GSJ: Volume 12, Issue 11, November 2024, Online: ISSN 2320-9186

www.globalscientificjournal.com

"Development and Optimization of an IoT-Based Smart Water Leakage Detection System in Water Pipelines with Real-Time Response Capability"

Khadidja NYIRANSABIMANA *1, Dr. Djuma SUMBIRI*,2,

*[1]Department of Information Technology , University of Lay Adventist of Kigali Rwanda

Abstract

Water loss through leaking pipes constitutes a major challenge to the operational service of water utilities. In recent years, increasing concern about the financial loss and environmental pollution caused by leaking pipes has driven the development of efficient technology for detecting leakage in water piping networks. Development and Optimization of an IoT-Based Smart Water Leak Detection in Water Pipelines with Real-Time Response Capability is introduced to directly detect leakage and interventions are provided on time. The system consists of a simulation used to detect leak points in a pipe using water flow sensors. These sensors measure the in-flow and out-flow rates of water. When the out-flow rate is less than the in-flow rate, it indicates a leakage and automatically a turn-off of water flow . The water flow sensor sends signal pulses to an Arduino Uno for processing. The processed data from the Arduino is then transmitted to the cloud for storage and analysis via a GSM module. Additionally, an SMS notification is sent to a mobile phone to alert the user of any detected leaks. This system ensures continuous monitoring and prompt detection of leaks, preventing water wastage and potential damage. The integration of cloud storage and mobile notifications enhances the system's reliability and efficiency, making it a robust solution for leak detection in various applications. The results show that the designed system is able to measure the in and out flow rate of water and senses whether this quantity is unbalanced; therefore, the system stops as it detects a leakage somewhere. This project aims to implement a water leakage detection system for plastic water supply pipelines using Simulations.

Keywords: *IoT, Water Leakage Detection, GSM, Water Flow Sensor*

1. INTRODUCTION

Water supply system leakage is a quiet problem that costs the world billions of dollars each year. Because a large amount of the water supply pipelines are underground, leaks can go unnoticed and unreported for a long time. Water is a valuable natural resource, and according to Liemberger and Wyatt, the anticipated annual cost of water loss is 126 billion cubic meters per year, which is conservatively assessed at $39 billion in 2019 [1]. Current system being used, provides a solution for water loss given that 40% of total water produced doesn't reach customers.

The location of the leakage water pipe that is the big challenge will be known by getting SMS and email. This system will reduce non-revenue water here in Rwanda. The recent report indicates that non-revenue water reaches 12-35% of the drinking water supply in the USA, 6-24% in Europe, and 4.7-24% in Korea [2], in Rwanda, RURA Statistics as of March 2020 indicates that Rwanda is losing 40% of water supplied in different areas before it reaches the customers. Real losses through overflows at storage tanks, burst leaks in distribution pipelines caused by bad connections, pipe corrosion, physical damages [3]. It is necessary to detect burst leaks in buried water pipes to reduce water production costs as well as to protect public safety [4].

Leak detection methods are classified into two groups: external and internal. The external group includes methods that failure (leakage) is found using signals collected outside pipelines [5]. Visual inspection, thermographic methods are the best examples. Internal methods are based on signals collected inside pipes. This category includes methods based on wave propagation phenomena or volume balance [5][6]. Changes in steady-state operating conditions of fluid transportation systems excite a guided wave. The guided wave has several modes that can propagate with different velocities along with pipeline systems.

Wave propagation in such systems is complicated, leading to phenomena that can be affected by many factors, including geometric properties of the system, pipeline network configuration, or the existence of hydraulic fitting [7]. In addition, medium flow characteristics also influence wave propagation. It is well known that wave propagation velocity depends on frequency, temperature, pressure, medium density, pipe material [8].This system will be useful here in Rwanda where such a level of leakage is likely to happen.

The reform is intended to deliver water with sanitation utilities sufficiently focused to deliver new infrastructure, efficient, effective service delivery, building a strong people capability, and meeting key national milestones. It is expected to reverse status that includes improving viability, autonomy, establishing a sustainable and customer-centric utility to deliver an important mandate that touches people of all walks of life.

2. METHODS AND MATERIAL

2.1 Research Design and Tools

A mixed research design tool was used for better understanding the existing water leakage detection system and provide complete evidence for integration of IoT into existing systems. Observation, documentation analysis were used as the main tools for collecting data.

The selection of those tools was guided by the nature of the data to be collected, time available as well as the objective of the study.

a. ***Observation Method***

During the observation, the research data findings were based on methods for detecting water leaks in pipelines. As a result, the research indicates that when there is a water leakage in the pipeline, the owner reports it to the concerned authority and it takes time to know the water leakage location as it requires them to dig a long distance in order to provide support.

b. Documentation Analysis

The documentation analysis was also employed in comparison to earlier similar studies, by researching how the problem of water leaking in various pipeline distribution networks was solved and also this method helped to identify different technology used to detect water leakage in the pipe.

