3. Methodology

3.1. Chapter Introduction

This chapter disseminates the methodology used to overcome the limitations of existing research, as described in Section 2.7. As discussed in Section 1.4.1, the aim of this research is to implement tactile internet to the existing PLC-driven plants by enhancing 5G wireless capabilities for the improved operation and effectiveness within the manufacturing sector which will result in the minimisation of production time [2], [28].

Tactile internet 5G technology topics have gained lot of attention at both research and application level recently. However, research revealed that PLC-driven plants have not been given enough consideration in this movement [28], [46]. This has led to a reckonable inability to adapt to 5G wireless network in PLC-driven smart plants which limits the implementation of an ultra-responsive tactile internet system into such plants.

To remediate this deficiency, it was established in Section 2.4 that the adaptation of a 5G wireless network into PLC-driven plants would improve data streaming, which will in turn minimise the production time, and thereby result in increased production capacity, enhanced collaboration with all stakeholders, and faster operation interaction as well as remote maintenance [27].

Based on the identified research gaps in Section 2.7, the methodology should answer the research questions that were postulated in Section1.3, which are:

1. Which effective and plausible amendments can be implemented on already existing PLC-driven plants to be able to adapt 5G network technology?
2. Can the system modification be scalable to all PLC-driven systems?
3. Will the developed experiment improve all considered network performance factors which affect production time?

All these questions of interest will be answered by the ability of the system design to be able to enhance 5G wireless capabilities revealed in the methodology chapter. This will be achieved by elaborating more on the selected case study for this project, reasons inspiring the choice of the case study, key sections of interest on the case study, and additional innovative modules on the setup to achieve the aim of the project.

To address this deficiency, numerous possible methods from different authors were reviewed, amongst which most possessed the least feasible solution of completely substituting PLC devices with other automation mechanisms. Among all the reviewed techniques, the incorporation of the Scalance MUM856-1 router to enhance 5G capabilities to already-existing industrial-level PLC devicess was found, and based on research it was deemed to be the most plausible solution.

The chapter (Chapter 2) went on to review network factors that can have a significant impact on production time and how they influence the considered production time. This review was accompanied by a detailed investigation into how these network factors can be measured to quantify the improvement brought on by 5G technology tactile internet applications. This chapter was concluded by further dissecting close citations in which the research gaps were identified and outlining the identified gap(s).

Chapter 3 guided the implemented methodology of the experiment to achieve the research aim and objectives. The chapter began by thoroughly explaining the case study selected for the research, which was the smart water bottling plant. In this explanation, reasons inspiring the choice, operations of the case study, and the PLC drive automating the smart water bottling plant were introduced.

The chapter then proceeded to the first phase of the methodology (Phase 1) in which the tactile internet was implemented on the smart water bottling plant using 4G network technology. The aim of this phase was to provide a reference for comparison purposes on 5G setup. Then, Chapter 3 went on to detail the key experiment of the research, which was to implement tactile internet on the smart water bottling using 5G technology.

At this juncture, it is significant to point out that the Scalance MUM856-1 router, which was found to be the most plausible solution to enhance 5G capabilities on an existing PLC drive instead of replacing it, was used to implement 5G network tactile internet application on the smart water bottling plant. Moreover, the G-NetTrack and Paessler PRTG network monitoring applications used to measure reviewed network performance factors were found, based on research, to be the most effective measuring platforms for the intended setup.

In Chapter 4, the results of all network performance factors measured on the experimental setup of tactile internet applications of both 4G and 5G were scientifically presented in tables and graphs. A detailed comparison was made on results to prove or disprove the ability of 5G technology to improve production time, upon which it was proven by experimental results that 5G network technology was able to improve production time in a PLC-driven smart manufacturing environment over 4G network technology.

In Chapter 5, a detailed discussion on the picture evinced by the results portrayed in Chapter 4 was raised. In this discussion, the percentages of improvements were technically presented on performance of latency, bandwidth (data rate), device density, reliability, and accessibility. Moreover, a comprehensive overview of the latest reviewed citations in which the research gap was identified was conducted, and the improvements contributed by this research on each identified gap were stated.

6.3. Overall Conclusions

Smart manufacturing, which is a dynamic manufacturing approach characterised by automation of a production/processing line, connectivity of IIoT nodes, digitisation of the plant through digital twins and augmented realities, and product customisation [4], [5], [7], is gradually replacing traditional manufacturing due to its advantages. These include increased data management, product uniformity, increased production volume, and effective resource management, to name few [3], [5], [7].

To facilitate remote operations which include data synchronisation, remote maintenance, predictive maintenance, remote operation, and data transparency amongst all authorised stakeholders, a visual presence termed tactile internet must be established to the plant using network connection [27], [70], [71].

For this tactile internet to be effective, the network connection used must be equipped with low latency, high bandwidth, increased device density, high reliability, and easy access [27], [69], [154]. Among all network technologies that were commercially available at the time of writing this thesis, research revealed that 5G technology is equipped with the lowest latency, highest bandwidth, maximum device density, high reliability, and is easily accessible over its predecessors, being 3G, 4G, and 4G-LTE technologies [15], [25], [69], [154].

Automation, which is one of the key features which distinguish smart manufacturing from traditional manufacturing, is achieved through the usage of Programmable Logic Controllers in most smart manufacturing plants, based on researched statistics [9], [11], [15]. However, research also revealed that most industrial level PLC devices automating the smart manufacturing and processing plants nowadays lack 5G capabilities [9], [15], [39]. To address this limitation, this research undertook the journey to improve 5G capabilities on already existing PLC-driven plants to implement tactile internet.

The hypothesis was that, if the project aim, to implement tactile internet using wireless 5G technology in a PLC-driven smart manufacturing plant, could be achieved successfully, production time would be minimised [15]. This would be due to improved data synchronisation on the tactile internet routed as the network technology has low latency, increased bandwidth, ability to multi-connect an increased number of IIoTs, being more reliable, and being easily accessible [15], [16].

To fulfil this aim, the pre-existing smart water bottling plant setup automated by an industrial level PLC was selected to be the case study, and a detailed review of possible ways to enhance 5G wireless features on the case study were researched. In this journey, the incorporation of the Scalance MUM856-1 router was found to be the most plausible solution as it does not phase out the existing PLC drive [147], [148].

The Scalance MUMU856-1 router solution was implemented in a pre-existing smart water bottling plant to experiment with tactile internet applications using wireless 5G technology [15], and the intended tactile internet application was successfully implemented using wireless 5G technology on the smart water bottling plant.

