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STRATEGIC NETWORK PLANNING FOR OPTIMIZING DIGITAL TRANSFORMATION IN THE COAL MINING INDUSTRY

Rizqi Pratama, Angga Margi S, Arisal Farzan
PT. Putra Perkasa Abadi, Indonesia
*e-mail: rizqiprtmaa@gmail.com angga.margi@ppa.co.id arisal.farzan@ppa.co.id

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ABSTRACT
The coal mining industry is one of the most important sectors in Indonesia's economy, and it has become a vital part of the national economy. As a result, the mining industry has become more and more digital. The application of the overlay method in this study aims to improve operational efficiency and work safety in the coal mine of PT Putra Perkasa Abadi (PPA) in Indonesia. The overlay method combines WiFi and LTE networks in the mining area, which improves network performance in terms of throughput, latency, packet loss, and signal coverage. The implementation of Strategic Network Planning to Optimize Digital Transformation in the Coal Mining Industry has proven to be effective in improving the quality of networks that support digital transformation in mining areas. The solution has the potential to be applied to other industrial sectors with similar operational challenges, optimizing the use of network technologies to support sustainability and productivity. Overall, this study makes a significant contribution to designing and implementing network systems that can support operational efficiency, improve occupational safety, and offer sustainable and adaptive solutions in the industry, ultimately supporting the digitalization and transformation of the industry.

INTRODUCTION

Digital transformation has become a key foundation of the industrial revolution 4.0, creating strategic opportunities to improve efficiency, productivity, and sustainability across various industrial sectors. The mineral and mineral sector (minerals and coal), which has a vital role in supporting the national economy, is required to adopt digital technology to optimize the added value of its products and strengthen global competitiveness (PwC, 2023; Westerman et al., 2015). Technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics enable process automation, more accurate data analysis, and seamless communication between humans and machines, thereby supporting more effective and innovative operations (Kagermann et al., 2013).

However, the implementation of digital transformation in the mineral and mineral sector is faced with challenges that are not simple, especially related to the limitations of telecommunication network infrastructure in the 3T (frontier, outermost, disadvantaged) areas, where most of the mines are located. Available network infrastructure, such as wireless access points and 4G networks, often face limited area coverage, signal interference interference, and changing geographical conditions, thereby reducing the effectiveness of technology-based communication and operational stability (Cisco Systems, 2023). This slows down the optimization of digital technologies required to support advanced devices, such as autonomous vehicles, real-time monitoring systems, and IoT-based process integration, which are a critical part of industrial transformation.

Careful network planning plays a crucial role in ensuring smooth coordination between units in the organization and improving overall operational efficiency. Optimal network design allows for faster and more accurate information flow, which in turn contributes to improved company performance and productivity (Javaid et al., 2021, 2023; Mercan et al., 2021). In the era of digital transformation, network planning not only focuses on the technical aspects of infrastructure, but also on achieving the company's strategic goals, including improving operational efficiency, data security, and meeting higher operational standards (Anthony Jnr et al., 2021; Ghosh et al., 2022; Warner & Wäger, 2019). A carefully designed network also supports the integration of various advanced technologies, such as real-time monitoring, machine automation, and data-driven production management, which require fast data transmission with low latency (Wan et al., 2021; Wu et al., 2022; Yang et al., 2020).

On the other hand, wireless network architectures, specifically Wireless Local Area Networks (WLANs), play a crucial role in supporting wireless communications in the industrial and mining sectors. WLAN consists of various components such as Access Points (APs) and interconnected user devices, which work together to provide stable and reliable connectivity (Verma et al., 2024). This WLAN architecture allows for efficient communication within limited areas, such as for machine monitoring or operational surveillance at the local level (Hajar et al., 2021). Meanwhile, for a wider range of applications that require high mobility, Long-Term Evolution (LTE) technology is a very effective solution. LTE provides high quality of service (QoS), low latency, and fast data transfer speeds, which are indispensable to support real-time applications such as machine monitoring and automation (Singh et al., 2021; Tuan et al., 2020).