2.2 System Development Model

Throughout the development of this system, the "Modified Waterfall Model" (MWF) served as the guiding framework for the software development lifecycle. Unlike the traditional waterfall model, the MWF model incorporates iterative elements, allowing for greater flexibility and adaptation to evolving project requirements. This iterative approach facilitates a more dynamic and responsive development process, where feedback from each stage informs subsequent iterations. The MWF model divides the software development process into distinct phases, each building upon the outputs of the preceding stage. By delineating clear milestones and deliverables for each phase, the MWF model promotes transparency, accountability, and progress tracking throughout the development lifecycle. Moreover, the iterative nature of the model enables stakeholders to validate and refine requirements iteratively, ensuring alignment with project objectives and user needs. Overall, the adoption of the MWF model facilitates a systematic and structured approach to software development, ultimately enhancing the efficiency, quality, and success of the system's implementation

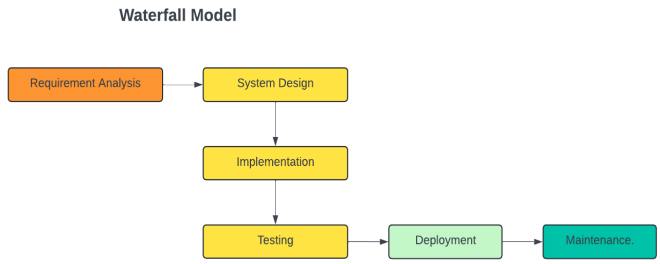


Figure 1:Waterfall Model

During the requirements phase, data collection was conducted through a combination of observation and internet searches. This comprehensive approach ensured a thorough understanding of the system's operational context and user needs. The gathered information was then meticulously analyzed to extract key insights and requirements, which served as the foundation for system design and functionality. Subsequently, the focus shifted to the implementation code phase, where coding became the primary objective. This phase centered on the development and testing of system sub-components in alignment with the established system design and requirements. Rigorous testing procedures were employed to validate the functionality and integrity of each component, ensuring that they operated seamlessly within the broader system architecture.

Transitioning to the testing system phase, the system underwent thorough examination to assess its compliance with the established requirements. A unit test was initially conducted to scrutinize individual activities, followed by comprehensive testing of all activities as a unified unit. This iterative testing approach allowed for the identification and resolution of any discrepancies or anomalies, thereby enhancing the system's overall robustness and reliability.

Finally, the system deployment and maintenance phase marked the culmination of the project lifecycle. The system was deployed to various locations to facilitate the detection of water leakage in pipes. Upon detection, the system provided immediate support, thereby minimizing water wastage and mitigating potential damage. Ongoing maintenance activities ensured the continued performance and effectiveness of the deployed system, underscoring the commitment to sustainable water management practices and operational excellence.

Overall, the systematic progression through these phases exemplified a structured and comprehensive approach to system development, culminating in the successful deployment of a robust and effective water leakage detection system

2.3 System Architecture

Figure 2**:** Give the system architecture. The main components of the architecture include sensing unit, the microcontroller connected to GSM internet gateway, open cloud server and user unit.

Water follow sensor measures the volume of water entering and sorting in the pipe and sends a signal pulse to Arduino Uno for processing, processed data is sent via GSM Module to cloud database for storage and analysis.

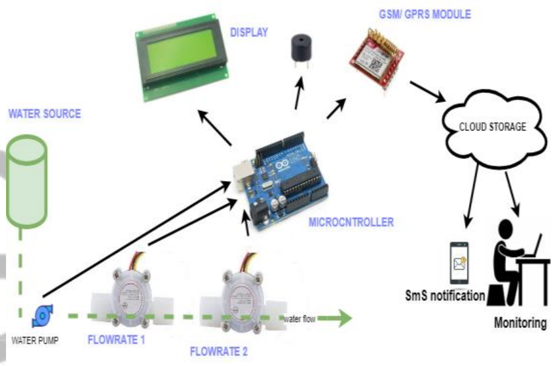


Figure 2:System Architecture

2.4 *System Flow Chart*

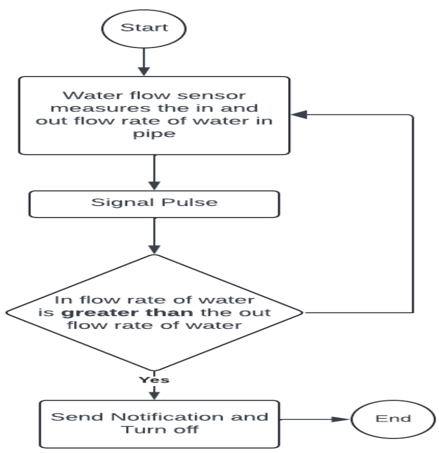


Figure 3:System Flow Chart

The figure above indicates an algorithm using flowchart by talking about how the IoT- Based Smart Water Leakage Detection System in this thesis is done. The system functionality continues its tasks of detecting water leakage in the pipe and notifying the water owner or author and an automatic way except if there are technical issues. The system functionality is based on embedded devices; an integrated system consists of both software and hardware parts. The main task of the system is to detect water leakage in the pipe using water flow sensors and give SMS notification to the water owner and in case a leak is detected.

