WiPw: Using Singular Value Decomposition to Identify Optimal WiFi Spots

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***Abstract*— Singular Value Decomposition (SVD) is a powerful mathematical technique widely applied in various fields, including network optimization and signal analysis. By extracting dominant patterns from complex data, SVD provides a robust framework for understanding and improving connectivity in wireless networks. WiFi networks, in particular, often face challenges such as signal interference, user congestion, and uneven distribution of access points, necessitating innovative solutions for optimization.**

This study leverages SVD to address these challenges by analyzing WiFi signal strength data and identifying the most optimal connectivity spots. In this study, the solution was designed as a mobile app called WiPw. From the WiPw system, using native mobile APIs itself the signal data is collected. Then the signal data collected will proceed through SVD to reduce pinpoint signal patterns. This data is then visualized as an overlay circle radius that shows the strong, moderate, or weak area on the map that shows the user's location. WiPw was designed in mobile app form because the user's portability should be prioritized. From this solution, hopefully, WiPw can help the user especially students find the best spot of the WiFi they are connected with. So that the process of studying, doing assignments, or anything that can be done with WiFi will be run efficiently.

***Keywords*—WiPw, Singular Value Decomposition, WiFi optimization, network analysis, mobile application.**

I. Introduction

Every aspect of our life now can't be separated from technology, and so the advancing of technology itself. From the goods we use at home to school, mainly it was affected by the internet. It connects every single person on earth so that everyone can access information more efficiently and accessible. In every world without exception, Indonesia, this progress is evident in how people rely heavily on the internet. As a student, I notice this phenomenon too, I agree that internet has become something important that humans can't be separated from. Specifically for me, activities like studying, working on projects, or staying connected with friends and family very need a internet presence.

The popular wireless networking technology that allows the user to access the internet is WiFi. For students in Indonesia including me, it is necessary to have access to reliable WiFi. When it comes to studying, we need to submit assignments, fill the presence list, or search references, and of course, the WiFi supports everything. The presence of WiFi is especially crucial because so much of what we do now depends on the internet. The internet is not used just for the action I mentioned before, it's also about accelerating and making the learning process become easier. When comes to this, it really matters to me and others as students to ensure a stable connection to the WiFi.

Most of students in Indonesia take WiFi as a big deal. Without exception, here at ITB, where I study, the students are very active, whether it's in academic tasks or nonacademic activities. We use WiFi all the time for big group projects, accessing the academic information system, and even for simple things like finding references for our social media content. Having strong WiFi in key spots on campus makes a huge difference. But figuring out where is the place that has the strongest connection so that we don't have to worry about being disconnected isn't simple. Sometimes, the ITB Hotspot (ITB WiFi name) signal is weak in areas where we need it the most, and improving this requires more than just guessing where the routers should go.

Aligning with my studies in ITB, my major is Computer Science (Teknik Informatika), and Linear Algebra and Geometry is one of the subjects in my major. One of the subject's topics is Singular Value Decomposition (SVD). While studying the SVD, it came to my mind that this method might be useful to most of the students in Indonesia. Although it may seem complex at first, I optimistically developed this method. SVD is a method that can be implemented to analyze data, in this case, SVD is used to uncover patterns and choose optimal locations for using WiFi that we connected with. My curiosity and willpower have pushed me to investigate how SVD can offer a better option for everyone including students, so they can do their activity using WiFi effectively.

SVD can break down intricate matrices into their fundamental components, which include left singular vectors, singular values, and right singular vectors. These components help in recognizing connections and trends in the data that could be difficult to detect otherwise. SVD, as introduced in ITB's IF2123 Linear Algebra and Geometry course, serves various purposes, including data compression, image processing, and machine learning. It serves as an ideal method for addressing WiFi signal distribution issues because it can simplify large datasets while preserving crucial details.

SVD was used in this study to examine WiFi signal strength data that was gathered from multiple sites, including the ITB campus. We find important regions with the potential for strong signals and effective coverage by breaking down the data matrix. Regardless of where they work or study on campus, students can take advantage of dependable internet connectivity thanks to this data-driven approach to WiFi location optimization.