To validate the improvements by comparison, the reference was induced by implementing the tactile internet using wired 4G network technology on the same case study and the results of network key performance factors which were reviewed to have significant impact on production time were measured. To prove/disprove the ability of 5G technology to improve production time, network factors were also measured on the tactile internet application implemented using wireless 5G network technology.

Upon comparison of wireless 5G technology results with wired 4G tactile internet results, it was concluded that 5G technology can reduce latency by 99.01%, increase data rate performance by 75.40%, improve device density by 90%, maintain 100% reliability, and increase accessibility in a tactile internet implemented on a PLC-driven smart water bottling plant over wire 4G network technology.

The research questions to be answered were:

1. Which effective and plausible amendments can be implemented on already existing PLC-driven plants to be able to adapt to 5G network technology?

2. Can the system modification ultimately be scalable to all PLC-driven systems?

3. Will the developed experiment improve all considered network performance factors which affect production time?

The answers to these research questions are:

1. The incorporation of the Scalance MUM856-1 router to an already existing PLC-driven smart factory was concluded to be the most effective solution to enhancing 5G wireless capabilities on the plant without phasing out the already existing PLC drive with the aim of implementing tactile internet.
2. Yes, the router was connected to the PLC through standard LAN/Ethernet communication. Hence, this solution is scalable to all PLC devices which are equipped with standard LAN/Ethernet interface.
3. Yes, based on measured results, the implemented tactile internet using 5G technology was able to improve network performance factors which affect production time. Hence, implementing tactile internet using 5G technology was able to minimise production time in a PLC-driven smart water bottling plant.

In conclusion, this research successfully explored the intended study environment, and tactile internet was successfully implemented on the PLC-driven smart water bottling plant using wireless 5G technology. Network factors were scientifically measured and compared. The comparison revealed that the wireless 5G network can improve production time over its predecessors in a PLC-driven smart manufacturing environment.

6.4. Future Work

This research was one of the innovative pillars branching from the series of Industry 4.0 research that stemmed from the smart water bottling plant located in the Central University of Technology (CUT), Free State, laboratory. As new technologies emerge and innovative ideas are discovered around the globe, the smart water bottling plant setup should also transform to keep with the evolution in real time.

The most immediate furtherance considered and foreseen from this research is to explore the innovative idea of wireless tactile internet in other most-used PLC devices in the smart manufacturing industries within and outside the Siemens family. The intention is to bring the recent network generations compatibility awareness to PLC production companies and possibly to design and produce PLC devices which also support 5G and B6G routers into the industry as automation and networking are becoming inseparable in the envisioned future of Industry 4.0.

Another envisioned future work considered as the media is briefing about the launching of 6G technology in near future will be to investigate and proactively align the adaptation of widely used PLC devices in smart manufacturing plants to communication protocols proposed for 6G technology and Beyond (B6G). The cyber-security and energy efficiency performance and improvement of tactile internet applications can also be explored as part of the future work.

6.5. Research Outputs

From this research, four articles were submitted to international conferences – two were already published, and the remaining two have already been accepted and are awaiting publishing.

- Kuriakose, R.B., Mokotjo, H.J. (2024). Implementing Tactile Internet Using 5G Network for Cloud Manufacturing in a PLC-Driven Water Bottling Plant. In: Iglesias, A., Shin, J., Patel, B., Joshi, A. (eds) Proceedings of World Conference on Information Systems for Business Management. ISBM 2023. Lecture Notes in Networks and Systems, vol 833. Springer, Singapore. https://doi.org/10.1007/978-981-99-8346-9_29

- Humane J. Mokotjo and Rangith B. Kuriakose, "Adaptation of 5G Technology in Programmable Logic Controller Automated Smart Manufacturing Plants to improve Network Factors that affect Production Time" 2025. (ISBM 3rd World Conference 2024, Bangkok, Thailand). The paper has been accepted and presented.

- Humane J. Mokotjo and Rangith B. Kuriakose, "Designing and Testing an Experimental Setup for Incorporating 5G wireless network in a PLC Automated Smart Manufacturing plant" 2025, (Intelligent Systems Conference (IntelliSys) 2025) Accepted and awaiting presentation on the 28-29 August 2025.

- Humane J. Mokotjo and Rangith B. Kuriakose, "Experimental Setup and Results Analysis of Tactile Internet Implemented using 5G Technology" (ICTIS Conference 2025, Bangkok, Thailand) Accepted and awaiting presentation on the 4th to 6th April 2025.

References

[1] M. Segovia and J. Garcia-Alfaro, "Design, Modeling and Implementation of Digital Twins," *Sensors*, vol. 22, no. 14, Jul. 2022, doi: 10.3390/s22145396.

[2] A. Ahmadi, C. Cherifi, V. Cheutet, Y. Ouzrout, and Y. Ouzrout, "Recent Advancements in Smart Manufacturing Technology for Modern Industrial Revolution: A Survey," Mar. 2024. [Online]. Available: https://hal.science/hal-03054284

[3] T. Pereira, J. V. Kennedy, and J. Potgieter, "A comparison of traditional manufacturing vs additive manufacturing, the best method for the job," in *Procedia Manufacturing*, Elsevier B.V., 2019, pp. 11–18. doi: 10.1016/j.promfg.2019.02.003.

[4] S. Mittal, M. A. Khan, D. Romero, and T. Wuest, "Smart manufacturing: Characteristics, technologies and enabling factors," *Proc Inst Mech Eng B J Eng Manuf*, vol. 233, no. 5, pp. 1342–1361, Apr. 2019, doi: 10.1177/0954405417736547.

[5] Y. Lu, K. Morris, and S. Frechette, "Current Standards Landscape for Smart Manufacturing Systems," Gaithersburg, MD, Feb. 2016. doi: 10.6028/NIST.IR.8107.

[6] A. S. George, A. S. Hovan George, and T. Baskar, "The Evolution of Smart Factories: How Industry 5.0 is Revolutionizing Manufacturing," 2023, doi: 10.5281/zenodo.10001380.

[7] S. Ramakrishna, T. C. Khong, and T. K. Leong, "Smart Manufacturing," in *Procedia Manufacturing*, Elsevier B.V., 2017, pp. 128–131. doi: 10.1016/j.promfg.2017.08.017.

