Design of Wireless Communication Network for the Idref Automated Control System II; Advancing Connectivity in the City of Rujban

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Abstract:

The quest for reliable water access has been a critical endeavor throughout history, and Rujban City is no exception. Faced with the challenges of aging infrastructure and reliance on external water sources, Rujban is turning towards technological innovation for solutions. This paper outlines the design of the communication component within the Idref Automated Control System 2 (IACS II), a significant advancement in the automation of Rujban's water distribution system. This system innovatively connects the city's central distributed tank to three distributed tanks via a robust wireless communication network, while maintaining a wired connection to the Idref collection tank, the main control station, and associated monitoring rooms and pumps. The system employs microcontroller-based automation to manage water levels, control signals, and monitor pump activity and potential leaks, with data displayed on an LCD screen. This approach is poised to dramatically improve the efficiency and reliability of water distribution in Rujban City, marking a key step forward in addressing its water supply challenges.

Key Words: Wireless Network, Transmitter, Receiver, Control System, Water Pumping, Water Distribution, Smart Irrigation System.

I. INTRODUCTION

The water management initiative for Rujban City is structured into three core systems, each comprising a wireless communication network and a control system. All these systems (KACS, IACS I, and IACS II) emphasize the integration of advanced monitoring capabilities and enhance the efficiency and reliability of water distribution by improving pump operations and enabling early detection of leaks, thereby streamlining the overall water supply process to meet the diverse needs of the city's expanding regions. KACS is the primary framework that manages the flow from deep wells to the Karthoom collection tank. IACS I, the subsequent phase, automates the transfer of water from the Karthoom collection tank to the Idref collection tank, tackling the 20 km distance. This paper will delve into IACS II, which focuses on the final stage: automating water distribution from the Idref collection tank to four high-lying distribution tanks, essential for serving the city's numerous separate villages nestled in the mountains. This segment resolves the complex communication and control interactions between the various tanks and the main Idref station.

Rujban City, mirroring the challenges faced by many mountainous regions, is fragmented into several separate villages. The IACS II initiative stands as a critical component in the water distribution project, aiming to efficiently supply water to these diverse communities. With tanks designated for specific areas, the East Tank is designated to serve Awlad Jaber and Awlad Atiyah. The Mid Tank provides for Awlad Abd Aljalil, Awlad Masoud, and Awlad Inan. With each tank having a significant capacity of 250 thousand liters, it underscores the effort to ensure an ample and reliable water supply for all the designated communities. The West Tank, boasting a capacity of 300 thousand liters, is allocated for Awlad Ibaid and Taridia. Lastly, The Idref Distributed Tank, established at the end of the 1960s, is specifically tasked with supplying the central Rujban area, including the communities of Al Brahma and Chfy. With a capacity of 150 thousand liters. Addressing the increasing water needs, the government is also developing five more upraised distributed tanks, ensuring that growing parts of the city have adequate water supply.

Figure 1 illustrates the layout of the Idref collection and distribution tanks, along with the other three distribution tanks within the Rujban City water management system. Additionally, it marks the location of the main building that is central to the system's operations.

Fig. 1 Main and distribution tanks' locations

This current paper focuses on enhancing Rujban City's water distribution system through modern wireless communication networks. It aims to seamlessly integrate these technologies within the city's water management framework, offering a significant step toward a fully automated system. The forthcoming paper will shift the focus to the control aspect, specifically exploring the integration and application of Programmable Logic Controllers (PLC) within this system to further optimize and refine the operational efficiency and reliability of water distribution in Rujban City.

Section II revisits prior research and literature relevant to the subject. Section III outlines the specific problem being addressed. Following this, Section IV introduces the methodology for resolving the identified issue, presenting incrementally developed solutions to showcase the comprehensive approach taken. Section V elaborates on the simulations conducted to validate the proposed methods, detailing the design, execution, and outcomes. Finally, Section VI wraps up the discussion with conclusions and identifies areas for focused future research.

II. LITERATURE REVIEW

Understanding the full scope of this project necessitates a review of pertinent literature, particularly focusing on advancements in wireless networks and automatic control systems. Prior works have laid the foundation for our research, with significant contributions in these areas highlighted in various studies.