system and users can obtain results notification from both. The below figure is a prototype diagram of the water leakage detection system, it shows how electronic devices used are connected to one another to communicate.

3. RESULTS AND DISCUSSION

3.1 System Prototype

The system consists of two parts such as hardware part and IoT Cloud dashboard Platform .Both parts are essential for the system and users can obtain results notification from both. The below figure is a prototype diagram of the water leakage detection system, it shows how electronic devices used are connected to one another to communicate.

The system consists of two parts such as hardware part and IoT Cloud dashboard Platform .Both parts are essential for the system and users can obtain results notification from both. The below figure is a prototype diagram of the water leakage detection system, it shows how electronic devices used are connected to one another to communicate.

Figure 4: *System Prototype*

This figure in an open case illustrates a prototype of the water leak detection system components and the way they are connected to each other.

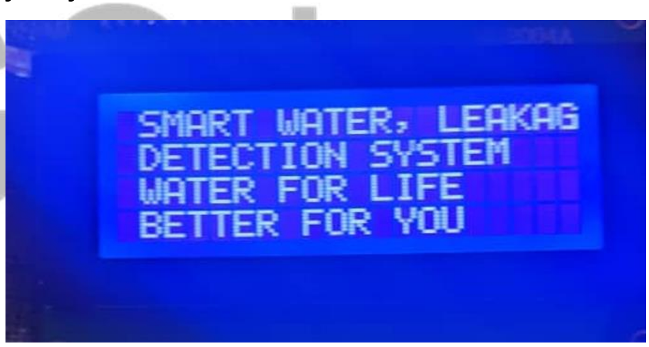


Figure 5: Data in LCD after powering the System

The above figure depicts the look of the LCD after getting the IoT Smart water leakage detection system. It shows an attractive message to the users of the system and motivates them on the benefits of using the system.

Figure 6: ensor 1 and Sensor 2 measurements

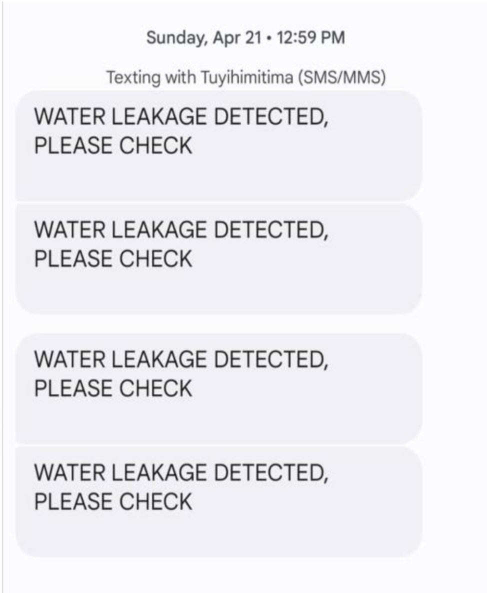
The figure above illustrates the system status after getting the measurements from two water flow sensors. In case the sensor 1 measurements are the same as sensor 2 measurements, the results definitely are that there is no water leakage detected. As mentioned in this figure, Sensor 1 measured 20L/MIN and Sensor 2 measured the same. This means, there is no water leakage.

However, in case sensor measurements are different, their results are that the water leakage is detected. For example at the entrance of the seal where a water flow sensor called"sensor1" is placed, when the poured water there is different from water at the end point of the seal, it means the water leakage is detected since the quantity of the inflowing water is different from the quantity of outflowing water. See the figure below:

Figure 7 Variation of Sensor1 and Sensor2 measurements

For this figure, sensor1 measured 20 L/MIN at the entrance of the seal and at the exit, the measurements are 10L/MIN. This shows the difference between the inflowing and outflowing water. Which means, water leakage is detected.

The figure below shows the decision made when the water leakage was detected. An SMS is sent to the person in charge of controlling the water showing that there is a water leakage to be able to fix the issue.



.

Figure 8:Water Leakage detection and SMS notification

3.2 Cloud Dashboard and Visualization

After the system data was collected by the sensors, it was sent via GSM Module to cloud storage.