[8] A. Costantini *et al.*, "IoTwins: Toward Implementation of Distributed Digital Twins in Industry 4.0 Settings," *Computers*, vol. 11, no. 5, May 2022, doi: 10.3390/computers11050067.

[9] Y. V. P. Kumar and R. Bhimasingu, "Key Aspects of Smart Grid Design for Distribution System Automation: Architecture and Responsibilities," *Procedia Technology*, vol. 21, pp. 352–359, 2015, doi: 10.1016/j.protcy.2015.10.047.

[10] J. Ansari *et al.*, "Performance of 5G Trials for Industrial Automation," *Electronics (Switzerland)*, vol. 11, no. 3, Feb. 2022, doi: 10.3390/electronics11030412.

[11] Y. Lu, X. Xu, and L. Wang, "Smart manufacturing process and system automation – A critical review of the standards and envisioned scenarios," Jul. 01, 2020, *Elsevier B.V.* doi: 10.1016/j.jmsy.2020.06.010.

[12] F. Mo *et al.*, "PLC orchestration automation to enhance human–machine integration in adaptive manufacturing systems," *J Manuf Syst*, vol. 71, pp. 172–187, Dec. 2023, doi: 10.1016/j.jmsy.2023.07.015.

[13] A. EL Zerk, M. Ouassaid, and Y. Zidani, "Development of a real-time framework between MATLAB and PLC through OPC-UA: A case study of a microgrid energy management system," *Sci Afr*, vol. 21, p. e01846, Sep. 2023, doi: 10.1016/j.sciaf.2023.e01846.

[14] Y. User and C. Kara, "Real-Time Communication between S7-1200 PLC and Matlab/Simulink and a Fuzzy Logic Temperature Humidity Control Application," *Techno-Science*, vol. 2, no. 1, pp. 7–14, 2019, [Online]. Available: www.dergipark.gov.tr/sjmakeu

[15] R. B. Kuriakose and H. J. Mokotjo, "Implementing Tactile Internet using 5G Network for Cloud Manufacturing in a PLC driven Water Bottling Plant," 2024. doi: 10.1007/978-981-99-8346-9_29.

[16] R. B. Kuriakose and H. J. Vermaak, "Optimization of a Real Time Web Enabled Mixed Model Stochastic Assembly Line to Reduce Production Time," in *Communications in Computer and Information Science*, Springer, 2019, pp. 39–50. doi: 10.1007/978-981-15-0108-1_5.

[17] S. Dani, A. Rahman, J. Jin, and A. Kulkarni, "Cloud-Empowered Data-Centric Paradigm for Smart Manufacturing," *Machines*, vol. 11, no. 4, Apr. 2023, doi: 10.3390/machines11040451.

[18] C. Siedler *et al.*, "5G as an enabler for cloud-based machine tool control," in *Procedia CIRP*, Elsevier B.V., 2021, pp. 235–240. doi: 10.1016/j.procir.2021.11.040.

[19] J. Siderska and K. Mubarok, "Cloud Manufacturing Platform and Architecture Design," *Multidisciplinary Aspects of Production Engineering*, vol. 1, no. 1, pp. 673–680, Sep. 2018, doi: 10.2478/mape-2018-0085.

[20] J. Alkenani and K. Nassar, "Network Monitoring Measurements for Quality of Service: A Review," *Iraqi Journal for Electrical and Electronic Engineering*, vol. 18, no. 2, pp. 33–42, Dec. 2022, doi: 10.37917/ijeee.18.2.5.

[21] D. Larrabeiti, L. M. Contreras, G. Otero, J. A. Hernández, and J. P. Fernandez-Palacios, "Toward end-to-end latency management of 5G network slicing and fronthaul traffic (Invited paper)," *Optical Fiber Technology*, vol. 76, Mar. 2023, doi: 10.1016/j.yofte.2022.103220.

[22] D. Mourtzis, "Smart Manufacturing and Tactile Internet Powered by 5G: Investigation of Current Developments, Challenges, and Future Trends," in *Procedia CIRP*, Elsevier B.V., 2021, pp. 1960–1969. doi: 10.1016/j.procir.2021.11.331.

[23] X. Ma, Y. Wang, Z. Liu, and X. Feng, "Comprehensive evaluation of 5G+ smart distribution network based on combined weighting method-cloud model," *Global Energy Interconnection*, vol. 5, no. 6, pp. 675–691, Dec. 2022, doi: 10.1016/j.gloei.2022.12.009.

[24] I. Salah, M. M. Mabrook, A. I. Hussein, and K. H. Raliouma, "Comparative study of efficiency enhancement technologies in 5G networks- A survey," in *Procedia Computer Science*, Elsevier B.V., 2021, pp. 150–158. doi: 10.1016/j.procs.2021.02.020.

[25] D. Mourtzis, J. Angelopoulos, and N. Panopoulos, "Smart manufacturing and tactile internet based on 5g in industry 4.0: Challenges, applications and new trends," Dec. 01, 2021, *MDPI*. doi: 10.3390/electronics10243175.

[26] V. Fanibhare, N. I. Sarkar, and A. Al-Anbuky, "A survey of the tactile internet: Design issues and challenges, applications, and future directions," *Electronics (Switzerland)*, vol. 10, no. 17, Sep. 2021, doi: 10.3390/electronics10172171.

[27] K. S. Kim *et al.*, "Ultrareliable and low-latency communication techniques for tactile internet services," *Proceedings of the IEEE*, vol. 107, no. 2, pp. 376–393, Feb. 2019, doi: 10.1109/JPROC.2018.2868995.

[28] S. K. Sharma, I. Woungang, A. Anpalagan, and S. Chatzinotas, "Toward Tactile Internet in beyond 5G Era: Recent Advances, Current Issues, and Future Directions," *IEEE Access*, vol. 8, pp. 56948–56991, 2020, doi: 10.1109/ACCESS.2020.2980369.

[29] R. B. Kuriakose and H. J. Vermaak, "Designing a Simulink model for a mixed model stochastic assembly line : A case study using a water bottling plant," *Journal of Discrete Mathematical Sciences and Cryptography*, vol. 23, no. 2, pp. 329–336, Feb. 2020, doi: 10.1080/09720529.2020.1741184.

[30] S. Ura and A. K. Ghosh, "Time latency-centric signal processing: A perspective of smart manufacturing," *Sensors*, vol. 21, no. 21, Nov. 2021, doi: 10.3390/s21217336.