The literature review for the Rujban City water management systems highlights a progression of studies emphasizing the design and implementation of wireless networks for improved water distribution efficiency. Zergalin and Hasan [1] laid the initial groundwork with a post-study design of wireless networks, tackling water issues in Rujban. Zargelin, Ali, and Lashhab [2] expanded this by designing a wireless network specifically for the Karthoom Automated Control System. Nagasa et al. [3] contributed to the theme with their design for Zintan City, suggesting the versatility of such systems. Ravi Kumar [4], Vasudevan, and Vengatesh present a compelling case for the use of Programmable Logic Controllers (PLCs) in enhancing the automation and efficiency of water supply systems, offering valuable insights into the integration of advanced control technologies within urban infrastructure frameworks. In their seminal work on urban water systems[5], Schuetze et al. (2003) underscored the transformative potential of real-time control technologies for enhancing the efficiency and sustainability of urban water management. Ali et al. [6], focused on the control aspects using PLCs to optimize water level control systems for urban water supply. Lastly, Alaribi, Elazhari, and Zargelin [7] provided a robust solution for urban water systems using PLCs, while Nam, Won-Ho, et al. [8] showcase how these technologies can significantly improve water use efficiency and operational sustainability in agriculture, presenting a compelling case for the broader adoption of WSNs in irrigation systems.

III. PROBLEM FORMULATION

In addressing the critical water supply challenges faced by the city of Rujban, as detailed in our previous publications [1, 5, 6], it becomes evident that the city, along with several others in developing nations, grapples with the severe issue of inconsistent access to dependable water sources. This dilemma is largely rooted in the reliance on manual operations and the absence of an automated water distribution system. Our proposed solution transitions the system from manual to 100% automatic operation, a change that is pivotal for overcoming the existing crisis.

Our comprehensive strategy encompasses the division of the project into three distinct systems: KACS, IACS I, and IACS II. Each system is designed with a wireless network and a PLC (Programmable Logic Controller) to ensure seamless operation and control. Our extensive investigation into the current state of the Idref automated control system II has uncovered several critical findings:

1. The reliance on manually operated pumps, situated close to the Idref collection tank.

2. The absence of a specialized monitoring system to track water levels and quality in the Idref collection tank as well as the four distributed tanks.

3. The logistical challenges faced in ascending the significantly elevated distributed tanks, complicate routine maintenance and monitoring efforts.

4. Frequent power outages significantly disrupt the water supply chain necessary to meet the city's needs.

5. A noticeable gap in communication and data regarding water supply interruptions, leading to inefficient crisis management.

6. The premature failure of pumps due to improper use and maintenance, notwithstanding the potential for a prolonged service life with appropriate care and monitoring.

7. The high cost associated with labor in maintaining and operating the water supply system manually.

The driving force behind our research and the development of our proposal is to address and mitigate the water crisis currently afflicting Rujban. Our goal is to establish a modern, extensive water distribution network that caters to all city districts. This network aims to ensure the delivery of a consistent and reliable water supply, thereby significantly improving the quality of life for the city's residents and contributing to the sustainable development of the region.

V. Design and development

To address the core issue described earlier, our team has engineered an automated mechanism for managing and observing the water flow from the Idref collection tank to four strategically placed tanks throughout the city. This infrastructure is the sole operational water supply linking to the city of Rujban. Given the extensive nature of this project, we partitioned the Idref Automated Control System 2 (IACS II) into two distinct components. The initial segment deals with the wireless communication framework, the focal point of this document. The second aspect of our solution is centered on a Programmable Logic Controller (PLC) system, which we will explore in detail in our forthcoming publication.

For IACS II's water level control in distribution tanks, we streamlined the wireless network design to efficiently transmit operational commands between individual distribution tanks and the Idref distribution tank. Utilizing Point-to-Point (PtP) links, this design ensures direct, reliable communication. We selected directional antennas with dual polarization to optimize the vertical and horizontal beam widths, critical for achieving precise signal alignment and maximizing signal strength.