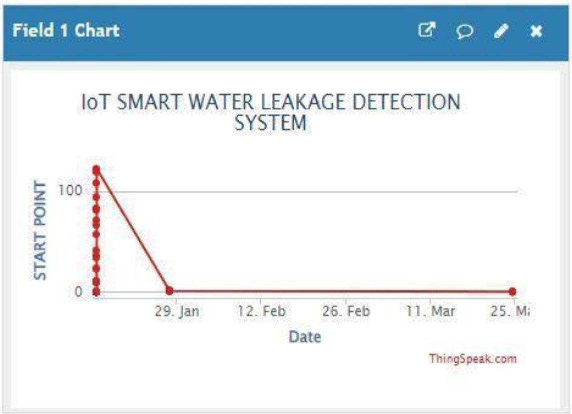


Figure 9: Thing speak data

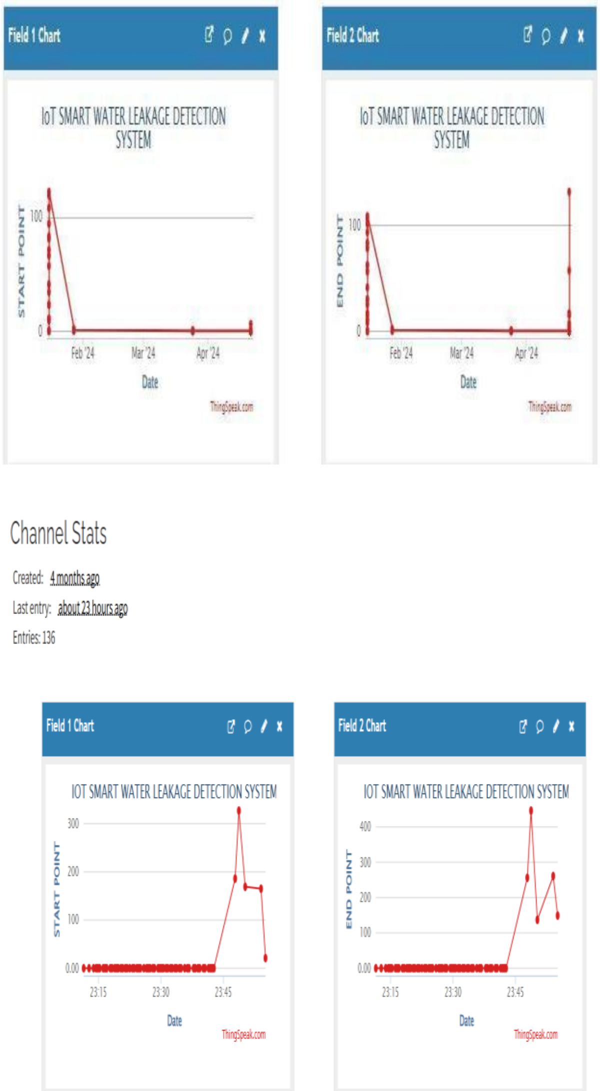


Figure 10:Smart Leakage Detection chart

The Figure above indicates a graph of data collected by the sensor stored on the cloud server. The system checks every minute if there is a leakage in the pipe and what it gets is sent to the server for further analysis.

In Detail to that Field 1 indicates the outflow water rate. the Field 2 indicate inflow water rate, The water rate is shown as End Point. If the Inflow water rate is greater than the out flow water, that means the leakage has been auto-detected. For each point date and time are shown as well.

3.3 *Discussion of results*

The aim of this research is to design and prototype an IoT Water Leakage Detection System in the pipeline and send real time data to the user and on the dashboard using IoT. The system was successfully designed, prototyped and tested. The prototype system is made up with two water flow sensors placed on the pipe to sense the rate of water passé through the pipe, the microcontroller unit to control the whole system and to process the data collected by the sensors, GSM module in the system is used to send SMS notification to the system users and also it has a water pump to turn off the water if the leakage in the pipe is detected. The water flow sensor collects data continuously every minute to check if there is a leakage in the pipe, and the sensor data is sent to the cloud server for storage and further analysis.

The collected sensor data generate automatic graph based on the rate of water passes through the pipe in every minute, and microcontroller process the data, it compares the obtained results based on the volume of water send to the pipe and what is received means that the in-flow and out-flow rate of water will be measured in order to detect if there is water leakage problem in the pipe to take decision. When the water leakage is detected the water pump automatically turns off the water and the SMS notification is sent to the water Owner the authority in charge for quick support. The report of all collected data is accessed via the server cloud platform where it was stored, visualized and for future use.