[31] K. S. Kim *et al.*, "Ultrareliable and low-latency communication techniques for tactile internet services," *Proceedings of the IEEE*, vol. 107, no. 2, pp. 376–393, Feb. 2019, doi: 10.1109/JPROC.2018.2868995.

[32] A. Atutxa, D. Franco, J. Sasiain, J. Astorga, and E. Jacob, "Achieving low latency communications in smart industrial networks with programmable data planes," *Sensors*, vol. 21, no. 15, Aug. 2021, doi: 10.3390/s21155199.

[33] F. Xiang, P. Zhou, Y. Zuo, F. Tao, and D. Zhang, "Manufacturing Service Network of Digital Twin Systems Under Cloud Computing Environment," in *Procedia CIRP*, Elsevier B.V., 2022, pp. 460–465. doi: 10.1016/j.procir.2022.05.318.

[34] T. C. Ng, S. Y. Lau, M. Ghobakhloo, M. Fathi, and M. S. Liang, "The Application of Industry 4.0 Technological Constituents for Sustainable Manufacturing: A Content-Centric Review," Apr. 01, 2022, *MDPI*. doi: 10.3390/su14074327.

[35] I. Rodriguez *et al.*, "An experimental framework for 5G wireless system integration into industry 4.0 applications," *Energies (Basel)*, vol. 14, no. 15, Aug. 2021, doi: 10.3390/en14154444.

[36] I. Rodriguez *et al.*, "An experimental framework for 5G wireless system integration into industry 4.0 applications," *Energies (Basel)*, vol. 14, no. 15, Aug. 2021, doi: 10.3390/en14154444.

[37] A. Low, "Technical Standards for Smart Manufacturing: Evolution and Strategic Positioning," 2017.

[38] Md. H. Kabir, J. A. Chowdhury, I. M. Fahim, M. N. Hasan, A. Hasnat, and A. J. Mahdi, "Design and Simulation of AI-Enabled Digital Twin Model for Smart Industry 4.0," in *The 10th International Electronic Conference on Sensors and Applications*, Basel Switzerland: MDPI, Nov. 2023, p. 119. doi: 10.3390/ecsa-10-16235.

[39] D. S. Fowler *et al.*, "A 5G Automated-Guided Vehicle SME Testbed for Resilient Future Factories," *IEEE Open Journal of the Industrial Electronics Society*, vol. 4, pp. 242–258, 2023, doi: 10.1109/OJIES.2023.3291234.

[40] H. Yang, S. Kumara, S. T. S. Bukkapatnam, and F. Tsung, "The internet of things for smart manufacturing: A review," *IISE Trans*, vol. 51, no. 11, pp. 1190–1216, 2019, doi: 10.1080/24725854.2018.1555383.

[41] S. Gupta, "An edge-computing based Industrial Gateway for Industry 4.0 using ARM TrustZone technology," *J Ind Inf Integr*, vol. 33, Jun. 2023, doi: 10.1016/j.jii.2023.100441.

[42] Q. Qi and F. Tao, "A Smart Manufacturing Service System Based on Edge Computing, Fog Computing, and Cloud Computing," *IEEE Access*, vol. 7, pp. 86769–86777, 2019, doi: 10.1109/ACCESS.2019.2923610.

[43] LightGuidesys Blog, "Your Guide to Smart Manufacturing and Industry 4.0," "https://www.lightguidesys.com/resource-center/blog/your-guide-to-smart-factories-and-industry-4-0/."

[44] M. Fanoro, M. Božanić, and S. Sinha, "A Review of 4IR/5IR Enabling Technologies and Their Linkage to Manufacturing Supply Chain," Dec. 01, 2021, *MDPI*. doi: 10.3390/technologies9040077.

[45] N. C. Sa, "5G for Connected Industries and Automation Second Edition 5G Alliance for Connected Industries and Automation 5G Alliance for Connected Industries and Automation Contact: Email: info@5g-acia.org www.5g-acia.org Publisher: ZVEI-German Electrical and Electronic Manufacturers' Association 5G Alliance for Connected Industries and Automation (5G-ACIA)," Aug. 2019. [Online]. Available: www.zvei.org

[46] S. Stankovski, G. Ostojic, I. Baranovski, S. Tegeltija, and V. Smirnov, "Robust automation with PLC/PAC and edge controllers," in *IFAC-PapersOnLine*, Elsevier B.V., 2022, pp. 316–321. doi: 10.1016/j.ifacol.2022.06.052.

[47] N. Zubair, A. Ayub, H. Yoo, and I. Ahmed, "PEM: Remote forensic acquisition of PLC memory in industrial control systems," *Forensic Science International: Digital Investigation*, vol. 40, Apr. 2022, doi: 10.1016/j.fsidi.2022.301336.

[48] L. T. Xiao, M. Y. Li, W. G. Wang, K. W. Hou, and Y. L. Li, "Implementation of FPGA-based controller in automatic control system platform for launch site," in *Procedia Computer Science*, Elsevier B.V., 2020, pp. 26–30. doi: 10.1016/j.procs.2020.02.007.

[49] Don Fitchett, “PLCvsPAC-Definition,” 2013, Accessed: Mar. 10, 2025. [Online]. Available: www.bin95.com

[50] A. EL Zerk, M. Ouassaid, and Y. Zidani, “Development of a real-time framework between MATLAB and PLC through OPC-UA: A case study of a microgrid energy management system,” *Sci Afr*, vol. 21, Sep. 2023, doi: 10.1016/j.sciaf.2023.e01846.

[51] A. Martins, J. Lucas, H. Costelha, and C. Neves, “CNC Machines Integration in Smart Factories using OPC UA,” *J Ind Inf Integr*, vol. 34, p. 100482, Aug. 2023, doi: 10.1016/j.jii.2023.100482.

[52] W. Zhou, “Soft PLC Research And Development System Based On PC,” Guangxi, China.

[53] D. Javier Perez, J. Waltl, L. Prenzel, and S. Steinhorst, “How Real (Time) Are Virtual PLCs?”

[54] V. P. Siemens and S. Cruz-Manzo, “Embedded, Edge and Cloud Computing for Gas Turbine Digital Twins Dynamic modelling of industrial gas turbines (IGTs) for fault diagnosis View project Remote Condition Monitoring of Industrial Gas Turbines View project.” [Online]. Available: https://www.researchgate.net/publication/351915586

[55] O. DUYMAZLAR and D. ENGİN, “Design, Application and Analysis of an OPC-based SCADA System,” *Politeknik Dergisi*, vol. 26, no. 2, pp. 991–999, Jul. 2023, doi: 10.2339/politeknik.1029629.

