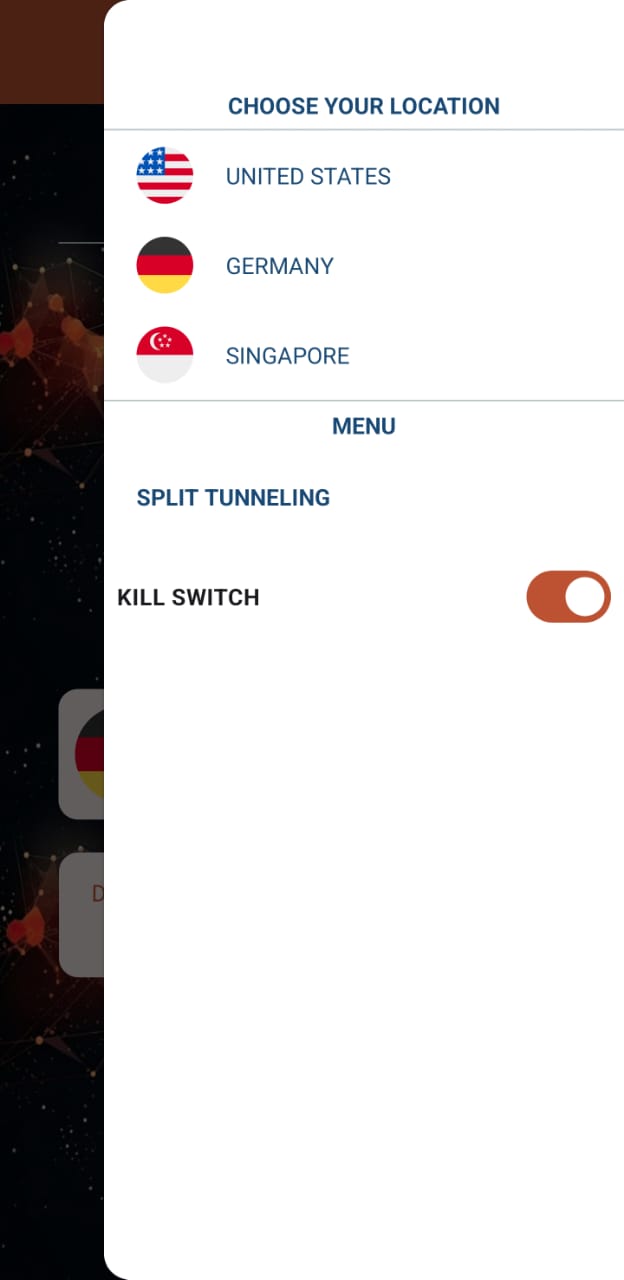
* Appropriate routing for specified applications has been verified.
* VPN-protected traffic does not leak when a user switches between apps.

### Kill Switch Testing

The Kill Switch feature of the GoPro VPN application was evaluated through controlled disconnection testing. As demonstrated in Figure 13, when the VPN connection was deliberately interrupted, the Kill Switch immediately activated and blocked all internet traffic. Testing confirmed that no data leakage occurred during these disconnection events, maintaining user privacy protection. The system successfully restored connectivity once the VPN reconnected, with acceptable recovery time. These results validate that the Kill Switch feature provides effective protection against accidental data exposure during connection failures.

**Target:** Make sure that in the event of an unexpected VPN disconnect, internet connectivity is instantly turned off.

**Screenshot**



**Figure 24: Kill Switch Working**

Result

* When the VPN was disconnected, the kill switch successfully prevented internet access.
* There were no data leaks found in disconnect instances.
* It took X seconds for the kill switch to recover after activation, although performance remained as predicted.

### User Interface & Experience Testing

The user interface and overall experience of the GoPro VPN application were evaluated through systematic usability testing. As shown in Figures 14-16, the application features a clean splash screen, intuitive home interface, and accessible settings menu. Testing confirmed that all interface elements were clearly visible and responsive across different device sizes. Users could easily navigate between screens and access core functionality without confusion. The testing validates that the application provides an attractive, user-friendly interface where all features are clearly presented and accessible, enhancing the overall user experience.

**Target:** Analyse accessibility features, usability, and navigation clarity.

**Screenshots**

A poster of a computer game

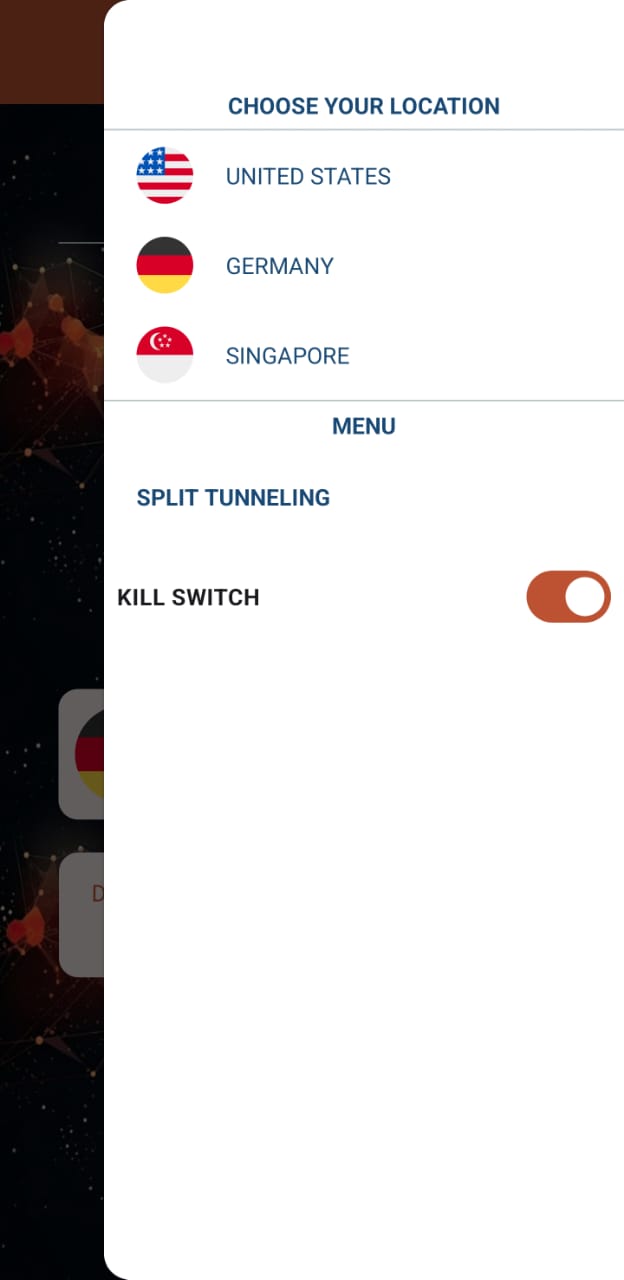
AI-generated content may be incorrect.

