NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY
[IJIERT] ISSN: 2394-3696 Website: ijiert.org
VOLUME 10, ISSUE 12, December -2023

A COMPREHENSIVE REVIEW OF WIRELESS SENSOR NETWORKS TO ENHANCE RAILWAY NETWORK OPERATIONS SYSTEMS

Tracy Hellen Nakaibaale
Africa Railway Center of Excellence-Addis Ababa Institute of Technology, AAU.

Birhanu Reesom Bisrat
Africa Railway Center of Excellence-Addis Ababa Institute of Technology, AAU.

Abstract

For decades, the railway infrastructure has been a pillar of the transportation infrastructure through its connection of towns and enabling the movement of people and freight on a worldwide scale. Railways have revolutionized transit from the earliest steam-powered locomotives to the latest high-speed trains. Today's railways are still developing due to technological improvements, with a focus on improving sustainability, efficiency, and safety. In the railway industry, Wireless Sensor Networks (WSNs) play a crucial role in addressing concerns such as security, safety, and traffic flow. These networks consist of sensors that gather real-time data to monitor current conditions, which accelerates decision-making and facilitates real-time monitoring, increasing efficiency. This review explores the fundamentals of wireless sensor networks i.e., characteristics of some of the most popular wireless communication technologies (Zigbee, Wi-Fi, GSM-R, LTE, Bluetooth, etc.), network topologies (star, mesh, tree, etc.) and the structure of the sensor nodes. Further, this paper also surveys the different types of wireless sensors used to monitor and detect faults in railway infrastructure (trains, tracks, bogies, wagons, and signaling infrastructure) and their applications. This paper outlines the benefits of integrating wireless sensors with railway infrastructures in crucial systems like signaling, traction, train control systems, etc., highlighting their advantages and challenges. In conclusion, WSN plays a major role in enhancing train and traction control safety, security, and efficiency.

Keywords: Wireless sensor Networks (WSNs), enhanced railway safety, railway sensors, wireless network technologies, railway industry.

1. INTRODUCTION

The railway industry has been in steady revolutionization right from the 18th century to date in order to meet the needs of a fast-growing globalized world. It has contributed greatly to the economic and social development of various places through its passenger and freight transportation. The railway industry all over the world is heavily investing in technologies with an estimation of over US$300 billion worth of investment since 2009 which has enhanced their infrastructure to increase rail efficiency, and reliability and to minimize maintenance costs [1]. However, there have been collision occurrences in some parts of the world due to a lack of monitoring systems for example in October 2016, a train in Cameroon that was traveling “abnormally” fast before the crash as reported by the investigation killed at least 79 people and injured about 550 others [2] and another collision happened in February 2023 between a freight train and passenger train on the route between Greece’s capital, Athens and Thessaloniki killing 57 people as reported in Al Jazeera [2]. Just like other means of transport, Railway transportation needs to be carefully assessed and monitored regularly [3].

The Wireless Sensor Network technology is crucial for the future expansion of the railway industry which is necessary to improve security, safety, condition monitoring, and risk management. The WSN system consists of multiple sensor points with each node equipped with a sensor. Wireless sensor networks are an innovative way to gather information and improve communication systems, leading to greater reliability and efficiency in railways. The wireless networks are controlled by a set of rules called wireless communication protocols which governs the way wireless devices receive and transmit data. The most commonly used in railway systems include Wi-Fi(Wireless Fidelity), Zigbee, LTE, GSM-R(Global System for Mobile Communications-Railways), and Bluetooth [4, 5]. Compared to wired solutions, WSN systems offer better positioning and greater flexibility [6]. WSNs are becoming increasingly popular for monitoring and tracking on a large scale due to their low-energy consumption, low data rate, and short-range network. This network allows for monitoring and controlling the physical world on a previously unattainable scale and resolution. The installation of many wireless sensors that can collect, process, and transmit information to external systems such as the satellite network or the Internet opens up new areas of application [7].