The collected sensor data generate automatic graph based on the rate of water passes through the pipe in every minute, and microcontroller process the data, it compares the obtained results based on the volume of water send to the pipe and what is received means that the in-flow and out-flow rate of water will be measured in order to detect if there is water leakage problem in the pipe to take decision. When the water leakage is detected the water pump automatically turns off the water and the SMS notification is sent to the water Owner the authority in charge for quick support. The report of all collected data is accessed via the server cloud platform where it was stored, visualized and for future use.

4. Conclusion

An IoT Water Leakage Detection System is a sophisticated solution designed to identify and monitor leaks in pipelines, providing real-time data to users to enhance water management and conservation efforts. This system of water leakage detection demonstrated a positive impact in real time monitoring by continuously monitoring pipeline integrity using IoT sensors that detect changes in pressure, flow, and sound patterns indicative of leaks. The system also demonstrated its capability of data collection and analysis; sensors collect data on various metrics, such as water pressure and flow rate, which are transmitted to a centralized system for analysis. Advanced analytics can identify anomalies that suggest leaks. In Addition when a leak is detected, this system sends immediate notifications or alerts to users or operators via SMS, enabling rapid response to prevent water loss and potential damage. By reducing water loss, this system help conserve precious water resources and minimize the environmental impact associated with excessive water extraction and infrastructure strain. Beside of costs saving,(Early detection of leaks can prevent costly repairs and reduce lost water), improved resources management(Enhanced monitoring helps utilities manage their water supply more effectively), increased system longevity(Regular monitoring and timely repairs help extend the lifespan of pipeline infrastructure.), this technology demonstrated the capability of enhanced Public trust with reliable system that minimize water waste can lead to improved public perception and trust in water management entities.

Therefore an IoT Water Leakage Detection System plays a critical role in modern water management by leveraging technology to enhance the detection and analysis of leaks, ultimately leading to more efficient use of water resources and improved infrastructure maintenance.

REFERENCES

1. R. Liemberger and A. Wyatt, ‘‘Quantifying the global non-revenue water problem,’’ Water Supply, vol. 19, no. 3, pp. 831–837, May 2019.

2. H. A. A. M. M. B. Zainab H. Ali, "Internet of Things (IoT): Definitions, Challenges, and Recent Research Directions," International Journal of Computer Applications 128(1):975-8887, 2015.

3. N. R. C. (. C. o. P. P. i. t. Laboratory., Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards: Updated Version., United States government: National Academy of Sciences., Bookshelf ID: NBK55884, 2011.

4. H. K. R. K. B. Y. Dao Van Hung, Leak Failure at the TP316L Welds of a Water Pipe Caused by Microbiologically Influenced Corrosion, Chung-Ang University, Seoul, South Korea: DOI:10.1016/j.engfailanal.2021.105244, January 2021.

[4] A. Kadri, E. Yaacoub, and M. Mushtaha, “Empirical evaluation of acoustical signals for leakage detection in underground plastic pipes,” in Proceedings of the Mediterranean Electrotechnical Conference - MELECON, 2014, pp. 54–58, DOI: 10.1109/MELCON.2014.6820506.

[5] K. Fukushima, Y. Maruta, K. Izumi, Y. Ito, A. Yoshizawa, and T. Tanaka, “A water leak detection service based on sensors and ICT solutions,” NEC Tech. J., vol. 9, no. 1, pp. 107–110, 2015.

[6] S. Geetha and S. Gouthami, “Internet of things enabled real-time water quality monitoring system,” Smart Water, vol. 2, no. 1, pp. 1–19, 2016, DOI: 10.1186/s40713-017-0005-y.

[7] M. Bentoumi, D. Chikouche, A. Mezache, and H. Bakhti, “A Novel Wavelet Double Thresholding Method for Water Leak-Detection using a Vibration Sensor: An Experimental Analysis IET Review Copy Only IET Signal Processing.”

[8] J. Choi, J. Shin, C. Song, S. Han, and D. Il Park, “Leak detection and location of water pipes using vibration sensors and modified ML prefilter,” Sensors (Switzerland), vol. 17, no. 9, Sep. 2017, DOI: 10.3390/s17092104.

[9] B. Vogelaar and M. Golombok, “Simplified Ultrasonic Damage Detection in Fluid-Filled Pipes,” J. Nondestructive. Eval., vol. 36, no. 4, Dec. 2017, DOI: 10.1007/s10921-017- 0443-3. [10] A. S. Almazyad et al., “A proposed scalable design and simulation of wireless sensor network-based long-distance water pipeline leakage monitoring system,” Sensors (Switzerland), vol. 14, no. 2, pp. 3557–3577, Feb. 2014, DOI: 10.3390/s140203557. 28

[11] M. J. Brennan et al., “On the Effects of Soil Properties on Leak Noise Propagation in Plastic Water Distribution Pipes,” 2017.