The combination of these two technologies, through the overlay method, allows for the implementation of optimal solutions in supporting efficient and reliable wireless communication. The overlay method allows WiFi networks to support local applications such as machine monitoring and operational surveillance in confined areas, while LTE provides connectivity for larger areas with faster real-time data transmission (Imran et al., 2024). The integration of these two technologies provides flexibility in building scalable infrastructure, which can support Internet of Things (IoT) and big data analytics applications, which are increasingly important for modern mining operations (Aziz et al., 2020). By leveraging overlay technology, companies can optimize the use of existing infrastructure without the need to make major changes, which in turn reduces costs and makes it easier to implement new technologies (Aithal, 2023; Behrendt et al., 2021).

In the industrial sector, especially in coal mines that have diverse geographical conditions, proper network mapping and management is essential to ensure smooth communication and successful implementation of digital technology. With the growing need for IoT-based applications, which require stable connectivity, high data transfer speeds, and low latency, proper network planning is a must. Research by Zaidi et al. (2020) shows that LTE has great potential to handle complex data traffic and support applications that require high mobility in a wide area. Network mapping using Point-to-Point (PTP) and Point-to-MultiPoint (PTMP) approaches has also proven to be effective in connecting various points in a large area efficiently and reliably, in accordance with operational needs in coal mines (Vujicic et al., 2024).

Through network design that integrates these two technologies, mining companies can accelerate the adoption of digital technologies such as automation, real-time monitoring, and data-driven prediction systems that are critical to optimizing worker productivity and safety (Ediriweera & Wiewiora, 2021; Onifade et al., 2024). This accurate network mapping also allows for long-term operational cost savings, while ensuring that data can be transferred quickly and securely between devices and major data centers, both in congested mining areas and in remote locations.

With the implementation of an integrated network strategy, mining companies can face diverse operational challenges, while supporting their digital transformation vision. This approach has the potential to increase productivity, reduce the risk of work accidents, and improve overall operational efficiency, which contributes to the company's competitiveness in an increasingly connected and technology-based global mining industry.

At the mine site of PT Putra Perkasa Abadi (PPA) Adaro Indonesia Jobsite, the challenge seems real. The current communication network uses a combination of wireless access points and 4G networks to support operational needs. However, limited coverage, high operational costs, and signal interference from many wireless devices in the mine area are often obstacles. This problem has an impact on the quality of data communication, which is crucial for modern mine operations, which rely on real-time data processing and digital-based monitoring.

As the population of advanced machines and workers in mining areas increases, the need for reliable networks is becoming increasingly urgent to support large data shipments and support digital technology to the fullest. Without adequate network infrastructure, digital transformation goals, such as operational efficiency, occupational safety, and cost savings, are difficult to achieve optimally.

As a solution, this study recommends network remapping using the latest approach that integrates wifi and 4G technology synergistically. With this approach, companies can improve network stability, expand area coverage, and reduce signal interference. This network optimization not only supports the application of more complex digital technologies, such as AI-based systems and big data analytics, but also enables cost efficiency, reduced occupational safety risks, and significant productivity improvements. This effort also supports the achievement of sustainability and corporate social responsibility (ESG) standards, which are now a priority in the global mining industry. Companies such as PT Antareja Mahada Makmur, for example, have shown the success of digitalization by collaborating with information technology providers to improve operational efficiency across their work areas. This step reflects the importance of digital transformation as a key strategy to create business sustainability that is adaptive to the challenges of the industrial revolution 4.0.

This research, with a focus on network development at PT PPA Jobsite Adaro Indonesia's mines, aims to provide strategic recommendations to overcome communication infrastructure constraints in the mining area. It is hoped that the results of this research can support companies in optimizing the implementation of digital technology, increasing operational efficiency, reducing the risk of work accidents, and strengthening the contribution of the mineral and mineral sector to the national economy in a sustainable manner.

METHODS

The application of the overlay method in this study aims to improve operational efficiency and work safety in the coal mine of PT Putra Perkasa Abadi (PPA). This overlay method allows the construction of virtual networks on top of existing physical infrastructure, integrating WiFi connectivity for local work areas and LTE for long-distance communication. Thus, this method creates a network system that supports a wide range of applications, such as real-time monitoring, automation, and more efficient data management, which is crucial in supporting complex and dynamic mine operations.

Overlays enable stable and effective communication between Internet of Things (IoT) devices, automated machines, and control centers. Through a real-time monitoring system applied with the overlay method, operational efficiency can be improved by ensuring that the machine operates optimally. This will reduce unplanned downtime and enable the implementation of predictive care based on the operational data collected. This application ultimately supports more consistent production, reduces operational costs, and minimizes the risk of production losses due to undetected equipment damage.