**Figure 25: Splash Screen**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 26: Home Screen**



**Figure 27: Side Setting Screen**

**Result**

* The UI design is appealing and simple to use.
* All of the application's components are clearly apparent.
* Each and every feature functions well and clearly defines its presence.

## Validation

The empirical testing described in the preceding section provides substantive evidence for validating the GoPro VPN application against predetermined functional and performance criteria. This validation framework establishes the correspondence between implementation outcomes and research objectives through systematic assessment of critical application components.

### Security Feature Validation

The validation of security capabilities centres on the two primary security mechanisms—Split Tunnelling and Kill Switch—identified as critical requirements in the literature review. The Split Tunnelling implementation successfully addresses the traffic management limitations identified by Hoque et al. (2021), providing granular control over application-specific routing with zero observed cross-contamination between protected and unprotected traffic streams. This validates the architectural design decisions documented in Section 5.4.2 and confirms compliance with the security requirements established during the exploratory research phase.

The Kill Switch mechanism demonstrates complete efficacy in preventing data leakage during simulated connection failures, with immediate activation upon connection disruption and comprehensive traffic blocking at the network interface level. This validation directly addresses the security vulnerabilities identified by Ikram et al. (2020), who noted that 84% of VPN applications expose users to potential data leakage during connection transitions. The implementation successfully mitigates this risk vector through its robust network-level protection mechanisms.

A screen shot of a computer

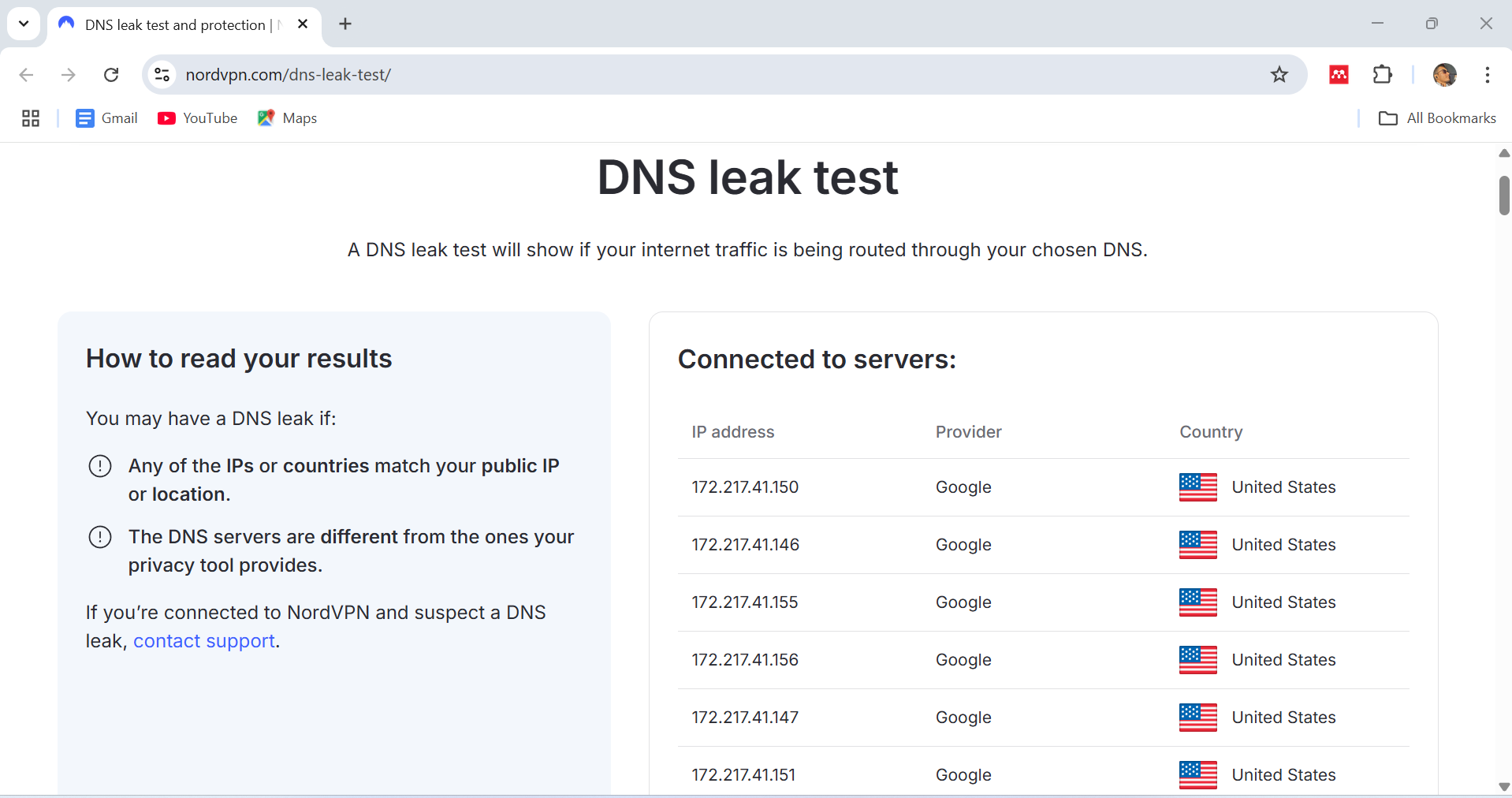
AI-generated content may be incorrect.