Due to its ability to operate in remote areas and simple deployment process, a wireless sensor network is a suitable option for an advanced signaling system for railways. Upon comparing it to the traditional signaling method, it is evident that implementing a Wireless Sensor Network in Railway Signaling System will enhance the railways' efficiency [8]. Continuous and near real-time data acquisition is made possible through WSN monitoring without any need for supervision. Compared to manual inspection, WSN monitoring allows for increased monitoring frequency [1]. All data can be collected and processed centrally, resulting in improved data accessibility, management, and utilization compared to non-networked systems. Intelligent algorithms are employed to analyze data and enable "predict and prevent" capabilities. WSN monitoring can also provide information about the status of important structures, infrastructure, and machinery by turning data into actionable insights. Finally, a global data view allows for trending information to be detected, especially in cases where degradation occurs slowly over a long period of time [1].

Analysis of Related Survey Articles.

Majority of the historical research has used a descriptive approach to look into the heavy work on wireless sensor networks in relation to railway infrastructure. For example [8] carried out a survey on wireless sensors networks with major emphasis on the railway signaling system, [9] proposed a wireless sensor network based model for secure railway operations that was proposed for the rail tracks, [10] also conducted an evaluation on WSN with emphasis on the applications and train control systems, [1] performed an assessment on WSNs for condition monitoring in the railway industry. Other authors and researchers put major emphasis on the wireless sensors in the railway industry and not necessarily the networks and technologies that may be involved for example [11] who focused on the fiber optic sensors. [12] accomplished a revision on the wireless sensors with emphasis on the rail defect detection. [13] conducted laboratory experiments to prove MEMs technologies for smarter railway infrastructure and lastly [6] also accomplished a revision on WSN for smarter railway stations but with less emphasis on the related technologies.

However, not many articles have tackled the wireless sensor network in the railway industry as a whole, instead they investigated a particular aspect of the system, with less emphasis on the WSN technologies, sensors, applications, and future expectations; as a result, this review is emphasizing the above to give the reader a more thorough study and systematic framework of these wireless sensor networks in relation to the railway industry.

Railway infrastructure can be categorized into 3 categories i.e, electrical, mechanical and civil infrastructure.