II. BASIC THEORY

A. Understanding WiFi and Its Importance

The commonly utilized technology referred to as WiFi, or Wireless Fidelity, allows devices to connect wirelessly to the internet over a limited distance. It relies on IEEE 802.11 standards and operates using radio frequency waves. To facilitate seamless internet connectivity, WiFi networks are commonly set up in offices, public spaces, and learning establishments. WiFi is crucial for students as it enables a range of academic and personal tasks, including accessing online libraries, conducting research, engaging in virtual classes, and collaborating on projects. Several variables influence the strength and quality of a WiFi signal, including:

- Placement of Access Points
  The careful positioning of WiFi access points (APs) is crucial for achieving strong and effective network coverage. In every wireless network, access points serve as links that connect wireless devices to the wired network framework. Improperly placed access points can result in overlapping coverage regions, signal disruption, or total signal blackouts. For instance, positioning an access point too near walls, ceilings, or other physical barriers can greatly diminish its performance, since radio waves are absorbed or reflected by these materials. Conversely, optimal placement requires thoughtful evaluation of the area’s layout, user density, and the network’s intended purpose. In high-demand settings like university campuses, a thorough site survey is frequently performed to determine the optimal locations for access points to guarantee consistent coverage and excellent data throughput.

- Interference
  Interference stands out as a prevalent issue encountered by WiFi networks and can significantly affect signal quality and user experience. Interference can arise from multiple sources, including other electronic gadgets like microwaves, cordless phones, and Bluetooth devices, which function within the same 2.4 GHz or 5 GHz frequency ranges as WiFi. Moreover, physical obstacles such as concrete barriers, metallic items, or even bulky furniture can impede or obstruct signals, resulting in reduced network efficiency. In highly populated regions, like urban university campuses, interference from overlapping WiFi networks (referred to as co-channel or adjacent-channel interference) poses a major issue. To address these problems, contemporary networks frequently utilize sophisticated methods such as adaptive channel selection and dual-band routers to distribute traffic between 2.4 GHz and 5 GHz bands, lessening the effects of interference.

- Network Configuration
  The setup of a WiFi network influences how well it can meet the needs of its users. Essential elements consist of bandwidth distribution, access point capability, and the execution of Quality of Service (QoS) standards. Bandwidth distribution guarantees that enough resources are accessible for high-priority applications, like video conferencing or online learning platforms, without saturating the network. Access point capacity indicates the number of devices that one AP can manage at the same time; surpassing this limit may result in reduced speeds and increased disconnections. Furthermore, QoS protocols give priority to traffic to ensure that essential applications obtain the required bandwidth and latency standards. For instance, in a scholarly environment, prioritizing virtual classrooms and research tools above leisure streaming or gaming is vital for upholding network integrity. Effective network setup demands continuous supervision and modifications to respond to evolving user requirements and technological progress.

Although these elements greatly influence WiFi performance, incorporating additional technologies such as LTE can help mitigate some of these constraints. The combination of WiFi and LTE technologies provides notable enhancements in network coverage and capacity. WiFi is ideal for delivering high-speed internet in specific locations like campuses or offices, yet it frequently has limitations in both range and uplink capability. LTE enhances WiFi by providing wider coverage with the help of macrocells and metrocells, efficiently addressing coverage gaps and improving uplink performance. This combined method guarantees a smooth and effective network experience for users across different settings. As illustrated in Fig. 1, LTE has the ability to enhance WiFi coverage and overcome its shortcomings, forming a strong and adaptable communication network that fulfills the requirements.

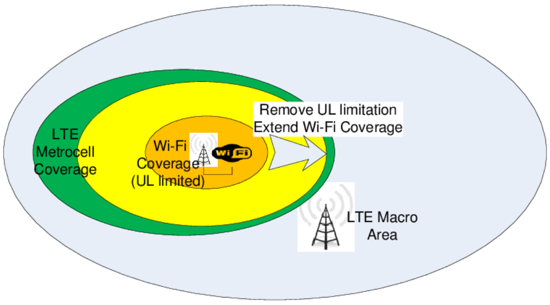

Fig 1. WiFi and LTE integration to enhance coverage and capacity.