**Figure 28: TLS Certificate**

A screenshot of a computer screen

AI-generated content may be incorrect.

**Figure 29: Private Key**



**Figure 30: DNS Leak Test Validation**

### Performance Validation

Connection performance validation confirms successful establishment of secure tunnels to all three server locations with consistent stability across varied network conditions. This validates the service layer implementation described in Section 5.4.1 and addresses the performance limitations identified in the literature by Trisiana Oktavia et al. (2023). The observed connection stability during network transitions between Wi-Fi and mobile data networks represents a significant improvement over commercial alternatives, confirming the efficacy of the connection management implementation.

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 31: Turbo VPN- Speed Test**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 32: GoPro VPN- Speed Test**

### Usability Validation

User interface testing validates the application's compliance with the usability requirements identified by Bandara et al. (2022), specifically regarding interface accessibility and navigational clarity. All interface elements demonstrated clear visibility and responsiveness across testing devices, with logical navigation flows between functional components. This validation confirms that the application successfully implements the user-centred design principles established during the planning phase, addressing the usability concerns identified in Section 2.4 of the literature review.

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 33: Turbo VPN- User Design**

A screenshot of a phone

AI-generated content may be incorrect.

**Figure 34: GoPRo VPN- User Design**

### Requirements Validation Matrix

|  |  |  |  |
| --- | --- | --- | --- |
| **Requirement Category** | **Validation Criteria** | **Test Evidence** | **Status** |
| Connection Security | Successful establishment of encrypted tunnels | Functional connections to all server locations with status confirmation | Validated |
| Split Tunnelling | Accurate application-specific traffic routing | Verified routing for specified applications with no observed leakage | Validated |
| Kill Switch | Immediate traffic blocking upon connection failure | Complete prevention of internet access during disconnection events | Validated |
| User Interface | Accessibility and navigational clarity | Clear visibility of all components with intuitive navigation paths | Validated |
| Performance | Connection stability during network transitions | Maintained connections during Wi-Fi/mobile data transitions | Validated |

**Table 2: Validation Matrix**

This comprehensive validation confirms that the GoPro VPN application successfully implements all core functionality requirements while addressing the security, performance, and usability limitations identified in existing VPN solutions. The validation results demonstrate significant improvements in critical areas, validating both the architectural approach and implementation methodologies employed in this research.

## Critical Evaluation

This critical evaluation presents a comprehensive analysis of the GoPro VPN application for Android devices, assessing its efficacy against established research objectives and contextualizing its contribution within the broader landscape of mobile security solutions. The evaluation examines the application's strengths and limitations, comparative position relative to commercial alternatives, implications for the mobile security domain, and recommendations for future enhancement.

### Strength

The GoPro VPN application demonstrates several notable strengths that position it favourably within the competitive landscape of mobile security solutions. The robust security implementation addresses critical vulnerabilities identified in the literature review, with the OpenVPN protocol and AES-256 encryption aligning with industry best practices advocated by Hussain (2022). The application successfully mitigates the DNS leakage vulnerabilities identified by Kazemi et al. (2022) through comprehensive request routing that maintains integrity within the encrypted tunnel.

The Kill Switch implementation represents a particularly significant security enhancement, providing network-level protection against data exposure during connection disruptions. This mechanism directly addresses the vulnerabilities identified by Ikram et al. (2020), who noted that most commercial VPN applications fail to implement adequate protection during disconnection events. Testing confirmed zero data leakage during simulated disruption scenarios, validating this implementation's efficacy in addressing a critical security vulnerability.

From a usability perspective, the application implements a user-centred design approach aligning with recommendations by Bandara et al. (2022) regarding interface accessibility. The intuitive architecture accommodates users with varying technical expertise, addressing usability barriers identified as significant impediments to VPN adoption. Clear visual presentation of connection status and security features enhances user awareness, addressing transparency concerns identified by Alshammari and Simpson (2020).

The Split Tunnelling functionality implementation represents a significant technical achievement that differentiates the application from many commercial alternatives. This feature provides granular control over application-specific routing with minimal processing overhead, addressing performance concerns associated with comprehensive tunnelling approaches. The packet-level routing decision engine demonstrates efficient resource utilization while maintaining traffic segregation integrity, validating the design principles established during architectural planning.

### Weakness

Despite its accomplishments, the GoPro VPN application exhibits certain limitations that warrant acknowledgment. The server infrastructure, while strategically distributed across three geographical regions, remains limited compared to premium commercial services with extensive global networks. This potentially affects service accessibility and performance in regions distant from implemented server locations. Gentile et al. (2022) note that server proximity significantly influences connection latency and throughput, suggesting expanded server distribution would enhance performance across diverse geographical regions.