Ensuring the antennas' correct height and alignment is paramount to avoid signal loss. This setup requires meticulous configuration to maintain high Received Signal Strength Level (RSSL) values and ensure an unobstructed Fresnel zone, crucial for minimizing signal degradation over distance. The design stipulates a clear Line of Sight (LOS) for each link, verified through a Received Signal Strength Indication (RSSI) to prevent obstructions.

Handling RF communications over long distances, especially in outdoor settings, introduces significant challenges due to free space path loss. This phenomenon typically results in a signal attenuation of about 0.020 dB for every foot traversed in open environments. The Friis Transmission Equation (1) provides a crucial mathematical relationship for estimating the power received based on the power transmitted, taking into account the distance between transmitter and receiver, as well as the gain of the transmitting and receiving antennas:

$$P_{RX} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (1)$$

This equation can be rewritten on a logarithmic scale as:

$$P_{RX/dBm} = P_{TX/dBm} + G_{TX/dB} + G_{RX/dB} + 20\log\left(\frac{\lambda}{4\pi d}\right) \qquad (2)$$

Where G_{TX} is the gain of the transmitting antenna, G_{RX} is the gain of the receiving antenna, λ is the wavelength, and *d is* the distance between transmitting and receiving antennas.

These equations are instrumental in determining whether the signal strength at the receiving end surpasses the minimum required received signal level (RSL), ensuring that the communication link remains viable and effective.

Our choice of antennas favors those operating at 5 GHz, with beam widths ranging from 20 to 60 degrees in the H-plane and 10 to 20 degrees in the E-plane, optimizing the network for high-gain scenarios and ensuring robust signal transmission. Employing Radio Mobile Frequency technology enables precise determination of antenna heights, facilitating optimal setup for each point-to-point link. This meticulous approach not only ensures efficient water level monitoring and control but also provides a robust fade margin, significantly reducing the risk of signal loss or data errors under varying environmental conditions.

IV. SIMULATION RESULTS

Incorporating the specific detail that the distance between the Idref collection tank and the Idref distributed tank is just 149 meters and acknowledging that both the main control system room and monitoring room are located adjacent to the Idref distributed tank within the same fenced area, the use of a communication cable for connecting these two tanks is even more advantageous. This relatively short distance allows for an efficient and cost-effective wired installation, avoiding potential wireless interference issues and ensuring the highest level of data transmission reliability and security critical for the operations managed from the control and monitoring rooms. Situating the control and monitoring facilities close to the distributed tank, and by extension, directly connecting it to the collection tank via a cable, creates a centralized hub of operations. This configuration not only facilitates real-time, high-speed data exchange and immediate response to any operational changes or emergencies but also enhances the overall integrity and security of the network's core. The hybrid network design, with a robust wired connection at its heart and wireless links extending to the peripheral tanks, offers an optimal blend of reliability, efficiency, and flexibility necessary for managing the complex dynamics of the tank infrastructure.

As with the IACS I, the antenna installation atop the Idref distribution tank is favored over the Idref collection tank, despite their proximity of just 149 meters, because of the substantial elevation difference and the inherent height of the distribution tank. The distribution tank's height of 20 meters above ground level, coupled with a 9-meter elevation advantage, allows for a clear line-of-sight for the antenna preventing us from constructing taller antenna towers, crucial for effective wireless communication. This strategic positioning facilitates broader coverage to the distributed tanks and is economically advantageous by mitigating the need for constructing new, costly antenna structures.

The results from Radio Mobile are organized into subsections covering geographical coordinates, antenna specifications, radio system parameters, propagation losses, and overall network performance metrics. Notably, the simulations consider the unique semi-arid environment, with negligible forest and urban losses. The system's effectiveness is validated by a series of successful links, for instance, between the main tank and various distributed tanks like the West Tank, demonstrating substantial fade margins and reliable signal reception over distances of several kilometers.

Each link's outcome is tailored to the specific elevation and distance challenges, optimizing antenna heights and system gains to maintain the necessary reliability and performance. These simulations guide the physical setup and technical adjustments needed to ensure consistent water management across Rujban City's terrain.