In addition, in terms of safety, the overlay method strongly supports the implementation of big data-based technology to monitor the environmental conditions of the mine continuously. Data obtained from sensors installed at mine sites—such as detection of hazardous gases, soil stability, and extreme weather conditions—can be analyzed in real-time to provide early warning of potential hazards. By using overlay networks, connected autonomous vehicles can minimize workers' exposure to hazardous areas, which in turn reduces the potential risk of accidents.

This overlay system is designed to ensure that safety-related critical data has the highest priority in its transmission. This allows for faster, data-driven decision-making in emergency situations. In addition, the network redundancy that exists in the overlay system ensures operational continuity, even if there is a disruption to any of the underlying physical infrastructure elements. Thus, the application of the overlay method creates a network system that not only supports increased productivity, but also contributes directly to worker safety, making it a highly relevant and high-value solution to meet the needs of the increasingly digital coal mining industry.

This research involves several main steps in the application of the overlay method, which include:

1) Mapping of Existing Network Infrastructure: At this stage, a survey was carried out to identify the availability of WiFi and LTE networks in the mining area. This mapping includes an analysis of signal strength, area coverage, and existing network data capacity. It is important to understand the potential and limitations of the available infrastructure.
2) Overlay Design: In the design phase, a virtual layer was created that integrated the WiFi network for local communications—for example, for machine monitoring, security CCTV, and attendance systems—with the LTE network to support long-distance connectivity and real-time communication, such as machine management systems (FMS) and device monitoring.

3) Network Simulation and Optimization: Simulations were conducted to test the performance of the designed overlay network. The parameters tested include data speed, latency, and network scalability. The optimization process is focused on selecting the most efficient data path and in accordance with the operational needs of the mine.
4) Implementation and Evaluation: At the implementation stage, the overlay system was applied directly to the operational area of PT PPA's mine in Adaro Wara. An evaluation was conducted to ensure that the overlay network could support operational needs that included real-time machine monitoring, resource management, and communication between automation devices. This evaluation also aims to identify and address potential issues that can hinder system performance.

RESULTS

Architecture and network coverage in the mine area

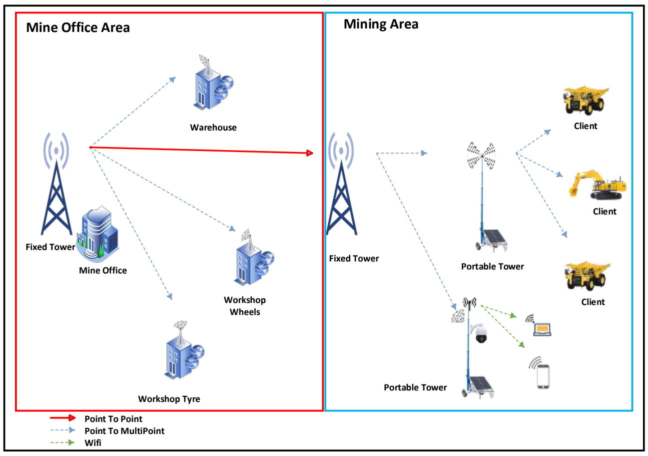

Figure 1. WLAN Network Architecture in the Mining Industry

The implementation of the WLAN network architecture with Point-to-Point (PtP) and Point-to-Multipoint (PtMP) topologies using fixed towers and mobile towers in the mine area has resulted in various advantages in supporting the efficiency and safety of PT Putra Perkasa Abadi's mine operations. In the PtP topology, fixed towers show superior performance with throughput reaching 300 Mbps, low latency of around 20 ms, and high network stability at a radius of up to 5 km. This is ideal for exclusive connections between control centers and specific machines, such as real-time data transmission for operational monitoring. Meanwhile, in the PtMP topology, fixed towers are able to cover a radius of up to 10 km with an average speed of 200 Mbps and latency of 30–40 ms, although performance decreases as the number of connected devices increases.