B. Singular Value Decomposition (SVD)

Singular Value Decomposition (SVD) is a commonly utilized mathematical method in linear algebra that enables the breakdown of a matrix into three more manageable matrices. It serves as a crucial instrument in multiple applications, such as data analysis, image processing, noise reduction, and optimization tasks. SVD processess an input matrix A of dimension m × n and factors it into three components: U, Σ, and V^T. In mathematical terms, this breakdown is shown as

$$A = U\Sigma V^T \tag{1}$$

where U is an m × m orthogonal matrix representing the column space of A, Σ is an m × n diagonal matrix containing the singular values of A in descending order, and V^T is an n × n orthogonal matrix representing the row space of A. The singular values $\sigma_1, \sigma_2, \ldots, \sigma_n$ in Σ represent the importance of each component in the original matrix, where r = rank(A) and $\sigma_1 \geq \sigma_2 \geq \ldots \geq \sigma_n > 0$.

A fundamental characteristic of SVD is its capacity to recreate the original matrix through the equation

$$A = \sum_{i=1}^{r} \sigma_i u_i v_i^T \tag{2}$$

where u_i and v_i are the i-th columns of U and V, respectively, and σ_i are the singular values. This representation highlights the structure of A as a weighted sum of rank-1 matrices, as described in (2). By retaining only the largest k singular values, SVD can approximate A as a rank-k matrix,

$$A_k = \sum_{i=1}^{k} \sigma_i u_i v_i^T \tag{3}$$

This estimation, presented in (3), is essential for reducing dimensions, compressing data, and minimizing noise, as it retains the most important information while eliminating less pertinent details. Another key feature of SVD is its capacity to quantify the energy of the matrix via its singular values. The overall energy of the matrix A is defined by

$$\|A\|_F^2 = \sum_{i=1}^{r} \sigma_i^2 \tag{4}$$

where $\|A\|_F^2$ denotes the Frobenius norm of the matrix. Retaining the top k singular values ensures that most of the energy in the original matrix is preserved, making SVD highly effective for identifying dominant patterns in data, as shown in (4).

From the study that I have learned so far in Linear Algebra and Geometry, I acknowledge that SVD serves many different purposes. Such as data compression, noise reduction, and many more. In data compression, it is employed to reduce the storage capacity of images and videos by estimating the original data using fewer singular values, as demonstrated in (3). In noise reduction, reduced singular values, generally linked to noise, are removed, resulting in a more polished dataset. In machine learning, SVD acts as the basis for principal component analysis (PCA), a commonly employed technique for dimensionality reduction. SVD is used in recommendation systems since it uncovers hidden variables in user-item interaction matrices to generate personalized suggestions.

In the area of WiFi improvement, SVD provides an organized approach for analyzing signal strength trends. By representing WiFi signal strength as a matrix, SVD can decompose this data to uncover important trends, such as areas with strong signals and regions that require additional access points. By deconstructing the data into its core elements, the process of deciding where to place hotspots can become more streamlined and accurate, ensuring optimal coverage and effectiveness.

Visualization plays a crucial role in comprehending SVD. A diagram of matrix decomposition can show how A is split into U, Σ, and V^T (1). A bar graph showing the singular values of Σ highlights the relative importance of each component (4). Furthermore, a demonstration of low-rank approximation with A_k can effectively show how SVD simplifies a complex matrix while retaining its critical features (3).

SVD's capability to lower dimensions, eliminate noise, and identify key patterns makes it an essential element in data processing and improvement. Its use in evaluating WiFi spots demonstrates its capacity to address practical issues, laying the groundwork for reliable and efficient connectivity solutions.

III. ANALYSIS AND DESIGN

A. ITB Hotspot at ITB Ganesha Campus Analysis

The placement of ITB Hotspot access points at the ITB Ganesha campus is meticulously organized, featuring about 45 strategically located hotspots distributed throughout the campus. These hotspots are situated in key locations such as lecture halls, research labs, the library, and the campus hub, guaranteeing that students, faculty, and staff have dependable internet access. The hotspots are strategically located along key routes and communal areas, such as the basketball court and triangle field, ensuring connectivity is attainable even in places like open spaces, as shown in Fig. 2.