[12] A. Lay-Ekuakille, V. Telesca, P. Visconti, and N. I. Giannoccaro, "Accurate spectral estimation technique based on decimated linear predictor for leak detection in waterworks," Sensors, vol. 21, no. 6, pp. 1–16, Mar. 2021, DOI: 10.3390/s21062185.

[13] Where is Earth's Water? Accessed: Sept. 27, 2024.

[14] P. J. Lee, J. P. Vítkovský, M. F. Lambert, A. R. Simpson, and J. A. Liggett, "Frequency Domain Analysis for Detecting Pipeline Leaks," J. Hydraul. Eng., vol. 131, no. 7, pp. 596–604, 2005, DOI: 10.1061/(ASCE)0733-9429(2005)131:7(596).

[15] M. Nikles, "Long-distance fiber optic sensing solutions for pipeline leakage, intrusion, and ground movement detection," Fiber Opt. Sensors Appl. VI, vol. 7316, no. May, p. 731602, 2009, DOI: 10.1117/12.818021.

[16] S. Rashid, S. Qaisar, H. Saeed, and E. Felemban, "A Method for Distributed Pipeline Burst and Leakage Detection in Wireless Sensor Networks Using Transform Analysis," Int. J. Distrib. Sens. Networks, vol. 2014, 2014, DOI: 10.1155/2014/939657.

[17] R. Hanson, "Water Leak Detection System," 2017.

[18] S. M. Rabeek, H. Beibei, and K. T. C. Chai, "Design of wireless IoT sensor node platform for water pipeline leak detection," Asia-Pacific Microw. Conf. Proceedings, APMC, vol. 2019-Decem, pp. 1328–1330, 2019, DOI: 10.1109/APMC46564.2019.9038809.

[19] A. E. U. Salam, M. Tola, M. Selintung, and F. Maricar, "On-line monitoring system of water leakage detection in pipe networks with artificial intelligence," ARPN J. Eng. Appl. Sci., vol. 9, no. 10, pp. 1817–1822, 2014.

[20] M. Thilagaraj, S. Akkara, M. Aakil Habibullah, T. Manikandan, M. Rajmohan, and P. Yuvaraj, "Water leakage detection and management system using IOT," Int. J. Adv. Sci. Technol., vol. 29, no. 9 Special Issue, pp. 683–689, 2020, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85085048870&partnerID=40&md5=6ec4addb136fa003d9f64eca6181a0d8.

[21] A. M. Sadeghioon, N. Metje, D. N. Chapman, and C. J. Anthony, "SmartPipes: Smart wireless sensor networks for leak detection in water pipelines," J. Sens. Actuator Networks, vol. 3, no. 1, pp. 64–78, 2014, DOI: 10.3390/jsan3010064. 29 Networks (SWLD)," Int. J. Networks Commun., vol. 7, no. 1, pp. 1–16, 2017, DOI: 10.5923/j.ijnc.20170701.01.

[22] T. K. Chan, C. S. Chin, and X. Zhong, ''Review of current technologies and proposed intelligent methodologies for water distributed network leakage detection,'' IEEE Access, vol. 6, pp. 78846–78867, 2018.

[23]K. B. Adedeji, Y. Hamam, B. T. Abe, and A. M. Abu-Mahfouz, ''Towards achieving a reliable leakage detection and localization algorithm for application in water piping networks: An overview,'' IEEE Access, vol. 5, pp. 20272–20285, 2017

[24] M. I. M. Ismail, R. A. Dziyauddin, N. A. A. Salleh, F. Muhammad-Sukki, N. A. Bani, M. A. M.

Izhar, and L. A. Latiff, ''A review of vibration detection methods using accelerometer sensors for water pipeline leakage,'' IEEE Access, vol. 7, pp. 51965–51981, 2019.

[25] S. Hamilton and B. Charalambous, Leak Detection: Technology and Implementation. London, U.K.: IWA Publishing, 2020.

[26] A. Annan, ''GPR-History, trends, and future developments,'' Subsurface Sens. Technol. Appl., vol. 3, no. 4, pp. 253–270, 2002.

[27] L. Ren, T. Jiang, Z.-G. Jia, D.-S. Li, C.-L. Yuan, and H.-N. Li, ''Pipeline corrosion and leakage monitoring based on the distributed optical fiber sensing technology,'' Measurement, vol. 122, pp. 57–65, Jul. 2018.

[28]L. Ren, T. Jiang, D.-S. Li, P. Zhang, H.-N. Li, and G.-B. Song, ''A method of pipeline corrosion detection based on hoop-strain monitoring technology,'' Struct. Control Health Monitor., vol. 24, no. 6, p. e1931, Jun. 2017.