Mobile towers provide high flexibility, especially to support dynamic mining areas or temporary locations. In the PtP topology, the mobile tower produces a throughput of 250 Mbps with a latency of 25 ms at a maximum radius of 3 km, suitable for heavy equipment that changes locations. Meanwhile, in PtMP, mobile towers can cover a radius of up to 5 km with an average bandwidth of 150 Mbps, although the stability is lower than fixed towers. The combination of fixed and mobile towers allows for network optimization in the mine area, where fixed towers are suitable for static operations with high bandwidth requirements, while mobile towers are more effective to support mobility in changing mine sites. The implementation of these two architectures supports real-time communication, improves data-driven decision-making, and ensures occupational safety through better operational monitoring. This strategic combination is a superior solution in meeting the needs of complex and dynamic mining networks.

There are other factors that can affect performance:

1. Environmental Disturbances: The presence of physical barriers in the mine area can reduce network coverage and throughput.
2. Signal Interference: Additional devices in the same area or the use of similar frequencies may cause interference.
3. Extreme Weather: Conditions such as dust storms or heavy rain can degrade signal quality, especially for mobile towers.

4. Excess Capacity: If the number of connected devices exceeds the recommendation, network performance may degrade, especially for PtMP.

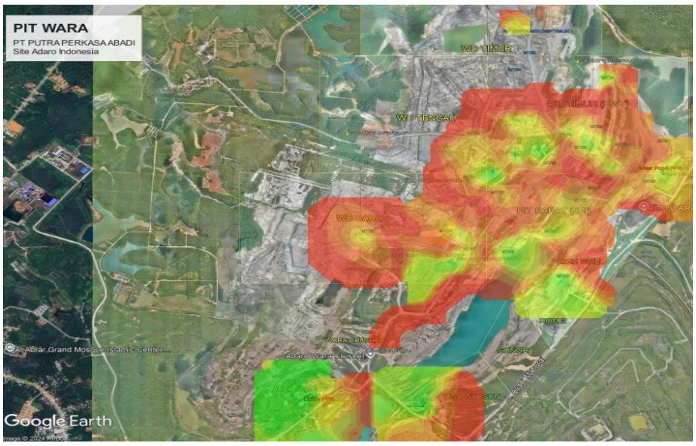

Figure 2. Wifi Network Coverage from Ekahau Site Survey (Maps: Google Earth 2024)

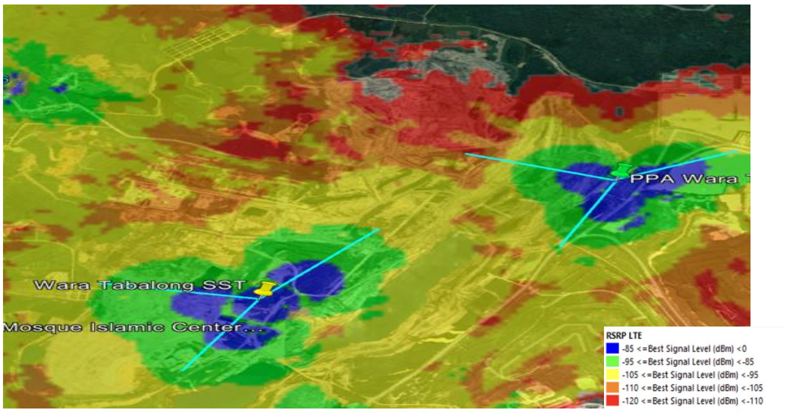

Figure 3. Planing Coverage LTE (Maps : Planning telkomsel)

In this study, the application of LTE in network overlay in mining areas provides various significant advantages compared to the use of PtP or PtMP-based WiFi network topologies**.** The LTE cellular network structure allows each Base Transceiver Station (BTS) to cover a larger area, known as a cell, with coverage of up to 15 km per cell, providing greater flexibility compared to WiFi topologies that are limited by distance and line-of-sight constraints. In dynamic and remote mining environments, LTE can serve multiple devices simultaneously, from autonomous vehicles, IoT sensors, to heavy machines, without compromising performance. Orthogonal Frequency Division Multiple Access (OFDMA) allows LTE to efficiently manage multi-device communications, maintaining quality of service even as the number of devices increases.

In addition, the design of LTE towers is a strategic element in supporting network efficiency in the mining area. The placement of towers outside the main mining area, utilizing land that is not used for operational activities, aims to avoid the risk of damage due to excavation, heavy equipment traffic, or other mining activities. This approach increases the lifespan of the network infrastructure as well as provides an important reference for future sustainable network planning, not only at the mine but also for other mining environments. In this study, network simulations were carried out to analyze the optimal coverage radius of each LTE tower, ensure that the entire mine area is well connected without excessive signal overlapping and optimize the use of frequency spectrum.