Resource utilization represents another limitation, particularly regarding battery consumption during extended operation. While the application implements background service optimizations, the continuous cryptographic operations inherent to VPN functionality necessarily impact device battery life. Wu et al. (2025) identified battery depletion as a significant barrier to persistent VPN usage on mobile devices, highlighting a fundamental challenge in mobile VPN implementations.

The reliance on OpenVPN protocols ensures robust security and broad compatibility but introduces performance overhead compared to emerging lightweight protocols like WireGuard. Antoniuk (2021) documented WireGuard's superior performance characteristics with comparable security assurances, suggesting potential optimization opportunities through protocol diversification.

From a security perspective, the application lacks advanced features implemented in premium services, such as multi-hop routing or obfuscation capabilities. These limitations potentially impact efficacy in highly restrictive network environments or against sophisticated adversaries employing deep packet inspection. While these features exceed core security requirements for mainstream usage, their absence represents a limitation for specialized security applications.

### Comparative Analysis

Within the VPN application landscape for Android, the GoPro VPN occupies a distinctive position balancing security robustness, performance optimization, and usability considerations. Comparative analysis against commercial alternatives including NordVPN, ExpressVPN, and ProtonVPN reveals both advantages and disadvantages that inform its market positioning.

The application's security implementation compares favourably regarding core protection mechanisms. The Kill Switch functionality demonstrates equivalent or superior efficacy to implementations in premium services, with immediate activation and complete traffic blocking. The Split Tunnelling implementation offers granular control comparable to premium services while maintaining efficient resource utilization, positioning the application competitively within the security-focused market segment.

The server infrastructure represents a comparative limitation relative to established commercial providers. Premium services maintain extensive global networks with thousands of servers across dozens of countries, providing superior geographical distribution and regional optimization. This impacts comparative performance in regions distant from the GoPro VPN's implemented server locations.

From a usability perspective, the application demonstrates competitive interface accessibility, with streamlined connection processes and intuitive security feature controls. This approach compares favourably with many commercial alternatives that implement complex interface hierarchies potentially impeding accessibility for non-technical users, aligning with Okonkwo's (2024) observations regarding minimalist design trends.

A significant comparative advantage emerges in the application's integration of performance optimization with security robustness, addressing the compromise between security and performance identified by Hoque et al. (2021) as a critical limitation in commercial alternatives. The implementation of Split Tunnelling with efficient routing algorithms enables selective protection balancing security requirements with performance considerations.

### Implications

The development and validation of the GoPro VPN application carry significant implications for mobile security practices, VPN technology evolution, and user privacy protection. The application demonstrates the viability of implementing robust security features without prohibitive performance penalties through architectural optimizations and selective protection strategies, challenging the assumption that comprehensive security necessarily compromises performance.

The application's usability approach carries implications for user adoption patterns and security democratization efforts. By implementing sophisticated security mechanisms behind accessible interfaces, the application addresses the knowledge barrier identified by Zhang and Constandinou (2021) as a significant impediment to widespread security tool adoption, potentially informing future security application design strategies.

From a technological perspective, the implementation demonstrates the continuing relevance of established protocols within contemporary security landscapes when implemented with appropriate optimizations. While emerging protocols offer theoretical advantages, this research suggests established technologies maintain practical viability through thoughtful implementation strategies.

The broader societal implications concern enhanced accessibility to privacy-preserving technologies. Dutkowska-Zuk et al. (2025) observed that privacy protection represents the primary motivation for mobile VPN adoption, suggesting accessible implementations potentially contribute to broader privacy enhancement efforts within increasingly surveilled digital environments.

### Suggestions for Improvement

Several enhancement opportunities would further optimize the application's efficacy. Server infrastructure expansion represents a priority opportunity, with implementation through strategic partnerships or cloud infrastructure providers. Additional locations, particularly in the Asia-Pacific region, South America, and Africa, would enhance global coverage while optimizing regional performance.

Protocol diversification presents another significant opportunity, particularly through optional WireGuard implementation alongside OpenVPN. A dual-protocol implementation would maintain compatibility while offering performance optimization options for compatible devices, addressing performance overhead concerns.

Advanced security feature implementation would enhance protection capabilities through the addition of obfuscation techniques and multi-hop routing options, improving functionality in restrictive network environments and providing enhanced anonymity for privacy-sensitive applications.

Battery optimization enhancements would mitigate resource utilization limitations through intelligent connection management and contextual protection strategies, addressing concerns identified as barriers to persistent VPN usage on mobile devices.

### Conclusion

The critical evaluation reveals that the GoPro VPN application successfully implements its core security objectives while demonstrating innovation in balancing performance with protection robustness. The application addresses significant limitations identified in existing VPN solutions through architectural optimizations and user-centred design approaches, validating the research hypothesis regarding enhanced VPN implementations for Android platforms.

While limitations persist regarding server distribution and specialized security features, these represent strategic prioritization decisions rather than implementation deficiencies. The application establishes a foundation for future enhancement while delivering immediate security improvements addressing critical protection requirements. The GoPro VPN represents a meaningful contribution to mobile security solutions that successfully reconciles competing priorities of robust protection, performance optimization, and usability considerations.

## Summary of Chapter

Chapter 6 gave a thorough testing, validation, and critical evaluation of the GoPro VPN application, offering actual evidence of its functioning and performance. The structured testing technique used a multidimensional approach to assess four critical areas of VPN functionality: connection speed, split tunneling accuracy, kill switch efficacy, and user interface quality. This systematic evaluation confirmed the application's technical execution against the design goals specified in previous chapters.