[29] R. F. Rahmat, I. S. Satria, B. Siregar, and R. Budiarto, ''Water pipeline monitoring and leak detection using flow liquid meter sensor,'' IOP

[30](PDF) A review of methods for leakage management in pipe networks. (2024). ResearchGate. https://doi.org/10.1080//15730621003610878

[32]A. S. Ali, M. N. Abdelmoez, M. Heshmat, and K. Ibrahim, ''A solution for water management and leakage detection problems using IoTs based approach,'' Internet Things, vol. 18, May 2022, Art. no. 100504

nial-of-service (DoS) attack? Retrieved from Cloudflare: https://www.cloudflare.com/learning/ddos/glossary/denial-of-service/

Dooley, K. (2024, June 16). *What is Multicast Networking? | Auvik*. Retrieved from Auvik Networks: https://www.auvik.com/franklyit/blog/multicast-networking/

Dost, K. M., Talal, A., Nadeem, A., Salman, Q., & Noman, K. A. (2023). Black Hole Attack Prevention in Mobile Ad-hoc Network (MANET) Using Ant Colony Optimization Technique. *Information Technology and Control*, 308 - 319.

Dost, M. K., Talal, A., Nadeem, A., Salman, Q., & Noman, A. K. (2020). Black Hole Attack Prevention in Mobile Ad-hoc Network (MANET) Using Ant Colony Optimization Technique. *Information Technology and control*, 308 - 319.

Firewall. (2024). *Multicast - Understand How IP Multicast Works*. Retrieved from Firewall: https://www.firewall.cx/networking/network-fundamentals/network-multicast.html

Firewall.cx. (2022). *Hybrid Routing Protocols - Advantages and Disadvantages - Comparison*. Retrieved from Firewall.cx: https://www.firewall.cx/networking/routing-protocols/hybrid-routing.html

Fortinet. (2024). *What Is a Wireless Network? Types of Wireless Network*. Retrieved from Fortinet:

https://www.fortinet.com/resources/cyberglossary/wireless-network

Froehlich, A. (2024). *What is a Wireless Ad Hoc Network and How Does it Work?* Retrieved from TechTarget: https://www.techtarget.com/searchmobilecomputing/definition/ad-hoc-network

Hamamreh, R. A. (2018). Protocol for Multiple Black Hole Attack Avoidance in Mobile Ad Hoc Networks. In P. Mitra, *Recent Advances in Cryptography and Network Security* (pp. 174-190).

Hamamreh, R. A. (2018). Protocol for Multiple Black Hole Attack Avoidance in Mobile Ad Hoc Networks. In P. Mitra, *Recent Advances in Cryptography and Network Security*. Intechopen.

Imperva. (2022). *What is a Sybil Attack | Examples & Prevention*. Retrieved from Imperva: https://www.imperva.com/learn/application-security/sybil-attack/

Jain, S. (2022, November 22). *Applications of Ad hoc network and it's problems*. Retrieved from GeeksforGeeks: https://www.geeksforgeeks.org/applications-of-ad-hoc-network-and-its-problems/

Jain, S. (2022, July 11). *History of Sybil Attack*. Retrieved from GeeksforGeeks: https://www.geeksforgeeks.org/sybil-attack/

Jain, S. (2023, May 04). *GeeksforGeeks*. Retrieved from Wormhole Attack in Wireless Sensor Networks: https://www.geeksforgeeks.org/wormhole-attack-in-wireless-sensor-networks/

Jain, S. (2024, April 16). *Active and Passive attacks in Information Security*. Retrieved from GeeksforGeeks: https://www.geeksforgeeks.org/active-and-passive-attacks-in-information-security/

Jain, S. (2024, July 01). *Introduction of Mobile Ad hoc Network (MANET)*. Retrieved from GeeksforGeeks: https://www.geeksforgeeks.org/introduction-of-mobile-ad-hoc-network-manet/

Janani, V., & Manikandan, M. (2018). Efficient trust management with BayesianEvidence theorem to secure public key infrastructure-based mobile ad hoc networks. *EURASIP Journal on Wireless Communications and Networking*, 1-27.

Javatpoint. (2024). *Mobile Communication | Routing*. Retrieved from Javatpoint: https://www.javatpoint.com/mobile-communication-routing

Jaydip, S., Girish, C., Harihara, S., Harish, R., & Balamuralidhar, P. (2007). A Mechanism for Detection of Gray Hole Attack in Mobile Ad Hoc Networks. *IEEE*, 1-5.

Jeferson, W. G., & Lee, L. L. (2013). Topology Control for Ad-Hoc Networks: A Comprehensive Review for Table Driven and On-Demand Routing Protocols. *Communications and Network*, 239-246.

Kanade, V. (2024, May 13). *All You Need to Know About Support Vector Machines*. Retrieved from Spiceworks: https://www.spiceworks.com/tech/big-data/articles/what-is-support-vector-machine/

Kosek-Szott, K. (2012). A survey of MAC layer solutions to the hidden node problem in ad-hoc networks. *Ad Hoc Networks*, 635-660.