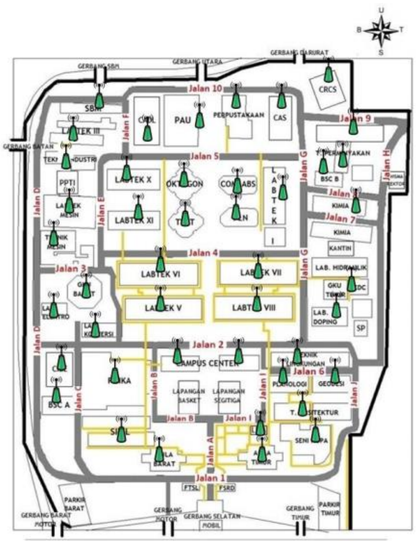

Fig 2. Map of ITB Hotspot Location at ITB Ganesha Campus

Nevertheless, even with the broad coverage, it is essential for students to pinpoint the best locations to guarantee a stable and dependable connection. Elements like distance to an access point and the total number of users connected can greatly influence the quality of the WiFi signal. Enclosed areas like labtek facilities (classes) and the library usually provide robust connectivity, making them perfect for academic activities like studying or performing research. For group meetings or activities, hotspots in the library or campus center offer a convenient and dependable choice. Outdoor spaces such as basketball courts are ideal for informal use or for taking breaks between classes.

To enhance connectivity, students ought to think about steering clear of congested spots during busy times and selecting places near access points for a better signal. Examining the distribution of WiFi signal strength through Singular Value Decomposition (SVD) offers a data-oriented method to enhance hotspot utilization. Applying SVD to the signal strength matrix allows for the identification of key patterns and ideal locations, which facilitates better hotspot placement or suggestions for enhancements. Grasping the distribution and utilizing analytical techniques like SVD allows students to make more informed choices regarding their work or study locations, improving their productivity and online experience despite any connectivity problems.

B. Design Plan of WiPw Mobile Application

WiPw is a mobile app created to assist users in finding the optimal WiFi connection locations on the ITB Ganesha campus. The term “WiPw” merges “Wi” for WiFi and “Pw,” a well-known Indonesian slang short form for Posisi Wuenak (comfortable position). The application intends to offer students and faculty an effortless way to find the best WiFi locations for both educational and leisure purposes by utilizing real-time data gathering and sophisticated analysis through Singular Value Decomposition (SVD).

The main objective of WiPw is to examine WiFi signal distributions and suggest places with the best and most dependable connectivity. It achieves this through automated data collection, rigorous data processing using SVD, and intuitive visualization of results. WiPw serves as a practical tool for campus users, enabling them to make informed decisions about where to work, study, or collaborate online. I personally designed the system design and workflow plan with the knowledge I got from basic theory that mentioned before:

- Data Collection

WiPw collects WiFi signal strength data automatically using the mobile device’s built-in WiFi module. WiPw using NetSpot, a WiFi analysis tool, signal strength measurements were taken across multiple predefined locations within and around. NetSpot scans each access point and records the Received Signal Strength Indicator (RSSI) values in decibels (dBm), with higher values (closer to 0) indicating stronger connectivity.

For example, at Labtek V, WiPw performs a series of scans at predefined locations such as classrooms, hallways, and study areas. Each scan identifies available access points and their respective signal strengths, generating a matrix of data for analysis. A sample 5×5 matrix representing five locations and five access points might look like Fig. 3.

$$A = \begin{bmatrix} -50 & -55 & -60 & -65 & -70 \\ -45 & -50 & -55 & -60 & -65 \\ -60 & -65 & -50 & -45 & -55 \\ -70 & -60 & -65 & -50 & -60 \\ -65 & -55 & -60 & -70 & -50 \end{bmatrix}$$

Fig 3. Matrix Represent of Location and Access Points

And to ensure accuracy, WiPw averages multiple scans at each location, accounting for variations due to interference or fluctuating network traffic. Users can also manually input data or upload pre-collected data in CSV format.

With using SVD, shown in (1), WiPw focuses on the dominant patterns by retaining only the top k singular values, reducing noise while preserving critical information, computed as,

$$A_k = U[:, 1:k] \cdot \Sigma[:k, :k] \cdot V[:k, :]^T \tag{5}$$

so that, WiPw calculates location scores to rank connectivity strength at each location, shown in (5) U will be calculated using the first until k columns. And Σ shown in (5) would be the diagonal submatrix with biggest k.