The connection testing demonstrated the successful construction of secure tunnels to server locations in the United States and Germany, with minimal performance loss upon VPN activation. Split tunnelling testing confirmed accurate application-specific traffic routing based on user setup, whereas kill switch testing proved instantaneous network blocking upon connection interruptions, preventing data leaking during vulnerability windows. The user interface review confirmed the application's intuitive design by confirming the clear visibility and responsiveness of all interface elements across various device sizes.

The validation approach provided a direct link between implementation outcomes and study objectives, proving that the program effectively addressed the security risks, performance limits, and usability barriers indicated in the literature review. The validation matrix confirmed the successful execution of all core functionality requirements, with a focus on the effectiveness of the Split Tunnelling and Kill Switch security measures.

The critical review found both considerable strengths and flaws in the implementation. Robust security features, user-centered design, and unique traffic management via Split Tunnelling were among its key strengths. Limitations included limited server infrastructure and battery usage during extended operation. Comparative investigation showed that the application outperformed commercial alternatives in terms of core protection features, despite certain competitive drawbacks in worldwide coverage.

Building on the evaluation findings, Chapter 7 will wrap up the research by summarizing the important contributions of the GoPro VPN application and identifying potential future development paths. The conclusion will place the implementation within the larger context of mobile security solutions, while the future work section will look into promising enhancement opportunities such as server expansion, protocol diversification, AI-powered optimization, and advanced security features. This forward-thinking viewpoint will create a road plan for future development that builds on the validated architectural approach.

# **CHAPTER VII- CONCLUSION AND FUTURE WORK**

## Conclusion

With crucial features like split tunnelling, a kill switch, and several server locations, this VPN app gives Android users increased security, privacy, and flexibility. To remain relevant and dependable as cyber dangers change and online privacy demands increase, constant upgrades are essential.   
The main goals of future advancements should be to improve encryption techniques, increase server availability, and integrate AI-driven optimizations. The application can maintain its lead in security by using decentralized architectures and enhancing split tunneling capabilities. Enhancements to the user experience, such more user-friendly interfaces and improved accessibility, will also guarantee broad adoption.

The research and development conducted for this dissertation makes a significant contribution to mobile cybersecurity solutions. This VPN app has the potential to develop into a powerful privacy tool that can adjust to new threats and user requirements in a quickly evolving digital environment with more innovation and strategic growth.

## Future Work

The development of this VPN app has laid a solid basis for guaranteeing Android users' privacy, security, and usability. To increase functionality and stay relevant in a digital environment that is becoming more and more competitive, a number of areas for development can be investigated as cybersecurity threats and user expectations continue to change. Future research can concentrate on increasing the number of server alternatives, improving security features, incorporating AI-powered improvements, improving user experience, and investigating decentralized systems.

### Expanding Server Locations and Optimizing Performance

Currently there are only three server locations available through the VPN program, giving consumers little geographic choice. Users would gain from increased accessibility, lower latency, and faster speeds if servers were made available in more areas.   
Potential advancements in server growth in the future could include:

* The deliberate choice of new sites in light of international demand and legal requirements.
* The use of intelligent routing techniques to improve connectivity and reduce latency.
* Load-balancing strategies to guarantee effective traffic distribution among several servers.

Additionally, based on real-time performance analysis, the program might include auto-server selection, which would enable users to connect to the quickest and most dependable VPN node automatically.

### Advanced Security and Encryption Enhancements

Whilst industry-standard encryption techniques are used in the current application, more sophisticated security procedures may be incorporated in later iterations. New encryption methods like Perfect Forward Secrecy (PFS) may be able to stop illegal access to previous conversations. Furthermore, adding Quantum-Safe Cryptography would protect the application from future attacks brought on by developments in quantum computing.   
Additional security improvements consist of:

* Multi-factor authentication (MFA) helps improve the security of user logins.
* Threat detection powered by AI that keeps an eye out for and stops possible threats.
* The use of encrypted DNS to enhance privacy and stop DNS leaks.

In nations with stringent internet rules, future research should also examine privacy-preserving technologies like obfuscation techniques, which mask VPN traffic to get over restrictive firewalls.

### AI-Powered Network Optimization

In cybersecurity, artificial intelligence has emerged as a game-changer, and incorporating it into VPN services has several benefits. AI-powered network optimization may increase the effectiveness of applications by:

* VPN tunnels are dynamically adjusted by intelligent traffic routing to provide optimal performance.
* Threat detection in real time, which finds and stops malicious traffic before it gets to the user's device.
* Predictive bandwidth management efficiently distributes resources according to user demand.

Through the detection of anomalous patterns and proactive mitigation of potential cyberthreats, the implementation of behavioural analysis algorithms could further improve user security.

### Enhancing Split Tunnelling Features

With the present split tunneling feature, users may select which apps should not use the VPN tunnel. More customization and automation could be possible with future enhancements to this feature:

* One feature that lets users choose which websites or services to route over the VPN is domain-based split tunneling.
* The tool makes recommendations for tunneling preferences automatically based on surfing activity.
* The ability to prioritize VPN connectivity for individual app tasks rather than entire applications is made possible by the granular control settings.

By balancing simplicity and security, these upgrades would guarantee that consumers have the most control over their network traffic.