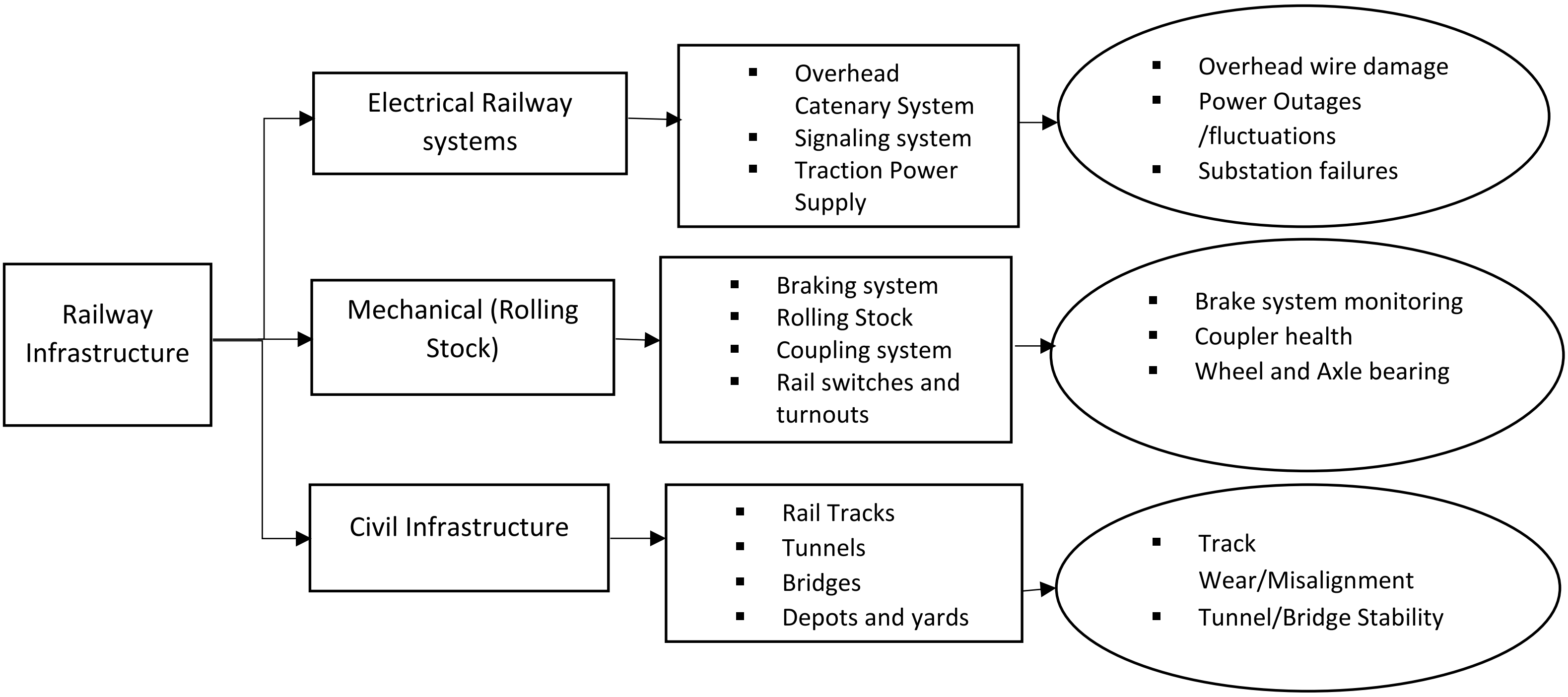

Figure 1: Showing railway infrastructure and the problems faced.

2. Fundamentals of Wireless Sensor Networks

WSNs, or wireless sensor networks, are networks made up of sensor nodes that can communicate wirelessly with one another. These sensor nodes have various capabilities depending on the application, and they connect with one another via protocols like Wi-Fi, Bluetooth, Zigbee, etc. In WSNs, various topologies, including mesh, star, etc., exist. Through studying and analyzing the fundamentals of WSN networks, we are able to unveil the efficiency of WSN applications in the railway industry.

2.1 Sensor Nodes

The creation of affordable, low-power, compact, and multipurpose sensor nodes is the result of advancements in wireless communications and electronics. These nodes are equipped with a microprocessor, RAM, a radio transmitter, a portable power supply, and a few sensors to communicate with the outside world. They can communicate through a LAN and are impacted by elements such as the application, operational environment, measurement type, sensor size, power consumption, resilience, and lifetime of the sensing element. A sensor network's design must take into account the choice of sensor, where to install it, how to supply power, how to transmit and store data, and how to analyze the data. A sensing subsystem, a computing subsystem, a short range radio system and a battery powered power supply subsystem make up the four basic subsystems of a sensor node.[1, 7]

1. A sensing subsystem that monitors the physical environment by using one or more sensors and actuators.
2. A computing subsystem with memories to store and process the data gathered by the sensor subsystem and comprised of a microcontroller or microprocessor.
3. A short-range radio system for wireless data communication in a communication subsystem.

4. A battery-powered power supply subsystem that runs the entire sensor node. If energy-harvesting methods are used, the power supply subsystem may also comprise a generator.

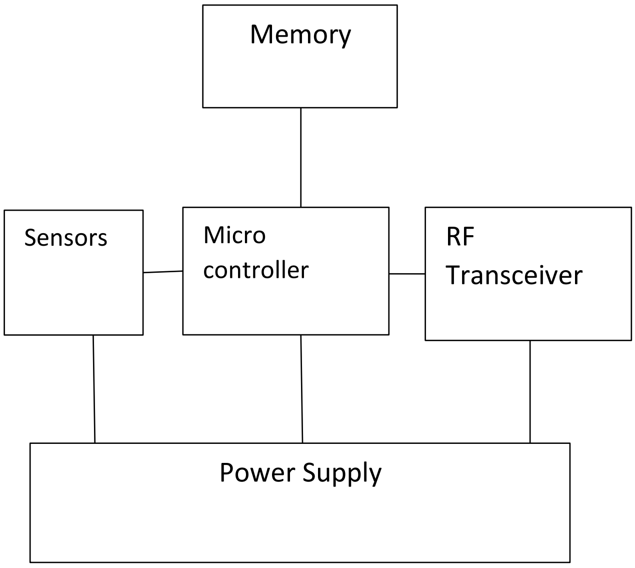

Figure 2: Schematic architecture of a wireless sensor node [7]

2.2 Transmission Technologies/Wireless Network Protocols.

The five layers in railway monitoring WSNs are physical, data link, network, transport, and application. The physical layer transmits sensor data, while the data link layer specifies network topology and manages access, permissions, and error checking. The network layer routes data as packets, considering energy constraints, and the transport layer controls data sending and receiving. Access to the data is made possible by the application layer [1].