Figure 2 in the network topology for the Idref Automated Control System 2 (IACS II) not only illustrates the expansive connectivity from the upraised distributed Idref tank to the three subsidiary tanks - East, Mid, and West - but also introduces a crucial variation in the antenna setup. Contrary to the transmitter antennas employed at the East, Mid, and West tanks, the antenna on the Idref distributed tank is uniquely a receiving antenna. This receiving antenna is strategically designed to cover at least a 90-degree angle, ensuring it can effectively capture signals from all three transmitting antennas. This setup is critical for maintaining seamless communication within the water distribution network, facilitating real-time monitoring and control over water levels and distribution across the various sectors of the system. Through this tailored approach, IACS II demonstrates a sophisticated integration of technology to optimize the efficiency and reliability of water management in the system.

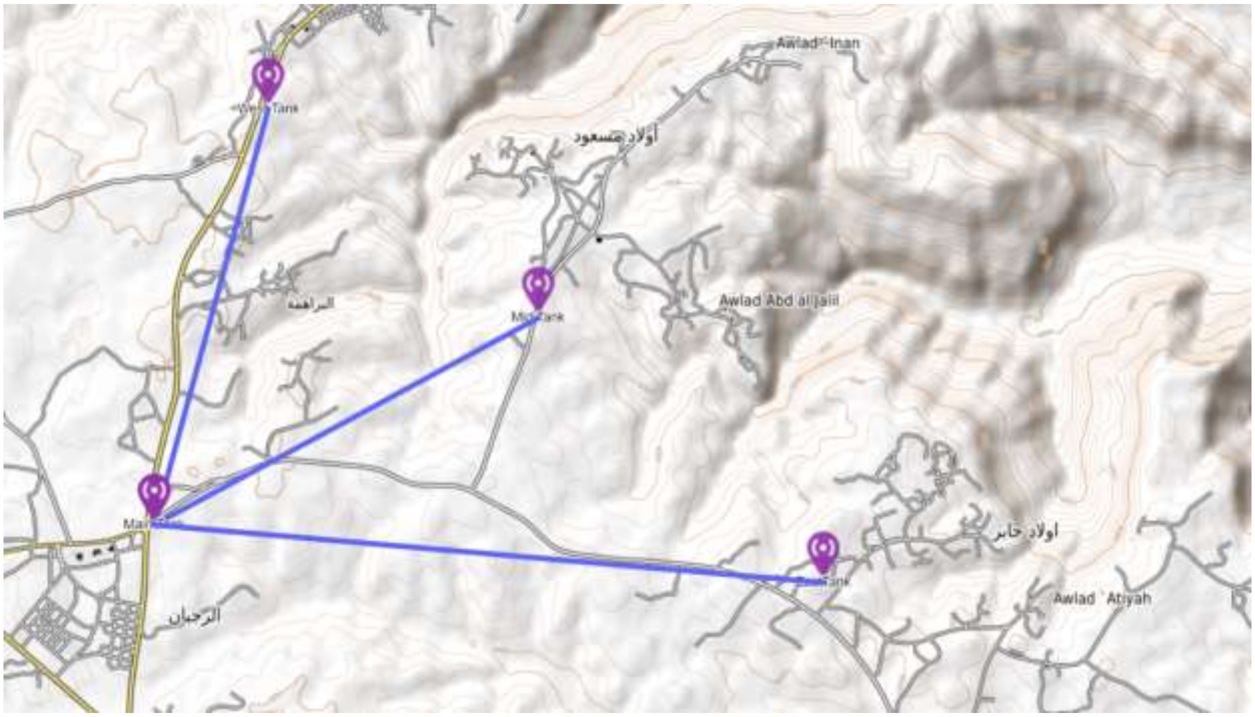
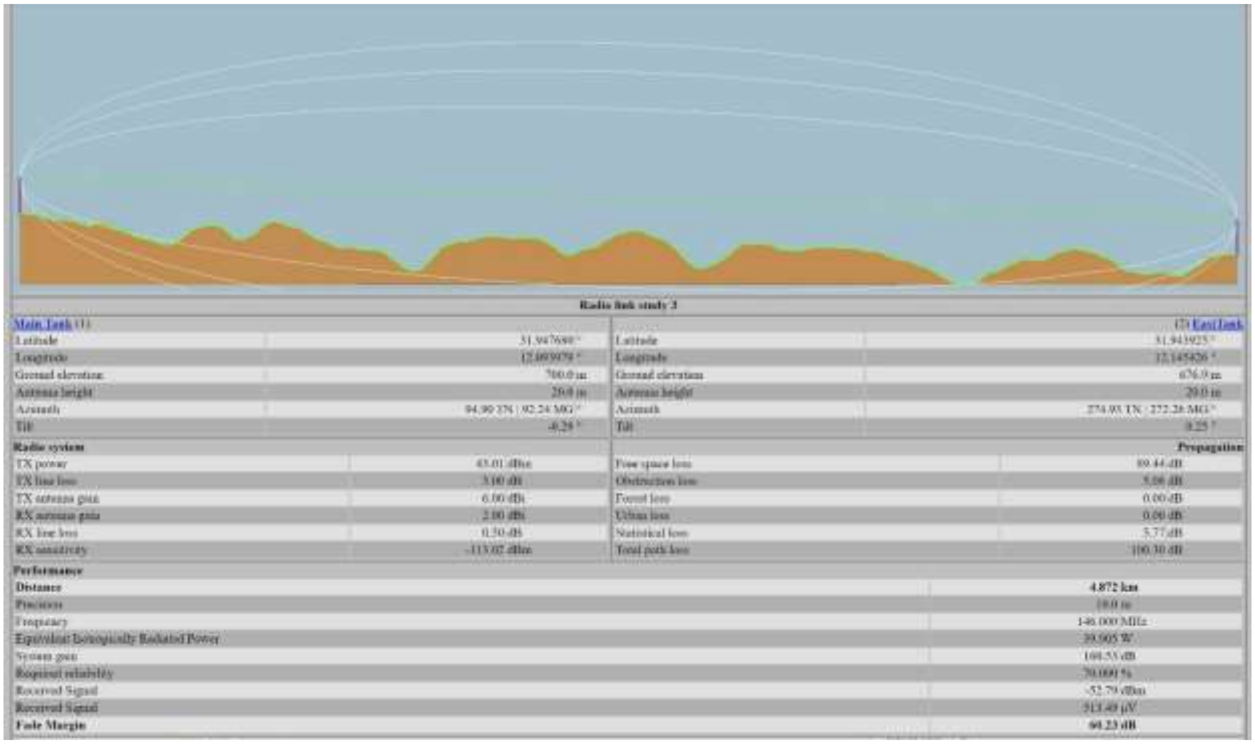