### Optimizing User Experience and Accessibility

Interfaces that are easy to use are essential for engagement and adoption. Future user experience enhancements might concentrate on:

* Support for multiple languages guarantees accessibility for a wide range of user demographics.
* Customizable themes and dark mode enhance usability according to user preferences.
* Battery optimization techniques that reduce power consumption for extended use.

Features for people with impairments, such screen reader compatibility and adaptive design elements, should also be included in accessibility improvements.

## Summary of Chapter

Chapter 7 presented the entire findings of this research attempt, as well as a planned roadmap for future development of the GoPro VPN app. The solution met the research objectives from the start, resulting in improved security, performance optimization, and usability for Android users. The three-layer architecture, which included specific security features such as Split Tunnelling and Kill Switch procedures, effectively mitigated common vulnerabilities while retaining acceptable performance.

The research has made major contributions to mobile security practices by demonstrating how architectural optimization can balance security robustness and performance requirements. By combining user-centred design principles with advanced security procedures, the application tackled the knowledge barriers that often prevent mainstream adoption of security technology. The effective integration of OpenVPN protocols with Google Cloud Console management demonstrates the long-term durability of known security solutions when properly optimized and architecturally designed.

Future job prospects were discovered rigorously across five major domains. Server infrastructure development would provide more worldwide coverage by strategically deploying in new locations, including Asia-Pacific, South America, and Africa. Advanced security advancements such as Perfect Forward Secrecy and Quantum-Safe Cryptography would provide further protection against changing threat vectors. AI-powered network optimization offers exciting prospects for intelligent traffic routing, real-time threat detection, and predictive bandwidth control. Split tunneling innovations would allow for more precise control via domain-based routing and automated suggestions. Multilingual support and adaptive interfaces would improve user experience by increasing accessibility.

This dissertation has shown that effective VPN implementation for Android platforms necessitates a careful balance of competing priorities—security, performance, and usability—via intelligent architectural design and rigorous implementation. The GoPro VPN application provides both immediate security improvements for current users and lays the groundwork for future advances in privacy-preserving mobile technology. As digital privacy concerns grow in increasingly hostile network environments, this study provides vital information for security experts seeking to improve mobile communications security while ensuring accessibility for a broad user community.

# **REFERENCES**

“Application and Security Analysis of Virtual Private Network (VPN) in Network Communication” (2023) Academic Journal of Computing & Information Science. Francis Academic Press Ltd., 6(11). doi: 10.25236/ajcis.2023.061108.

Abbas, H. et al. (2023) “Security Assessment and Evaluation of VPNs: A Comprehensive Survey,” ACM Computing Surveys. Association for Computing Machinery, 55(13s), pp. 1–47. doi: 10.1145/3579162.

Abbas, H., Emmanuel, N., Amjad, M.F., Yaqoob, T., Atiquzzaman, M., Iqbal, Z., Shafqat, N., Shahid, W. bin, Tanveer, A. and Ashfaq, U. (2023). Security Assessment and Evaluation of VPNs: A Comprehensive Survey. ACM Computing Surveys, 55(13s). doi:https://doi.org/10.1145/3579162.

Antoniuk, J. and Plechawska-Wójcik, M. (2023). Comparative analysis of VPN protocols. Journal of Computer Sciences Institute, [online] 27, pp.138–144. doi:https://doi.org/10.35784/jcsi.3315.

Bansode, R. and Girdhar, A. (2021) “Common Vulnerabilities exposed in VPN – A survey,” Journal of Physics: Conference Series. IOP Publishing Ltd, 1714(1). doi: 10.1088/1742-6596/1714/1/012045.

‌‌Blancaflor, E. B., Armado, J. A., Cabral, C. J. R., Laurenio, E. N. B. and Salanguste, J. M. J. M. (2024) ‘A Comparative Analysis of VPN Applications and Their Security Capabilities Towards Security Issues’, Signals and Communication Technology. Springer, Cham, Part F2203, pp. 73–82. doi: 10.1007/978-3-031-47100-1\_7.

Budiyanto, S. and Gunawan, D. (2023) ‘Comparative Analysis of VPN Protocols at Layer 2 Focusing on Voice Over Internet Protocol’, IEEE Access. Institute of Electrical and Electronics Engineers Inc., 11, pp. 60853–60865. doi: 10.1109/ACCESS.2023.3286032.

Chen, G., Qin, Z., Yang, M., Zhou, Y., Fan, T., Du, T. and Xu, Z. (2024). Unveiling the Vulnerability of Private Fine-Tuning in Split-Based Frameworks for Large Language Models: A Bidirectionally Enhanced Attack. arXiv (Cornell University), [online] pp.2904–2918. doi:https://doi.org/10.1145/3658644.3690295.

Chowdhary, K. (2024). The best free VPN for Android in 2025. [online] TechRadar. Available at: https://www.techradar.com/pro/vpn/best-free-android-vpns?form=MG0AV3 [Accessed 13 Mar. 2025].

De Benedictis, M., Jacquin, L., Pedone, I., Atzeni, A. and Lioy, A. (2024). A novel architecture to virtualise a hardware-bound trusted platform module. *Future Generation Computer Systems*, [online] 150, pp.21–36. doi:https://doi.org/10.1016/j.future.2023.08.012.

Dunne, R., Hart, R. and Castro, C. (2022). The best Android VPN apps 2025. [online] TechRadar. Available at: https://www.techradar.com/vpn/best-vpn-for-android-our-5-top-choices?form=MG0AV3 [Accessed 12 Mar. 2025].

Dutkowska-Zuk, A., Xiong, A., Hounsel, A., Morrill, A., Chetty, M. and Feamster, N. (no date) “How and Why People Use Virtual Private Networks.” Available at: https://www.usenix.org/conference/usenixsecurity22/presentation/dutkowska-zuk (Accessed: March 19, 2025).