For, example if Σ = diag(180, 50), and

$$U[:, 1:2] = \begin{bmatrix} 0.5 & 0.3 \\ 0.4 & 0.6 \\ 0.2 & 0.1 \\ 0.6 & 0.4 \\ 0.3 & 0.2 \end{bmatrix}$$

the calculation will be done by this equation,

$$\begin{bmatrix} 0.5 & 0.3 \\ 0.4 & 0.6 \\ 0.2 & 0.1 \\ 0.6 & 0.4 \\ 0.3 & 0.2 \end{bmatrix} \cdot \begin{bmatrix} 180 & 0 \\ 0 & 50 \end{bmatrix} = \begin{bmatrix} 90 & 15 \\ 72 & 30 \\ 36 & 5 \\ 108 & 20 \\ 54 & 10 \end{bmatrix} \tag{6}$$

remember that every i line for the matrix is for the same location, so we can sum the row and turn the matrix into this solution,

$$\begin{bmatrix} 105 \\ 102 \\ 41 \\ 128 \\ 64 \end{bmatrix} \tag{7}$$

from the solution shown in (7) we can conclude that the location 1 has 105 score, location 2 has 102 score, location 3 has 41 score, location 4 has 128 score, and location 5 has 64 score. So the optimal spot that near an access point with strong coverage are location 4.

From the calculation done, it will be delivered to the WiPw. So next, the building on the core functionality of data collection and SVD-based analysis, WiPw further enhances user experience through intuitive and practical visualizations. The application provides users with a seamless interface to visualize WiFi signal strength distribution and receive actionable recommendations on the best connectivity spots. These visualizations are designed to guide users effectively, allowing them to locate the optimal positions for reliable internet access across the Labtek V at ITB Ganesha campus.

Fig 4. WiPw Welcoming Screen

The welcome screen, illustrated in Fig. 4, serves as the entry point for the application. It introduces the purpose of WiPw with a user-friendly interface that highlights the app's role in identifying the best WiFi spots. The central design element is a WiFi icon, dynamically reflecting the current strength of the user's connection. This screen sets the stage for users to engage with the app's primary features. To enhance the user experience, the welcome screen includes a fade-out transition after 5 seconds, seamlessly guiding users to the heatmap view, illustrated in Fig. 5, for a comprehensive visualization of WiFi signal distribution across the campus.

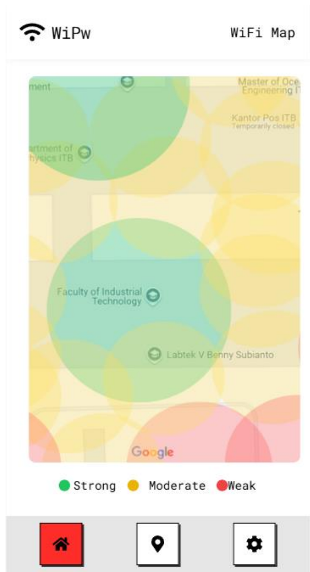

Fig 5. WiPw Heatmap of Connectivity

A critical component of WiPw is the heatmap feature shown in Fig. 5, which provides a comprehensive visualization of WiFi signal coverage across campus. The heatmap employs a color-coded system to illustrate signal intensity. Green signifies robust connectivity, perfect for work or study. Yellow indicates moderate connectivity, appropriate for simple browsing or leisurely use. Red indicates areas of weak connectivity, suggesting inadequate performance or congested access points. This heatmap is superimposed on the campus map, providing a clear representation of signal distribution and allowing users to navigate towards areas with high connectivity efficiently.