Wireless network protocols are standards/set of rules that govern the way wireless devices receive and transmit data. The following are the types;

2.2.1 Bluetooth

2.2.2 Wi-Fi (Wireless Fidelity)

Wi-Fi is a Wireless local area networking (WLAN) technology created to offer 54 Mbps data rates for in-building internet coverage, often covering an area of 100 meters indoors [16]. It has a network standard of IEEE 802.11. Wi-Fi often needs a main power supply and is utilized for applications with significant data throughput [7]. Data is sent from the sensor nodes to the base station using short-range communication methods like Wi-Fi [1]. Because Wi-Fi nodes require a lot of power, it is important to locate them where regular battery replacement and charging are simpler. This is crucial for establishing a reliable network.

[Wi-Fi devices can support increased bandwidth up to several Mb/s, which is very advantageous in the railway network [17].*]*

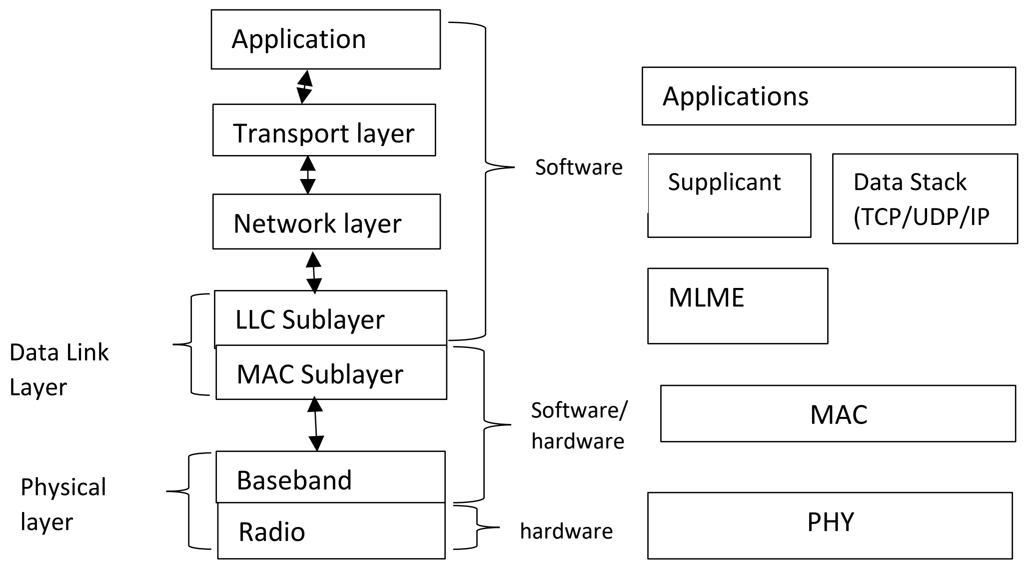

Figure 4 : Wi-Fi protocol stack [18]

2.2.3 Zigbee

This is a communication protocol that was created by Zigbee Alliance based on the network standard of IEEE802.15.4. It is one of the most widely used wireless sensor Network transceiver standard in wireless networks [19]. ZigBee is a wireless networking standard that is used to enable remote control and sensor applications in radio settings and remote places [15]. This low power wireless communication protocol is intended for applications involving remote monitoring and control. In order to support high-level, low-cost communication protocols, Zigbee was developed as a standard. This allows small low power digital radios to be used to establish personal area networks that can simultaneously send data over extended distances. Several topologies are supported by Zigbee for example star, mesh and tree network technology [4]. The following are the reasons for using Zigbee; easy to deploy, low cost, used globally, secure, very long battery life, open standards protocol with little or no licensing fees, supports a large number of nodes, reliable and self-healing, low maintenance, standards based security[AES128] etc., [19]. All of the security measures suggested by IEEE 802.15.4 (such as message encryption) are included in ZigBee [12].