Fig. 2 Wireless links layout

The following figures (Fig. 3, Fig. 4, and Fig. 5) present a detailed overview of the network connections between the elevated distributed Idref tank and the east, mid, and west tanks, including geographical and technical data critical for system implementation. Each figure is complemented by tables divided into five subsections, detailing latitude, longitude, elevation, antenna specifications, radio system parameters (such as power and sensitivity), propagation losses (including free space and obstructions), and overall network performance metrics (distance, signal precision, and fade margin). Notably, antenna heights are calculated based on ground elevation, ensuring the design optimizes for both signal clarity and infrastructure cost-effectiveness.

Figure 3 shows the data from the simulation provides a quantitative assessment of the wireless link between the Idref Tank and the East Tank. Key parameters include the Idref Tank's antenna height of 20 meters, allowing clear transmission over the 4.872 km to the East Tank, which also has an antenna height of 20 meters. Free space loss is calculated at 89.44 dB, and total path loss at 100.30 dB. The system's frequency is set at 146.000 MHz, with an equivalent isotopically radiated power (EIRP) of 39.905 W. Significantly, the fade margin-a critical measure of signal reliability is 60.23 dB, indicating a robust link capable of maintaining communication despite potential signal degradations.



Radio link study 3

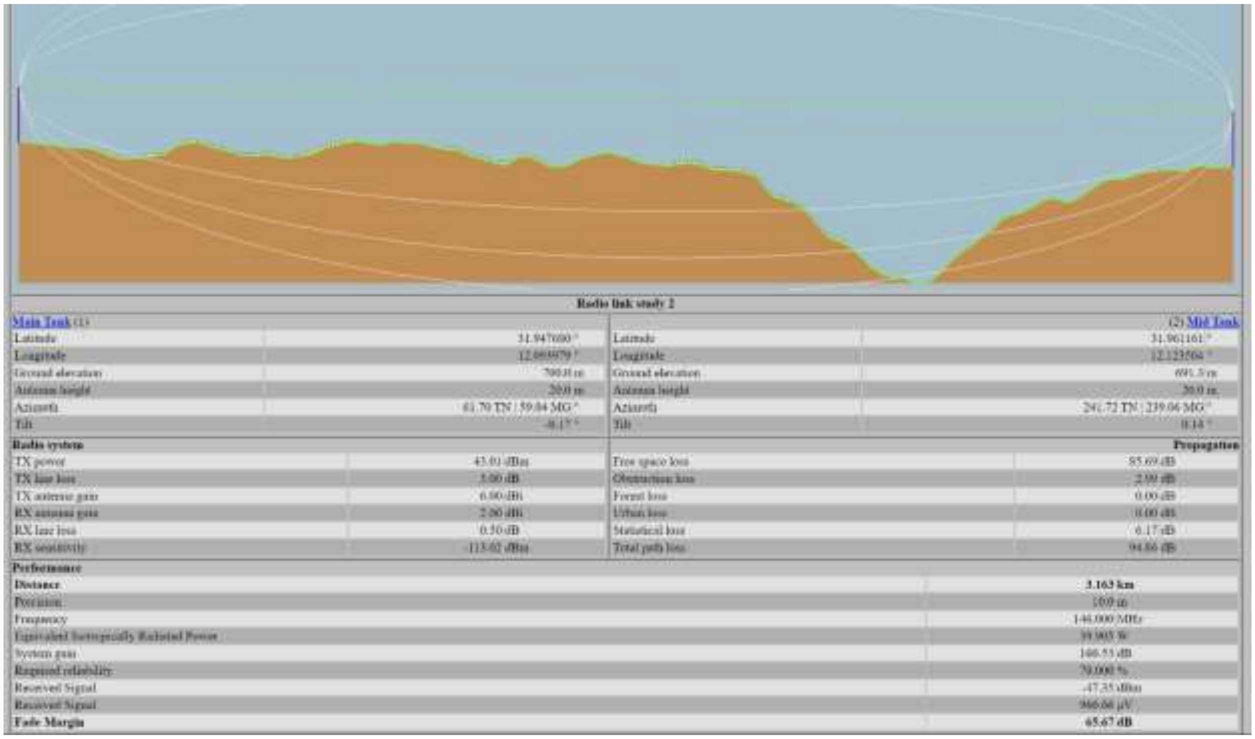
Main Tank (1)			(2) East Tank
Latitude	31.947690 °	Latitude	31.943925 °
Longitude	12.093979 °	Longitude	12.145426 °
Ground elevation	700.0 m	Ground elevation	676.9 m
Antenna height	20.0 m	Antenna height	20.0 m
Azimuth	94.90 TN | 92.24 MG °	Azimuth	274.93 TN | 272.28 MG °
Tilt	-0.25 °	Tilt	0.25 °

Radio system			Propagation
TX power	43.01 dBm	Free space loss	89.44 dB
TX line loss	3.00 dB	Obstruction loss	5.08 dB
TX antenna gain	6.00 dBi	Forest loss	0.00 dB
RX antenna gain	2.00 dBi	Urban loss	0.00 dB
RX line loss	0.50 dB	Statistical loss	5.77 dB
RX sensitivity	-113.02 dBm	Total path loss	100.30 dB

Performance	
Distance	**4.872 km**
Precision	10.0 m
Frequency	146.000 MHz
Equivalent Isotopically Radiated Power	39.905 W
System gain	160.53 dB
Required reliability	70.000 %
Received Signal	-52.79 dBm
Received Signal	513.49 µV
Fade Margin	**60.23 dB**

Fig. 3 Layout for link 1

Figure 4 illustrates the simulation for the link between the Idref Tank and the Mid Tank illustrating a well-planned wireless network design. With the Idref Tank positioned at an elevation of 700m and the Mid Tank at 691.3m, the antennas are placed at a height of 20m to ensure clear signal transmission over a distance of 3.163 km. Key metrics such as a free space loss of 85.69 dB and a total path loss of 94.86 dB are calculated to ensure signal integrity, taking into account the network's frequency of 146.000 MHz and the system's required reliability. A substantial fade margin of 65.67 dB indicates a robust link, pivotal for the successful operation of the automated control system.