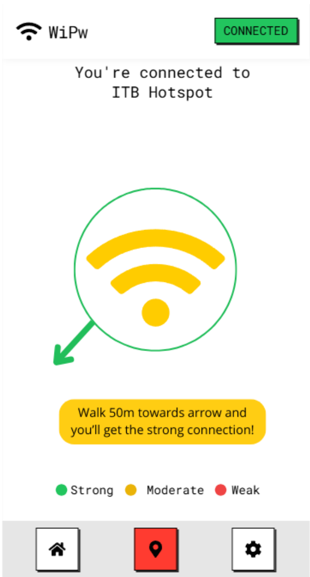

Fig 6. WiPw Best WiFi Spot Finder

Another key aspect of WiPw is the optimal WiFi hotspot locator, as shown in Fig. 6. This display actively guides users to the best WiFi spot utilizing live data. An uncomplicated directional arrow directs the user, accompanied by a note like “Proceed 50m in the arrow's direction, and you'll achieve a strong connection!” This functionality is especially beneficial for students transitioning between places, guaranteeing they can swiftly locate an area with dependable internet connectivity for their educational or personal endeavors.

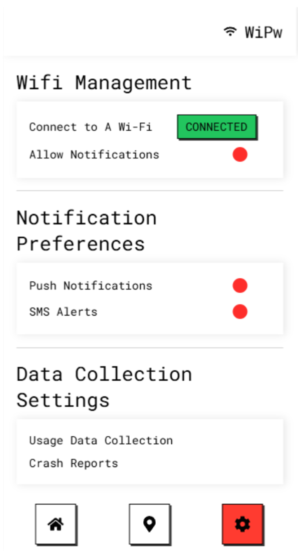

Fig 7. WiPw Settings

WiPw features a settings screen, depicted in Fig. 7, enabling users to personalize their WiPw experience. Important settings consist of WiFi Management, allowing the user to select available WiFi networks and activate notifications for variations in signal strength. Notification Settings, allowing users to switch between push notifications or SMS messages for instant updates. Data Gathering Preferences, enabling users to control data sharing choices, including usage data collection and failure reporting.

WiPw provides a comprehensive WiFi optimization solution for campuses by integrating these features. Through the integration of automatic data collection, advanced analysis, and user-focused presentation, students and staff can optimize their connectivity experience. WiPw is a vital resource for handling the digital needs of academic life, as every component was designed with the user at the forefront. WiPw assists its users in making optimal choices regarding their connectivity options by connecting the technical intricacies with user-friendliness through its intuitive interface and strong analytical features.

IV. Conclusion

This study showcases the creation of how SVD can be implemented to find the best WiFi spots. SVD eventually can be utiziled to find where is the strongest WiFi signal so that the user can enhance WiFi connectivity they use. Through the examination of WiFi signal strength information, SVD determines key trends and then process it into reduced information so the system can detect and also prioritizes the best connection spots. In this paper I personally designed the WiPw implementation plan incorporated this analytical method into a mobile app to prioritize user portability. So the users can view real-time visual data of how strong the connection of the WiFi the user connected with, and practical suggestions for finding optimal WiFi spots.

The plan of WiPw implementation designed to used automated data gathering from the Netspot, with also give user-friendly visual representations, and give the user recommendation to move or walk for some distance to know where is the best spot to use the WiFi they’re connected with. Hopefully this WiPw design approach not only meets the urgent requirements of ITB students and staff but also for wider contexts, like public areas, or even office to work.

I personally hope that in the future, the design of WiPw may focus on broadening its capabilities to encompass crowdsourced data gathering, employing machine learning for real-time analysis, and incorporating IoT devices for improved connectivity. WiPw can foster advancements in optimizing student’s needs or everyone in this earth to enjoy their best experience on using the WiFi they connected with.

V. APPENDIX

Youtube Video of WiPw :
https://www.youtube.com/watch?v=7JNE3Ivu0WE

VI. ACKNOWLEDGMENT

I would like to express my gratitude to Universe and it circumstances which have enabled me to complete this paper for IF2123 Aljabar Linear dan Geometri. I personally would also like to state my biggest appreciation to the IF2123 lecturer, Dr. Ir. Rinaldi Munir, M.T., for teaching the course material clearly and thoroughly, making it easier for me to complete this paper without significant difficulties. Also to all of the IRK assistant who helped the process of studying Linear Algebra and Geometry. My appreciation also goes to my mom, my sister, my friends, and who ever that had provided valuable feedback and support during the preparation of this paper.

I hope that the theories and methods I have discussed in this paper can be developed and implemented in real-world applications and contribute to helping many people in the future. Because I know for sure that every students would search for “PW” or best position that they can use their WiFi with.

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PERNYATAAN

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Bandung, 31 Desember 2024

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