[With reference to railway industry, it enables a variety of monitoring and control applications to run for years on affordable batteries [20]. The problems of eavesdropping, traffic analysis, disruption of the sensor application, or hijacking have been studied by numerous research scientists and engineers. For use in Structure Health Monitoring (SHM), ZigBee has proven to be a dependable, practical, and efficient wireless sensor technology [12].]

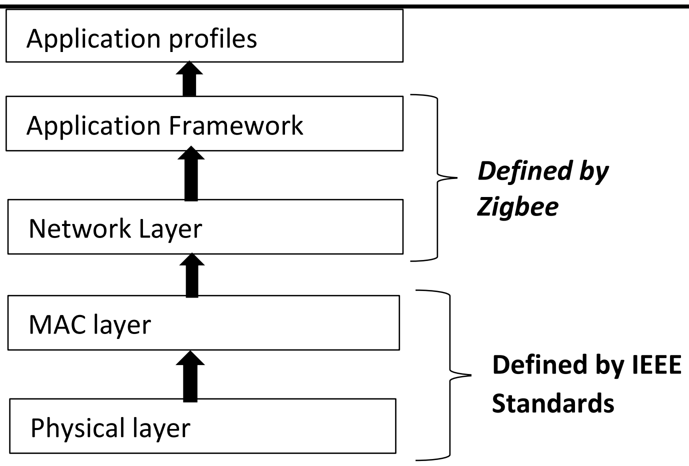

Figure 5: Zigbee Protocol Stack [7]

2.2.4 GSM-R (Global System for Mobile Communications – Railways)

GSM-R is a wireless communication protocol that is basically GSM standard with railway features. Train communications and applications use the global wireless communications standard GSM-R [21]. Throughout the world, GSM-R is used on more than 70000 km of railway lines, including more than 22000 km of HSR lines. It uses a particular frequency range between 800 and 900 MHz [22]. Dedicated base stations placed close to the train track are often used to execute GSM-R. It needs to meet the HSR radio services' strict availability and performance standards. ETCS (European Train Control System), the European signaling system used for railway control uses the GSM-R network as a data carrier. The most specialized services provided by GSM-R are Voice Group Call Service(VGCS), Voice Broadcast Service(VBS), enhanced Multilevel Precedence and Preemption(eMLPP), Shunting mode, Functional Addressing and Location Dependent Addressing(LDA) [22].

[By facilitating secure, dependable communication between drivers, signallers, rolling stock, and railway regulation control, GSM-R improves safety, operational efficiency, and staff cooperation in railway operations.]

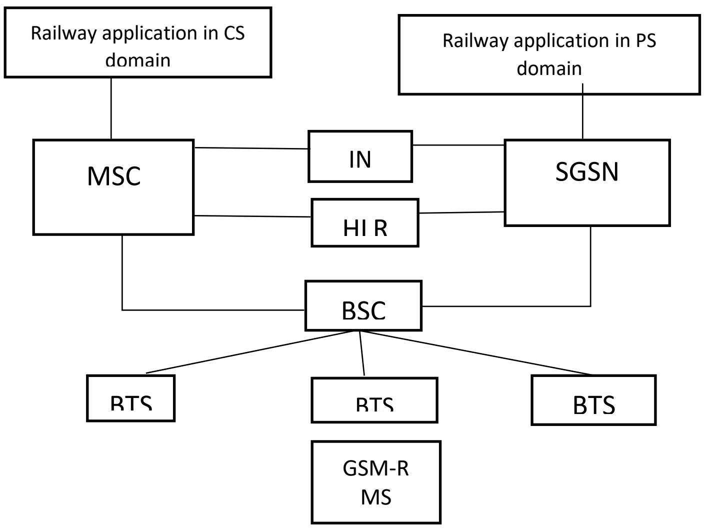

Figure 6: Network Architecture of GSM-R [21].