[56] A. Martins, J. Lucas, H. Costelha, and C. Neves, “Developing an OPC UA Server for CNC Machines,” in *Procedia Computer Science*, Elsevier B.V., 2021, pp. 561–570. doi: 10.1016/j.procs.2021.01.276.

[57] R. Lange, R. A. Elliot, and K. Vestin, “INTEGRATING OPC UA DEVICES IN EPICS,” 2022, doi: 10.18429/JACoW-ICALEPCS2021-MOPV026.

[58] G. Jo, S. H. Jang, and J. Jeong, “Design and implementation of cpps and edge computing architecture based on OPC UA server,” in *Procedia Computer Science*, Elsevier B.V., 2019, pp. 97–104. doi: 10.1016/j.procs.2019.08.017.

[59] S. Industry Online Support, “Connecting a PC Station to an S7-1200 using OPC NCM PC or STEP 7 V5.5 SP3, TIA Portal.” [Online]. Available: http://support.automation.siemens.com/WW/view/en/39960679

[60] “Understanding Programmable Automation Controllers (PACs) in Industrial Automation Meet the Modern Industrial Application.”

[61] M. Alanazi, A. Mahmood, and M. J. M. Chowdhury, “SCADA vulnerabilities and attacks: A review of the state-of-the-art and open issues,” Feb. 01, 2023, *Elsevier Ltd*. doi: 10.1016/j.cose.2022.103028.

[62] T. Adams, “SCADA System Fundamentals Credit: 1 PDH SCADA System Fundamentals.”

[63] K. Borowski and A. Wojtulewicz, “Implementation of Robotic Kinematics Algorithm for Industrial Robot Model Using Microcontrollers,” in *IFAC-PapersOnLine*, Elsevier B.V., 2022, pp. 248–253. doi: 10.1016/j.ifacol.2022.06.041.

[64] P. Holeko, “Overview of distributed control systems formalisms.”

[65] Gavin Towler and Ray Sinnott, “Process Control in the Chemical Industries DISTRIBUTED CONTROL SYSTEMS,” 2016.

[66] K. V. S. Srinidhi, “Distributed Control Systems & it’s Industrial Applications,” 2020. [Online]. Available: www.ijeijournal.com

[67] T. Gross, K. Anderson, and N. Tsuchiya, "Programmable Automation Controller Mechatronic Experiment," *IAES International Journal of Robotics and Automation (IJRA)*, vol. 6, no. 1, p. 39, Mar. 2017, doi: 10.11591/ijra.v6i1.pp39-48.

[68] G. A. Gericke, H. Vermaak, and R. B. Kurakose, "Communication Protocol Review for SMART Manufacturing Units within a Cloud Manufacturing Environment," Nov. 2019. doi: DOI:10.1109/ICFIR.2019.8894788.

[69] D. Rico, K. J. Grinemmo, A. Brunstrom, and P. Merino, "Performance Analysis of the Multi-connection Tactile Internet Protocol over 5G," *Journal of Network and Systems Management*, vol. 31, no. 3, Jul. 2023, doi: 10.1007/s10922-023-09737-0.

[70] N. Promwongsa *et al.*, "A Comprehensive Survey of the Tactile Internet: State-of-the-art and Research Directions," Sep. 2020. doi: 10.1109/COMST.2020.3025995.

[71] V. Fanibhare, N. I. Sarkar, and A. Al-Anbuky, "A survey of the tactile internet: Design issues and challenges, applications, and future directions," *Electronics (Switzerland)*, vol. 10, no. 17, Sep. 2021, doi: 10.3390/electronics10172171.

[72] M. H. Miraz, M. Ali, P. S. Excell, and R. Picking, "A review on Internet of Things (IoT), Internet of Everything (IoE) and Internet of Nano Things (IoNT)," in *2015 Internet Technologies and Applications, ITA 2015 - Proceedings of the 6th International Conference*, Institute of Electrical and Electronics Engineers Inc., Nov. 2015, pp. 219–224. doi: 10.1109/ITechA.2015.7317398.

[73] L. T. Yang, B. Di Martino, and Q. Zhang, "Internet of Everything," 2017, *Hindawi Limited*. doi: 10.1155/2017/8035421.

[74] G. D. Monek and S. Fischer, "DES and IIoT fusion approach towards real-time synchronization of physical and digital components in manufacturing processes," *Reports in Mechanical Engineering*, vol. 4, no. 1, pp. 161–174, Dec. 2023, doi: 10.31181/rme040115092023m.

[75] F. M. Abdullah, A. M. Al-Ahmari, and S. Anwar, "Analyzing Interdependencies among Influencing Factors in Smart Manufacturing," *Sustainability (Switzerland)*, vol. 15, no. 4, Feb. 2023, doi: 10.3390/su15043864.

[76] J. Kim, H. R. Jeong, and H. Park, "Key Drivers and Performances of Smart Manufacturing Adoption: A Meta-Analysis," *Sustainability (Switzerland)*, vol. 15, no. 8, Apr. 2023, doi: 10.3390/su15086496.

[77] E. O'Connell, D. Moore, and T. Newe, "Challenges Associated with Implementing 5G in Manufacturing," Jun. 01, 2020, *MDPI*. doi: 10.3390/telecom1010005.

[78] J. John *et al.*, "Wireless Communications for Smart Manufacturing and Industrial IoT: Existing Technologies, 5G, and Beyond", doi: 10.48550/arXiv.2208.06697.

[79] A. Aijaz, M. Dohler, A. H. Aghvami, V. Friderikos, and M. Frodigh, "Realizing the Tactile Internet: Haptic Communications over Next Generation 5G Cellular Networks," Oct. 2015, doi: 10.1109/MWC.2016.1500157RP.

[80] S. Friston and A. Steed, "Measuring latency in virtual environments," *IEEE Trans Vis Comput Graph*, vol. 20, no. 4, pp. 616–625, 2014, doi: 10.1109/TVCG.2014.30.

[81] K. T. Chen, Y. C. Chang, P. H. Tseng, C. Y. Huang, and C. L. Lei, "Measuring the latency of cloud gaming systems," in *MM'11 - Proceedings of the 2011 ACM Multimedia Conference and Co-Located Workshops*, 2011, pp. 1269–1272. doi: 10.1145/2072298.2071991.