This overlay method, which combines LTE and WiFi networks, provides a layer of redundancy that improves network reliability and availability. LTE acts as the primary layer for long-distance communication, while WiFi is used for local data needs with lower latency. Dynamic resource allocation in LTE adapts bandwidth to operational needs in real-time, such as machine data transmission or video streaming of mine condition monitoring. The implementation of fixed towers as the main foundation of the network and mobile towers as a flexible solution in dynamic mining areas allows the network to be more reliable and scalable.

The application of LTE in this overlay method not only improves mine operational efficiency and safety, with real-time data transmission related to safety and heavy equipment movement, but also makes an important contribution to the development of future network technology. This approach can be a reference for network development in other industrial sectors with similar operational challenges, and provides an overview of how LTE-based network designs can improve efficiency and safety in mining areas.

Network Performance Comparison

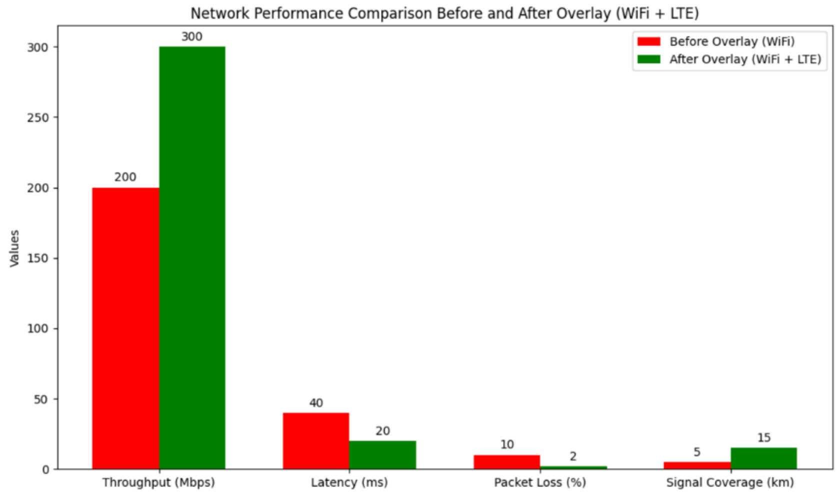

Figure 4. Comparison of network performance before and after using the overlay method

The data visualization presented illustrates a significant improvement in four main parameters of network performance after the implementation of the overlay method, namely throughput, latency, packet loss, and signal coverage. This increase not only reflects the efficiency of the network, but also its impact on operations and work safety at the PT Putra Perkasa Abadi (PPA) coal mine. Here's a more in-depth description:

1. Throughput(Mbps): Before the implementation of the overlay (WiFi), the network throughput was recorded at 200 Mbps. After the overlay was implemented by adding LTE, the throughput increased significantly to 300 Mbps. This indicates an improvement in network performance that allows for faster and more efficient data transfer, which is important for real-time data management in the mine.
2. Latency(ms): The latency before the overlay (WiFi) is 40 ms, while after the overlay (WiFi + LTE) decreases to 20 ms. This reduction in latency indicates that communication within the network becomes more responsive, which is critical in supporting systems that require quick decision-making, such as machine monitoring and safety in the mine area.
3. PacketLoss(%):P packet loss on the WiFi network before the overlay is recorded at 10%. After overlaying with LTE, packet loss decreases to 2%. This decrease indicates that with the overlay method, the reliability of the network is increased, so that data transmission is more stable and can reduce interference that can affect the safety and operational efficiency of the mine.
4. SignalCoverage (km): The signal coverage on WiFi before the overlay is limited to only 5 km. Once the overlay method was implemented, the signal coverage increased to 15 km thanks to LTE's ability to cover a wider area. This allows for more stable connectivity across the wider mine area, including areas far from control centers and heavy equipment.

Overall, this visualization shows a significant improvement in network efficiency after the implementation of the overlay method, which focuses on increasing throughput, reducing latency, decreasing packet loss, and expanding signal coverage. With these improvements, the WiFi and LTE overlay methods provide great advantages in supporting safer, more efficient, and more stable mine operations.