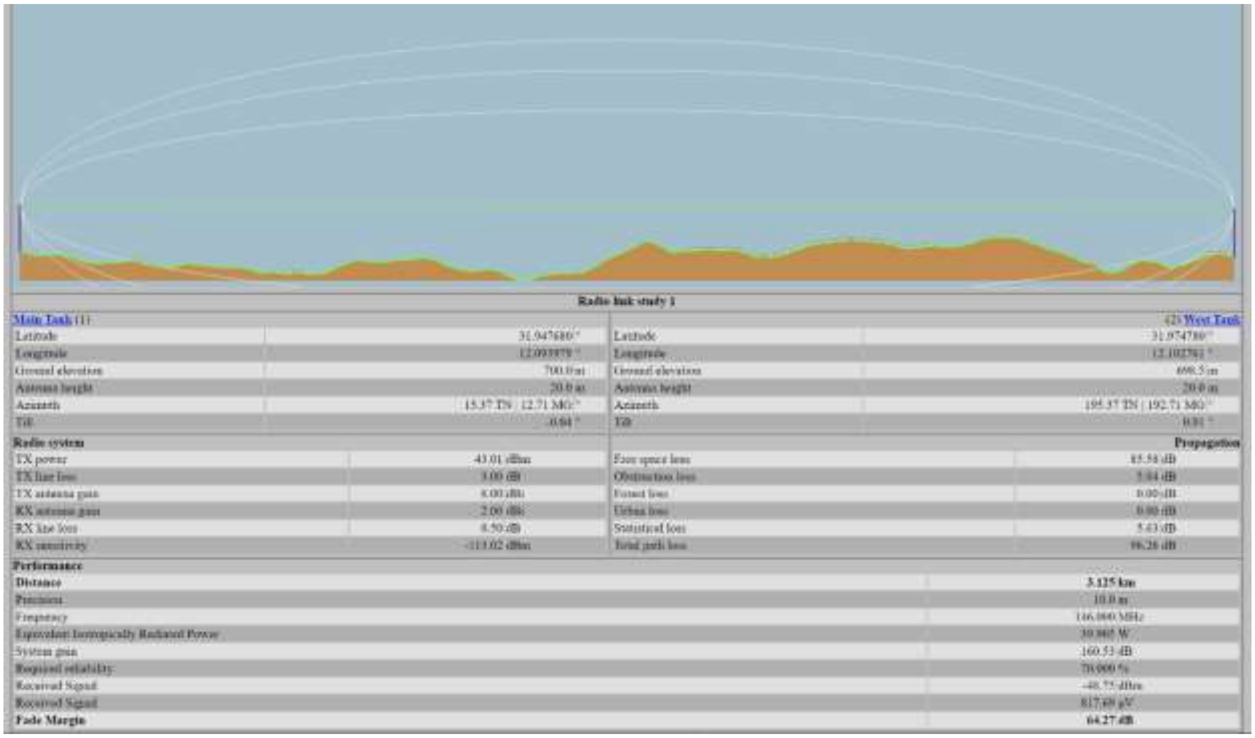
Radio link study 2

Main Tank (1)		(2) Mid Tank	
Latitude	31.947690 °	Latitude	31.961161 °
Longitude	12.093979 °	Longitude	12.123504 °
Ground elevation	700.0 m	Ground elevation	691.5 m
Antenna height	20.0 m	Antenna height	20.0 m
Azimuth	61.70 TN / 59.04 MG °	Azimuth	241.72 TN / 239.06 MG °
Tilt	-0.17 °	Tilt	0.14 °
Radio system			**Propagation**
TX power	43.01 dBm	Free space loss	85.69 dB
TX line loss	3.00 dB	Obstruction loss	2.99 dB
TX antenna gain	6.00 dBi	Forest loss	0.00 dB
RX antenna gain	2.00 dBi	Urban loss	0.00 dB
RX line loss	0.50 dB	Statistical loss	6.17 dB
RX sensitivity	-113.02 dBm	Total path loss	94.86 dB