[82] D. Lan, Z. Pang, C. Fischione, Y. Liu, A. Taherkordi, and F. Eliassen, "Latency Analysis of Wireless Networks for Proximity Services in Smart Home and Building Automation: The Case of Thread," *IEEE Access*, vol. 7, pp. 4856–4867, 2019, doi: 10.1109/ACCESS.2018.2888939.

[83] D. Lindenschmitt *et al.*, "6G Underlayer Network Concepts for Ultra Reliable and Low Latency Communication in Manufacturing," Sep. 2023, [Online]. Available: http://arxiv.org/abs/2309.10624

[84] D. Muyizere, L. K. Letting, and B. B. Munyazikwiye, "Effects of Communication Signal Delay on the Power Grid: A Review," Mar. 01, 2022, *MDPI*. doi: 10.3390/electronics11060874.

[85] A. A. El-Saleh, M. A. Al Jahdhami, A. Alhammadi, Z. A. Shamsan, I. Shayea, and W. H. Hassan, "Measurements and Analyses of 4G/5G Mobile Broadband Networks: An Overview and a Case Study," *Wirel Commun Mob Comput*, vol. 2023, 2023, doi: 10.1155/2023/6205689.

[86] S. Sun, G. R. Maccartney, and T. S. Rappaport, "A novel millimeter-wave channel simulator and applications for 5G wireless communications," in *IEEE International Conference on Communications*, Institute of Electrical and Electronics Engineers Inc., Jul. 2017. doi: 10.1109/ICC.2017.7996792.

[87] T. I. Yahiya and P. Kirci, "Issues and Challenges Facing Low Latency in Tactile Internet," *UKH Journal of Science and Engineering*, vol. 3, no. 1, pp. 47–58, Jun. 2019, doi: 10.25079/ukhjse.v3n1y2019.pp47-58.

[88] D. S. Fowler *et al.*, "A 5G Automated-Guided Vehicle SME Testbed for Resilient Future Factories," *IEEE Open Journal of the Industrial Electronics Society*, vol. 4, pp. 242–258, 2023, doi: 10.1109/OJIES.2023.3291234.

[89] D. Miller and G. Bishop, "Latency Meter: A device to measure end-to-end latency of VE systems," 2024. [Online]. Available: http://www.cs.unc.edu

[90] M. R. Mine, "CHARACTERIZATION OF END-TO-END DELAYS IN HEAD-MOUNTED DISPLAY SYSTEMS," Mar. 2024.

[91] "NYUSIM User Manual," 2017. [Online]. Available: http://wireless.engineering.nyu.edu/5g-

[92] Alcatel-Lucent, "The LTE Network Architecture A comprehensive tutorial," 2009.

[93] Sumukh Bhandarkar and Ranjana Kammar, "4G Technology," Jan. 2016, doi: 10.5281/zenodo.158935.

[94] D. V Naik, ; Gaurav, and S. Kapdekar, "3G COMMUNICATION TECHNOLOGY (ADVANCE COMMUNICATION)," 2014. [Online]. Available: www.iosrjournals.org

[95] Gyokov Solutions, "G-NetTrack Pro Manual," 2018. Accessed: Jul. 10, 2024. [Online]. Available: http://www.gyokovsolutions.com/manuals/G-NetTrack_Pro-manual.pdf

[96] O. Akinmerese and F. Adedeji, "An Energy-Saving and Cost-Reduction Bandwidth Monitoring Model Using PRTG Monitoring Software," *Int J Innov Sci Res Technol*, vol. 8, no. 5, 2023, doi: 10.5281/zenodo.8008464.

[97] P. A. Paessler PRTG, "Monitoring IT, OT and IIoT with Paessler PRTG: use cases and dashboards," Apr. 2022.

[98] H. Metropolia, "Mats Nordin Implementing a monitoring system using PRTG," 2021. Accessed: Mar. 10, 2024. [Online]. Available: metropolia.fi.en

[99] PAessler GmbH, "prtgmanual," no. User Manual, 2024, Accessed: Nov. 10, 2024. [Online]. Available: https://www.paessler.com/prtg/history/stable

[100] S. J. Castro, "Bandwidth Optimization," 2009. [Online]. Available: https://www.researchgate.net/publication/259568465

[101] K. Jakimoski *et al.*, "Measurements of available bandwidth in computer networks," *International Journal of Grid and Distributed Computing*, vol. 9, no. 4, pp. 201–210, 2016, doi: 10.14257/ijgdc.2016.9.4.18.

[102] K. Ghanem, S. Ugwuanyi, R. Asif, and J. Irvine, "2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe) Virtual." [Online]. Available: https://pndc.co.uk

[103] J. Guojun, "Algorithms and Requirements for Measuring Network Bandwidth," Dec. 2002. Accessed: Mar. 10, 2025. [Online]. Available: https://escholarship.org/uc/item/0hz4670k

[104] J. Strauss, D. Katabi, and F. Kaashoek, "A Measurement Study of Available Bandwidth Estimation Tools *," 2003. doi: 10.1145/948205.94821.

[105] K. Lai, M. G. Baker, and M. Baker, "Measuring Bandwidth," 1999. [Online]. Available: https://www.researchgate.net/publication/2775891

[106] "4_pathload".

[107] R. Jain, "Internet Control Message Protocol," 1997. [Online]. Available: https://www.researchgate.net/publication/2449272

[108] "Internet Control Message Protocol."

[109] K. A. Tychola, K. Voulgaridis, and T. Lagkas, "Tactile IoT and 5G & beyond schemes as key enabling technologies for the future metaverse," Nov. 01, 2023, *Springer*. doi: 10.1007/s11235-023-01052-y.

[110] D. Zidic, T. Mastelic, I. Nizetic Kosovic, M. Cagalj, and J. Lorincz, "Analyses of ping-pong handovers in real 4G telecommunication networks," *Computer Networks*, vol. 227, May 2023, doi: 10.1016/j.comnet.2023.109699.

[111] D. Rico, M. del M. Gallardo, and P. Merino, "Verification of a multi-connectivity protocol for Tactile Internet applications," *Comput Commun*, vol. 212, pp. 390–406, Dec. 2023, doi: 10.1016/j.comcom.2023.10.013.

[112] D. Rico, M. del M. Gallardo, and P. Merino, "Verification of a multi-connectivity protocol for Tactile Internet applications," *Comput Commun*, vol. 212, pp. 390–406, Dec. 2023, doi: 10.1016/j.comcom.2023.10.013.