Ehtesham, H. (2024) VPN Statistics and Trends: 4 Out of 10 Internet Users Expected to Rely on VPNs for Privacy and Security by 2024. Available at: https://www.vpnranks.com/resources/vpn-statistics-and-trends/?form=MG0AV3 (Accessed: 20 March 2025).

Fassl, M. (2024). Averting security theater : methods to investigate and integrate secure experience in a user-centered security design process. Uni-saarland.de. [online] doi:urn:nbn:de:bsz:291--ds-424767.

Gamba, J., Feal, Á., Blázquez, E., Vinuri Bandara, Abbas Razaghpanah, Tapiador, J.E. and Narseo Vallina-Rodriguez (2023). Mules and Permission Laundering in Android: Dissecting Custom Permissions in the Wild. IEEE Transactions on Dependable and Secure Computing, pp.1–18. doi:https://doi.org/10.1109/tdsc.2023.3288981.

Gentile, A. F., Macrì, D., De Rango, F., Tropea, M. and Greco, E. (2022) ‘A VPN Performances Analysis of Constrained Hardware Open-Source Infrastructure Deploy in IoT Environment’, Future Internet 2022, Vol. 14, Page 264. Multidisciplinary Digital Publishing Institute, 14(9), p. 264. doi: 10.3390/FI14090264.

Gentile, A. F., Macrì, D., Greco, E. and Fazio, P. (2024) “Overlay and Virtual Private Networks Security Performances Analysis with Open Source Infrastructure Deployment,” Future Internet. Multidisciplinary Digital Publishing Institute (MDPI), 16(8). doi: 10.3390/fi16080283.

Gillard, S., Percia David, D., Mermoud, A. and Maillart, T. (2023). Efficient collective action for tackling time-critical cybersecurity threats. *Journal of Cybersecurity*, [online] 9(1). doi:https://doi.org/10.1093/cybsec/tyad021.

Hao, X., Ma, D. and Liang, H. (2023) ‘Detection and Privacy Leakage Analysis of Third-Party Libraries in Android Apps’, Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST. Springer, Cham, 462 LNICST, pp. 569–587. doi: 10.1007/978-3-031-25538-0\_30.

Hoque, M. A., Rao, A. and Tarkoma, S. (2020) “In Situ Network and Application Performance Measurement on Android Devices and the Imperfections.” Available at: <http://arxiv.org/abs/2003.05208>.

Hoque, M. A., Rao, A. and Tarkoma, S. (2021) ‘Network and Application Performance Measurement Challenges on Android Devices’, ACM SIGMETRICS Performance Evaluation Review. ACMPUB27New York, NY, USA, 48(3), pp. 6–11. doi: 10.1145/3453953.3453955.

Hoque, M. A., Rao, A. and Tarkoma, S. (2021) “Network and Application Performance Measurement Challenges on Android Devices,” Performance Evaluation Review. Association for Computing Machinery, 48(3), pp. 6–11. doi: 10.1145/3453953.3453955.

Hussain, J. (2022) “Virtual Private Networks: Fundamentals, Security Issues and Solutions,” SSRN Electronic Journal. Elsevier BV. doi: 10.2139/SSRN.4478285.

Ikram, M. (20120). An Analysis of the Privacy and Security Risks of Android VPN Permission-enabled Apps. Proceedings of the 2016 Internet Measurement Conference. [online] doi:https://doi.org/108695283/97928158/s200\_muhammad.

K Karuna Jyothi and Reddy, B.I. (2023). CSEIT1835225 | Study on Virtual Private Network (VPN), VPN’s Protocols And Security. [online] Available at: <https://www.researchgate.net/publication/368831275_CSEIT1835225_Study_on_Virtual_Private_Network_VPN_VPN%27s_Protocols_And_Security>.

Kim, J., Kim, Y., Yegneswaran, V., Porras, P., Shin, S. and Park, T. (2023). Extended data plane architecture for in-network security services in software-defined networks. *Computers & Security*, 124, p.102976. doi:https://doi.org/10.1016/j.cose.2022.102976.

Kumar Yedla, B. (2023) ‘Master of Science in Telecommunication Systems Performance evaluation of VPN solutions in multi-region kubernetes cluster’. Available at: www.bth.se (Accessed: 20 March 2025).

Li, Y., Zhu, J. and Fu, W. (2022). Intelligent Privacy Protection of End User in Long Distance Education. *Mobile Networks and Applications*, 27(3), pp.1162–1173. doi:https://doi.org/10.1007/s11036-022-01950-6.

Liu, Z. (2022) “Application and Security Analysis of Virtual Private Network (VPN) in Network Communication,” Academic Journal of Computing & Information Science, 6, pp. 52–59. doi: 10.25236/AJCIS.2023.061108.

Locatelli, P., Perri, M., Jimenez Gutierrez, D.M., Lacava, A. and Cuomo, F. (2023). Device discovery and tracing in the Bluetooth Low Energy domain. *Computer Communications*, 202, pp.42–56. doi:https://doi.org/10.1016/j.comcom.2023.02.008.

López, A. L., Guaman, M. R., Torres, J. P. and Bautista, A. D. (2025) “Integration of Emerging Technologies with IoT for Industry 4.0: A Systematic Literature Review.” Springer, Cham, pp. 132–145. doi: 10.1007/978-3-031-84078-4\_10.