Mohamed, H., & Noreddine, B. (2008). Security and Privacy in Wireless Sensor Networks: Challenges and Solutions. In *Handbook of Research on Wireless Security*. Carthage, Tunisia: University of November 7th at Carthage, Tunisia.

Mohammad, A.-S., Seong-Moo, Y., & Seungjin, P. (2018). Black Hole Attack in Mobile Ad Hoc Networks. *Proceedings of the 56nd Annual Southeast Regional Conference, 2018* (pp. 93-96). Huntsville, Alabama, USA: DBLP.

NCSC. (2022). *Who and what is this guidance for?* Retrieved from Denial of Service (DoS) guidance - NCSC.GOV.UK: https://www.ncsc.gov.uk/collection/denial-service-dos-guidance-collection

NetworkLessons.com. (2022). *Introduction to Multicast*. Retrieved from NetworkLessons.com: https://networklessons.com/multicast/introduction-to-multicast

Newman, A. (2022, January 05). *How does a Blackhole attack work?* Retrieved from Gremlin: https://www.gremlin.com/blog/getting-started-with-blackhole-attacks

NordVPN. (2022). *Hybrid routing protocol definition – Glossary*. Retrieved from NordVPN: https://nordvpn.com/cybersecurity/glossary/hybrid-routing-protocol/

Pettersson, A. (2022). *Implementing and evaluating variations of the Blackhole attack on RPL.* Uppsala, Sweeden: Uppsala University, Uppsala.

Priyanka, T., & Hemalatha, M. (2018). A Way to Detect Black hole Attack in MANET and Protect Packets in Networks. *INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT)*, 1-6.

Ricardo, G. H., Antonio, L., & Raquel, M. (2010). QoS: Requirements, Design Features, and Challenges on Wireless Sensor Networks. In *Handbook of Research on Developments and Trends in Wireless Sensor Networks: From Principle to Practice.*

RUCKUS. (2024). *Wireless Network Technology: A Comprehensive Overview*. Retrieved from RUCKUS Networks: https://www.ruckusnetworks.com/insights/wireless-networks-understanding-your-wireless-connection/

Salonee, M., & Binod, P. K. (2013). POWER AWARE ROUTING IN MOBILE AD HOC NETWORKS:A SURVEY. *ARPN*

Journal of Engineering and Applied Sciences, 173-189.

Scikit-learn. (2022). *RandomForestClassifier — scikit-learn 1.5.1 documentation*. Retrieved from Scikit-learn: https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.RandomForestClassifier.html

Souad, H. E., Mohammed-Alamine, E. H., & Jamal El, E. K. (2022). Novel approach of detecting the black hole attack for vehicular ad-hoc networks based on capability indicators. *International Journal of Pervasive Computing and Communications*, 112-119.

Studocu. (2022). *Attacks - Routing Table Poisoning Attacks,*. Retrieved from Studocu: https://www.studocu.com/ph/document/saint-louis-college/networking2/attacks-routing-table-poisoning-attacks/44649448

Study. (2024). *Ad Hoc Network | Definition & Types*. Retrieved from Study: https://study.com/academy/lesson/what-is-an-ad-hoc-network.html

Tanya, K. A., Mazdak, Z., Azizah, B. M., Shahidan, M., Hoda, S. B., & Sagheb, K. (2013). A Secure Model For Prevention Of Black Hole Attack In Wireless Mobile Ad Hoc Networks. *Latest Trends in Applied Computational Science*, 158 - 163.

TechTarget. (2024, April 16). *What is an Active Attack?* Retrieved from TechTarget: https://www.techtarget.com/whatis/definition/active-attack

Tomar, P., Kumar, G., Verma, L. P., Sharma, V. K., Dimitris, K., Rawat, S. S., & Alotaibi, Y. (2022). CMT-SCTPandMPTCPMultipathTransport Protocols: A Comprehensive Review. *MDPI, Electronics*, 1-38.

Vimal, K., Mahima, S., Aanjey, T. M., Vikash, Y., Anjani, K. R., Uzair, K., & Mayur, R. (2022). Prevention of Blackhole Attack in MANET using Certificateless. *Journal of Scientific & Industrial Research*, 1061-1072.

Yasin, A. (2018). Detecting and Isolating Black-Hole Attacks in MANET Using Timer Based Baited Technique. *Hindawi - Wireless communications and Mobile computing*, 78-92.

Yi-Ting, H., & Ku, C.-Y. (2018). Detection of Gray Hole Attack in Software Defined Networks. *ICEB 2018 Proceedings (Guilin, China)* (pp. 1-6). Guilin, China: AIS, eLibrary.