[113] ZTE Corporation, "Wi-Fi 6 Technology and Evolution White Paper," 2020.

[114] D. Nunez, F. Wilhelmi, L. Galati-Giordano, G. Geraci, and B. Bellalta, "Spatial Reuse in IEEE 802.11bn Coordinated Multi-AP WLANs: A Throughput Analysis," Jul. 2024, [Online]. Available: http://arxiv.org/abs/2407.16390

[115] D. Halperin, W. Hu, A. Sheth, and D. Wetherall, "802.11 with Multiple Antennas for Dummies," Jan. 2010.

[116] T. Raj, R. Mishra, P. Kumar, and A. Kapoor, "Advances in MIMO Antenna Design for 5G: A Comprehensive Review," Jul. 01, 2023, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/s23146329.

[117] M. Zhu, S. Gao, G. Tu, and D. Chen, "Multi-Access Edge Computing (MEC) Based on MIMO: A Survey," Apr. 01, 2023, *MDPI*. doi: 10.3390/s23083883.

[118] C. Yeh, G. Do Jo, Y. J. Ko, and H. K. Chung, "Perspectives on 6G wireless communications," Feb. 01, 2023, *Korean Institute of Communication Sciences*. doi: 10.1016/j.icte.2021.12.017.

[119] A. Aijaz, M. Dohler, A. H. Aghvami, V. Friderikos, and M. Frodigh, "Realizing the Tactile Internet: Haptic Communications over Next Generation 5G Cellular Networks," Oct. 2015, doi: 10.1109/MWC.2016.1500157RP.

[120] N. Bush, H. Meischke, and R. J. Robbins, "What Do We Mean by Internet Access? A Framework for Health Researchers," 2014.

[121] M. A. Habibi, M. Nasimi, B. Han, and H. D. Schotten, "A Comprehensive Survey of RAN Architectures Toward 5G Mobile Communication System," 2019, *Institute of Electrical and Electronics Engineers Inc.* doi: 10.1109/ACCESS.2019.2919657.

[122] S. V. Singh, A. Khursheed, and Z. Alam, "Wired Communication Technologies and Networks for Smart Grid—A Review," in *Studies in Computational Intelligence*, vol. 1007, Springer Science and Business Media Deutschland GmbH, 2022, pp. 183–195. doi: 10.1007/978-981-16-8012-0_15.

[123] A. Huynh, "Study of Wired and Wireless Data Transmissions Wired and Wireless Data Transmission," 2010.

[124] K. Renaud and L. Coles-Kemp, "Accessible and Inclusive Cyber Security: A Nuanced and Complex Challenge," *SN Comput Sci*, vol. 3, no. 5, Sep. 2022, doi: 10.1007/s42979-022-01239-1.

[125] J. Li, D. Della Penda, H. Sahlin, and P. Schliwa-Bertling, "An Overview of 5G System Accessibility Differentiation and Control," 2012.

[126] G. P. fettwis, "The Tactile Internet – Applications & Challenges," *IEEE Vehicular Technology Magazine*, no. TU Dresden, Germany, Mar. 2024.

[127] S. Marzia and A. Azab, "Manufacturing Letters Automated Process Planning and Dynamic Scheduling for Smart Manufacturing: A Systematic Literature Review-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0) Peer-review under responsibility of the Scientific Committee of the NAMRI/SME," 2023, [Online]. Available: www.sciencedirect.com

[128] A. Kumar, "3G Networks: Opportunities and Challenges," *Bulletin of Mathematical Sciences and Applications*, vol. 3, pp. 28–36, Feb. 2013, doi: 10.18052/www.scipress.com/bmsa.3.28.

[129] A. Talaat, "LTE fundamentals and system architect," Nokia Siemens Networks, NSN Saudi - NPO, 2020.

[130] R. Jansen and T. Noren, "Long Term Evolution (LTE): An Introduction, rev A," Ericsson, White Paper, Oct. 2007.

[131] M. J. Alam, M. R. Hossain, S. Azad, and R. Chugh, "An overview of LTE/LTE-A heterogeneous networks for 5G and beyond," Aug. 01, 2023, *John Wiley and Sons Inc*. doi: 10.1002/ett.4806.

[132] P. Paudel and A. Bhattarai, "5G Telecommunication Technology: History, Overview, Requirements and Use Case Scenario in Context of Nepal."

[133] J. V. Cordeiro, N. Kubota, H. Kao, H. Li, and C. Guo, "Application of 5G network combined with AI robots in personalized nursing in China: A literature review."

[134] Y. Banday, G. M. Rather, and G. Rasool Begh, "Effect of atmospheric absorption on millimetre wave frequencies for 5G cellular networks," Feb. 19, 2019, *Institution of Engineering and Technology*. doi: 10.1049/iet-com.2018.5044.

[135] R. Singh, W. Lehr, D. Sicker, K. Mohammed, and S. Huq, "Beyond 5G: The Role of THz Spectrum." [Online]. Available: https://ssrn.com/abstract=3426810

[136] A. Tikhomirov, E. Omelyanchuk, and A. Semenova, "Recommended 5G frequency bands evaluation," in *2018 Systems of Signals Generating and Processing in the Field of on Board*

Communications, Institute of Electrical and Electronics Engineers Inc., Apr. 2018, pp. 1–4. doi: 10.1109/SOSG.2018.8350639.

[137] R. Dilli, "Analysis of 5G Wireless Systems in FR1 and FR2 Frequency Bands," in *2nd International Conference on Innovative Mechanisms for Industry Applications, ICIMIA 2020 - Conference Proceedings*, Institute of Electrical and Electronics Engineers Inc., Mar. 2020, pp. 767–772. doi: 10.1109/ICIMIA48430.2020.9074973.

[138] B. Junying and A. Yongli, "Research and Development of Millimeter Wave Technology," *International Journal of Advanced Network, Monitoring and Controls*, vol. 4, no. 3, pp. 73–78, Jan. 2019, doi: 10.21307/ijanmc-2019-061.

[139] W. C. and Mobile Computing, "Retracted: Visual Communication Design Based on 5G Technology," *Wirel Commun Mob Comput*, vol. 2023, pp. 1–1, Jul. 2023, doi: 10.1155/2023/9839464.

[140] M. Lefki, S. Baccar, H. Shall, M. Ghorbel, and M. Kadi, "5G Ambient Backscatter Communications: Achievable Range and Power Levels in an Urban Environment," in *2022 IEEE 12th International Conference on RFID Technology and Applications, RFID-TA 2022*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 74–77. doi: 10.1109/RFID-TA54958.2022.9924037.