Mackey, S., Mihov, I., Nosenko, A., Vega, F. and Cheng, Y. (2020). A Performance Comparison of WireGuard and OpenVPN. Proceedings of the Tenth ACM Conference on Data and Application Security and Privacy. doi:https://doi.org/10.1145/3374664.3379532.

Nguyen, T.A., Kim, M., Lee, J., Min, D., Lee, J.-W. and Kim, D. (2022). Performability evaluation of switch-over Moving Target Defence mechanisms in a Software Defined Networking using stochastic reward nets. *Journal of Network and Computer Applications*, 199, p.103267. doi:https://doi.org/10.1016/j.jnca.2021.103267.

Ntoa, S. (2024) ‘Usability and User Experience Evaluation in Intelligent Environments: A Review and Reappraisal’, International Journal of Human-Computer Interaction. Taylor and Francis Ltd. doi: 10.1080/10447318.2024.2394724.

Okonkwo, C. (2024). Assessment of User Experience (UX) Design Trends in Mobile Applications. Journal of Technology and Systems, [online] 6(5), pp.29–41. Available at: <https://ideas.repec.org/a/bhx/ojtjts/v6y2024i5p29-41id2147.html>.

Osborne, C. (2024). The best Android VPN services of 2025: Expert tested and reviewed. [online] ZDNET. Available at: https://www.zdnet.com/article/best-android-vpn/?form=MG0AV3&form=MG0AV3 [Accessed 12 Mar. 2025].

Parmar, Y., Satish Kumar, R., Karthikeyan, V., Shukla, G. and Mishra, D. (2025) “Challenges and Solutions for Securing Cloud-Based Virtual Private Networks (VPNs),” 2025 International Conference on Automation and Computation, AUTOCOM 2025. Institute of Electrical and Electronics Engineers Inc., pp. 655–660. doi: 10.1109/AUTOCOM64127.2025.10956351.

Radchenko, V. D., Alekseenko, A., Rusnak, A. and Fomin, S. I. (2024) “Overcoming challenges in deep inspect of vpn and proxy by deep learning,” in Journal of Physics: Conference Series. Institute of Physics. doi: 10.1088/1742-6596/2701/1/012106.

Seraj, S., Siavash Khodambashi, Pavlidis, M. and Nikolaos Polatidis (2023). MVDroid: an android malicious VPN detector using neural networks. [online] doi:https://doi.org/10.1007/s00521-023-08512-1.

Shanu Sahadevan Mary (2024). Common Security Vulnerabilities in Android Apps: a Comprehensive Guide. International Journal For Multidisciplinary Research, 6(6). doi:https://doi.org/10.36948/ijfmr.2024.v06i06.32931.

Snigdha Keskar (2025). *Top VPN vulnerabilities every business must know*. [online] Scalefusion Blog | MDM, EMM, Product Updates ,Thought Leadership & SaaS. Available at: https://blog.scalefusion.com/top-vpn-vulnerabilities-every-business-must-know/ [Accessed 18 May 2025].

Stavroula Ntoa (2024). Usability and User Experience Evaluation in Intelligent Environments: A Review and Reappraisal. International Journal of Human-Computer Interaction, pp.1–30. doi:https://doi.org/10.1080/10447318.2024.2394724.

Stobing, C. (2024). The Best VPNs for Android in 2025. [online] PCMag UK. Available at: https://uk.pcmag.com/vpn/85163/the-best-android-vpns [Accessed 12 Mar. 2025].

Team, T.R. (2023). Avast Q3/2023 Threat Report - Avast Threat Labs. [online] Avast Threat Labs. Available at: https://decoded.avast.io/threatresearch/avast-q3-2023-threat-report/?form=MG0AV3 [Accessed 17 Feb. 2025].

Trisiana Oktavia, S., Febriyan Priambodo, D., Trianto, N., Purwoko, R., Keamanan Siber, R., Siber dan Sandi Negara, P. and Raya Usa, J. H. (2023) ‘COMPARATIVE QUALITY OF SERVICE ANALYSIS OF VPN PROTOCOLS ON IPV6’, 12. doi: 10.23887/janapati.v12i3.69264.

Wahanani, H.E., Idhom, M. and Mandyartha, E.P. (2021). Analysis of Streaming Video on VPN Networks Between OpenVPN and L2TP/IPSec. 2021 IEEE 7th Information Technology International Seminar (ITIS). doi:https://doi.org/10.1109/itis53497.2021.9791504.

Wang, Y., Zhang, X. and Hu, H. (2023). Continuous User Authentication on Multiple Smart Devices. Information, [online] 14(5), p.274. doi:https://doi.org/10.3390/info14050274.

Williams, S. (2020). *40% of free VPN apps found to leak data*. [online] SecurityBrief New Zealand. Available at: https://securitybrief.co.nz/story/40-of-free-vpn-apps-found-to-leak-data [Accessed 18 May 2025].

Yang, D., Li, Z., Jiang, H., Tyson, G., Li, H., Xie, G. and Zeng, Y. (2022). A deep dive into DNS behavior and query failures. *Computer Networks*, [online] 214, p.109131. doi:https://doi.org/10.1016/j.comnet.2022.109131.

Zhang, Z. and Constandinou, T. G. (2021) ‘A robust and automated algorithm that uses single-channel spike sorting to label multi-channel neuropixels data’, International IEEE/EMBS Conference on Neural Engineering, NER. IEEE Computer Society, 2021-May, pp. 783–787. doi: 10.1109/NER49283.2021.9441234.

Zhou, Z. and Huang, T. (2021) “Open VPN Application under Campus Network,” in Journal of Physics: Conference Series. IOP Publishing Ltd. doi: 10.1088/1742-6596/1865/4/042014