Added Value for Operations and Safety:

This increase in network metrics provides strategic value for the efficiency and safety of mine operations. Overlay-optimized network systems are capable of supporting:

1) Operational Efficiency: Data from machines and environmental sensors can be quickly collected and analyzed to identify optimization opportunities, such as reducing machine idle time or improving production schedules.
2) Improved Safety: With low latency and better signal coverage, the system can provide early warning of potential hazards, such as landslides, fires, or gas explosions. This allows for more proactive risk mitigation.
3) Data-Driven Management: The overlay network supports the integration of big data and edge computing technologies, which enables the analysis of big data at the mine site to generate strategic insights.

Overall, the application of the overlay method not only improves network performance technically, but also has a real impact in supporting the digital transformation of PT PPA's mines. This underscores the relevance of overlay methods as a strategic approach to address communication and operational challenges in a complex and dynamic industrial environment.

Data and device clustering

Table 1. Data and device clustering

Device Category	WiFi Device (Before Overlay)	LTE Devices (After Overlay)	Overlay Device (WiFi + LTE)
Access Points (AP)	Ubiquiti UniFi Mesh Pro, Mikrotik RBMetalG-52SHPacn	Base Transceiver Station (BTS) LTE	BTS LTE + WiFi Access Points combination for local areas
Connected Devices	Tablets, Smartphones, Certain Heavy Equipment	Autonomous Vehicles, Heavy Equipment, Drones, IoT Sensors	Heavy Equipment, Autonomous Vehicles, Field Workers, IoT Sensors, Monitoring Systems
Network Specifications	Range up to 5 km, Speed up to 100 Mbps	Range up to 15 km, Speed up to 300 Mbps	Combining the advantages of WiFi for short-range and LTE for wide coverage
Superiority	Low cost, easy installation, ideal for static areas	Wide coverage, stable connectivity in dynamic and remote areas	Combining the advantages of WiFi and LTE for an optimal, adaptive solution in the mine area
Limitations	Limited coverage, affected by interference and signal interference	Infrastructure is more expensive, requires additional BTS	Greater complexity of network management and coordination needs

Explanation**:**

1) WiFi: Prior to the implementation of overlays, WiFi was optimized for network needs in relatively static mining areas, such as monitoring posts and control rooms, with speeds of up to 100 Mbps and limited range (up to 5 km). The use of WiFi is very cost-effective and makes it easier to install the network in a limited area, but it has a limited signal coverage that is susceptible to interference interference.
2) LTE: After the implementation of the overlay, LTE technology was introduced to overcome the limitations of WiFi with wider coverage (up to 15 km) and higher speeds (up to 300 Mbps). LTE enables stable communication across mine areas, including dynamic and remote locations such as autonomous vehicles, heavy equipment, and IoT devices that require low-latency, real-time data connections.
3) Overlay (WiFi + LTE): The simultaneous use of both technologies provides a significant advantage. WiFi serves as a layer to meet the needs of low-latency local connections, while LTE serves as the main layer for more reliable and efficient long-distance communication. This overlay approach ensures a more flexible network and can accommodate the dynamic needs of mine operations and support safety through better real-time monitoring.

The application of this overlay method not only offers a more reliable network solution, but also contributes significantly to improving operational efficiency and work safety in the mining environment. The solution has the potential to be applied to other industrial sectors with similar operational challenges, optimizing the use of network technologies to support sustainability and productivity.

CONCLUSION

The research on strategic network planning for optimizing digital transformation in the coal mining industry reveals several key conclusions. Firstly, the implementation of an overlay method combining WiFi and LTE networks significantly enhances network performance at PT Putra Perkasa Abadi, achieving increased throughput of up to 300 Mbps, reduced latency to 20 ms, decreased packet loss to 2%, and extended signal coverage by 15 km. This strategic planning improves operational efficiency by enabling real-time monitoring and communication between devices, while also enhancing occupational safety through stable communication lines that facilitate immediate data transmission regarding hazardous conditions. Additionally, the study indicates that this network design can be adapted for other industries with similar needs, paving the way for future innovations in network technology. Overall, the research contributes to the development of network systems that support efficiency, safety, and digital transformation in the mining sector. Future research could focus on comparing this method across different industries, assessing long-term impacts on operational metrics, exploring user satisfaction, and integrating emerging technologies like IoT and AI to further enhance these systems.

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