[141] 5G-PPP, "5G Vision- The 5G Infrastructure Public Private Partnership: the next generation of communication networks and services.," 2020.

[142] G. Gericke, R. B. Kuriakose, H. Vermaak, and O. Madsen, "The Impact of Communication Protocols Within SMART Manufacturing and Their Benefits," *International Journal of Simulation Systems Science & Technology*, Mar. 2020, doi: 10.5013/ijssst.a.21.02.22.

[143] C. Xu *et al.*, "5G-Based Industrial Wireless Controller: Protocol Adaptation, Prototype Development, and Experimental Evaluation," *Actuators*, vol. 12, no. 2, Feb. 2023, doi: 10.3390/act12020049.

[144] Mesa Electronics, "7I76E/7I76ED ETHERNET STEP/DIR PLUS I/O DAUGHTERCARD," 2019.

[145] V. Vujović and M. Maksimović, "Raspberry Pi as a Wireless Sensor node: Performances and constraints," in *2014 37th International Convention on Information and Communication Technology, Electronics and Microelectronics, MIPRO 2014 - Proceedings*, IEEE Computer Society, 2014, pp. 1013–1018. doi: 10.1109/MIPRO.2014.6859717.

[146] "Deliverable D2.1 DESIGN OF 5G-BASED TESTBED FOR INDUSTRIAL ROBOTICS." [Online]. Available: www.5gsmart.eu

[147] Siemens Industrials, "Configuration of a VXLAN tunnel between a SCALANCE MUM85x-1 and a SCALANCE SC-600," 2022. [Online]. Available: https://www.siemens.com/industrialsecurity.

[148] Siemens AG, "SCALANCE MUM856-1," 2023. doi: SiemensIndustrials.

[149] Chol Kour and Mika Oinonen, "Transfer of Production PLC Data to a Database System," 2021. doi: 10.13140/RG.2.2.16257.63844.

[150] V. B. Ramu, "Performance Testing for Hybrid Cloud Environments," *The Review of Contemporary Scientific and Academic Studies*, vol. 3, no. 7, Jul. 2023, doi: 10.55454/rcsas.3.07.2023.005.

[151] A. Krishnan, H. J. Lee, J. Emontsbotz, and S. Brell-Cokcan, "Bridging depths and data in mines: 5G-based point cloud mapping in unstructured environments," *Construction Robotics*, vol. 8, no. 1, Jun. 2024, doi: 10.1007/s41693-024-00114-0.

[152] S. Manual, "S7-1200 Programmable controller," 2012. [Online]. Available: http://www.siemens.com/automation/

[153] S. Industry Automation and D. Technologies - http, "SIMATIC S7 S7-1200 Programmable controller." [Online]. Available: https://www.automation.siemens.com/mdm/default.aspx?DocVersionId=41524141835&Language=en-US&TopicId=40816548235

[154] M. Simsek, A. Aijaz, M. Dohler, J. Sachs, and G. Fettweis, "5G-Enabled Tactile Internet," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 3, pp. 460–473, Mar. 2016, doi: 10.1109/JSAC.2016.2525398.

[155] K. A. Tychola, K. Voulgaridis, and T. Lagkas, "Tactile IoT and 5G & beyond schemes as key enabling technologies for the future metaverse," Nov. 01, 2023, *Springer*. doi: 10.1007/s11235-023-01052-y.

[156] P. Joshi, "Multi-sensory data transmission using 5G and B5G enabled network for healthcare: survey," Dec. 01, 2024, *Springer Nature*. doi: 10.1007/s43926-024-00067-4.

[157] V. Fanibhare, N. I. Sarkar, and A. Al-Anbuky, "A Study of Downlink Power-Domain Non-Orthogonal Multiple Access Performance in Tactile Internet Employing Sensors and Actuators," *Sensors*, vol. 24, no. 22, Nov. 2024, doi: 10.3390/s24227220.

[158] G. Dickmann, "digitalSTROM ® : A centralized PLC Topology for Home Automation and Energy Management," Udine, Italy, May 2011. doi: 10.1109/ISPLC.2011.5764421.

[159] A. Salkic, H. Muhovic, and D. Jokic, "Siemens S7-1200 PLC DC Motor control capabilities," in *IFAC-PapersOnLine*, Elsevier B.V., 2022, pp. 103–108. doi: 10.1016/j.ifacol.2022.06.017.

[160] S. Industry Online Support, "Programming Guideline for S7-1200/1500 TIA Portal," Dec. 2018. [Online]. Available: https://www.siemens.com/industrialsecurity.

[161] S. Manual, "S7-1200 Programmable controller," 2012. [Online]. Available: http://www.siemens.com/automation/

[162] C. Y. Lin and S. Nadjm-Tehrani, "Protocol study and anomaly detection for server-driven traffic in SCADA networks," *International Journal of Critical Infrastructure Protection*, vol. 42, Sep. 2023, doi: 10.1016/j.ijcip.2023.100612.

[163] K. Technologies, "KEPServerEX V6," 2022. Accessed: Mar. 10, 2024. [Online]. Available: www.ptc.com

[164] K. Technologies, "Manufacturing Suite for KEPServerEX," Portland, Maine 04101, 2012. [Online]. Available: www.kepware.com

[165] L. Paananen, "IEC 61850 and KEPServerEX Data Communication in a Power Plant En-vironment," May 2024.

[166] J. Kopec, M. Pekarcikova, M. Kliment, and J. Trojan, "Case study of using KEPServerEX software as a connection tool between Tecnomatix Plant Simulation and a real device," *Acta Tecnología*, vol. 9, no. 3, pp. 85–89, Sep. 2023, doi: 10.22306/atec.v9i3.175.

[167] M. Ladegourdie and J. Kua, "Performance Analysis of OPC UA for Industrial Interoperability towards Industry 4.0," *Internet of Things*, vol. 3, no. 4, pp. 507–525, Dec. 2022, doi: 10.3390/iot3040027.

[168] Siemens AG, "TeleService of a S7-1200 station via mobile network," 2018. [Online]. Available: https://www.siemens.com/industrialsecurity.

[169] T. Gateway FAQ, "Service & Support Answers for industry. Teleservice of an S7-1200 over Internet/GPRS," 2013. [Online]. Available: www.siemens.com/nutzungsbedingungen.