Performance	
Distance	**3.163 km**
Precision	10.0 m
Frequency	146.000 MHz
Equivalent Isotropically Radiated Power	39.905 W
System gain	160.53 dB
Required reliability	70.000 %
Received Signal	-47.35 dBm
Received Signal	960.66 µV
Fade Margin	**65.67 dB**

Fig. 4 Layout for link 2

In Fig. 5, the simulation illustrates a wireless link from the Idref Tank to the West Tank. It details the setup with the Idref Tank's antenna elevated 20 meters above a ground level of 700 meters, aiming towards the West Tank with a similar antenna elevation. Free space loss is marked at 85.58 dB with a total path loss of 96.26 dB for the 3.125 km distance. The link operates at a frequency of 146.000 MHz, boasting an impressive fade margin of 64.27 dB, indicative of a strong and reliable signal for the network's operational requirements.



Radio link study 1

Main Tank (1)			(2) West Tank
Latitude	31.947680 °	Latitude	31.974780 °
Longitude	12.093979 °	Longitude	12.102783 °
Ground elevation	700.0 m	Ground elevation	698.5 m
Antenna height	20.0 m	Antenna height	20.0 m
Azimuth	15.37 TN | 12.71 MG °	Azimuth	195.37 TN | 192.71 MG °
Tilt	-0.04 °	Tilt	0.01 °
Radio system			**Propagation**
TX power	43.01 dBm	Free space loss	85.58 dB
TX line loss	3.00 dB	Obstruction loss	5.04 dB
TX antenna gain	6.00 dBi	Forest loss	0.00 dB
RX antenna gain	2.00 dBi	Urban loss	0.00 dB
RX line loss	0.50 dB	Statistical loss	5.63 dB
RX sensitivity	-113.02 dBm	Total path loss	96.26 dB

Performance	
Distance	**3.125 km**
Precision	10.0 m
Frequency	146.000 MHz
Equivalent Isotropically Radiated Power	39.905 W
System gain	160.53 dB
Required reliability	70.000 %
Received Signal	-48.75 dBm
Received Signal	817.69 µV
Fade Margin	**64.27 dB**

Fig. 5 Layout for link 3

V. Conclusion and Future Work

In conclusion, the development and implementation of the Idref Automated Control System II (IACS2) in Rujban City represents a landmark advancement in addressing the long-standing challenges of water distribution within the region. By integrating cutting-edge technological innovations, including a robust wireless communication network and microcontroller-based automation, IACS2 has significantly enhanced the efficiency and reliability of the city's water supply system. The design of the communication component, connecting the city's central and distributed tanks, ensures a seamless and automated management of water levels, pump activities, and potential leak detections, all monitored through an intuitive LCD display interface.

In our findings, the optimal height for the transmitter and receiving antennas has been identified as 20 meters above ground level. This strategic insight allows us to leverage the existing infrastructure of water distribution tanks, utilizing their height to mount antennas without the necessity for constructing additional towers. This approach not only capitalizes on the available structures but also contributes to cost efficiency and minimizes the environmental footprint of expanding our communication network. This synergy between the water distribution system's infrastructure and the communication network's requirements exemplifies a practical and innovative solution to enhance system efficiency and reliability.

Moving forward, the focus of future efforts will be on further refining the control mechanisms of both Idref Automatic Control Systems, aiming to enhance the efficiency and reliability of water distribution in Rujban City. Additionally, there is a planned expansion to complete the water distribution infrastructure management in Al-Zintan, leveraging the insights and successes from Rujban as a model for addressing similar challenges in other cities. This approach signifies a commitment to not only improving local water management practices but also to sharing knowledge and solutions that can benefit broader communities facing water distribution issues.

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