2.2.5 LTE-R (Long Term Evolution-Railways)

The entirety of the critical elements of LTE are carried over into LTE-R, which also offers an additional radio access system for wireless signal exchange with onboard equipment to meet the specifications of the railway industry [22]. LTE-R's access network structure is E-UTRAN, while the core network is EPC [21]. LTE-R is a network that is entirely packet switched. Most LTE-R frequencies are now 450MHz, 800MHz, 1.4GHz, and 1.8GHz, with a bandwidth of 1.4MHz - 20MHz. LTE-R functions include real-time monitoring, control system information transmission, train multimedia dispatching, railway emergency communications, and the Railway Internet of Things [22].

[LTE-R offers the following benefits for enhanced railway services: fast data rate, packet transmission, low latency, wide area coverage, and backwards compatibility.[21]]

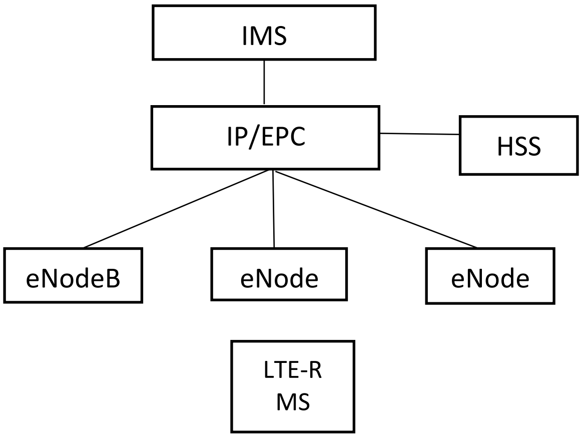

Figure 7: Network architecture of LTE-R [21]

2.2.6 5G technology.

The fifth generation(5G) is the most recent development in mobile telecommunication standards as it offers multi-technology solution to meet diverse capacity and service quality needs. In order to offer faster data transfer rates, lower latency, expanded network capacity, and improved dependability, the fifth generation of mobile communication, or 5G, combines existing and upcoming radio access technologies [23]. In order to realize 5G services, employment of key techniques is required. These include; massive (multiple-input multiple-output) MIMO, Millimeter Wave, Ultra Reliable Low Latency Communications (URLLC), Network slicing and non-orthogonal multiple access (NOMA) [22, 23].

- Massive MIMO (multiple-input multiple-output) :- Massive MIMO, originally called "large-scale antenna systems," offers significant spectral efficiency enhancements without increasing BS densification. It smooths channel responses due to vast spatial diversity, reducing small-scale randomness. The quasi-orthogonal nature of channels between BS and active users sharpens orthogonality, allowing simple linear transceivers and single-user beamforming to perform optimally [25].
- Millimeter Wave(mmWave): - The exploration of millimeter wave bands for 5G, such as Ka-band, license-free band, and E-band, is driven by the need for higher data rates. However, cell size reduction and new network architecture are needed. Beam management, a crucial factor, is essential to address high isotropic free-space path loss and blockage issues in mmWave transmissions [24].
- Ultra-Reliable Low Latency Communications (uRLLC): - 5G uRLLC for railway is made possible by edge computing, big data, and artificial intelligence, offering self-learning intelligence and low latency

data connectivity. Synchronized operations, over-the-air coordination, and traffic prioritization are examples of technical challenges [22, 23].

- Non-orthogonal multiple access (NOMA) :- Non-orthogonal multiple access (NOMA) allows multiple UEs to use the same time, code, space, and frequency resources, with strong processing capability for interference cancellation key for 5G networks and IoT device grant-free access[24].
- Network slicing :- The KPIs of 5G networks serve a variety of businesses, including vital communications, IoT, and vehicle-to-everything (V2X) communications, however network slicing should address multi-slice linked user equipment as well as unresolved concerns [24].

  [5G technology can improve railway scenarios by enabling IoT and blockchain, providing ubiquitous perception of components and environments. It can also utilize edge computing, big data, and artificial intelligence for self-learning intelligence and smoother virtual reality, enhancing rail service experiences.[23]]

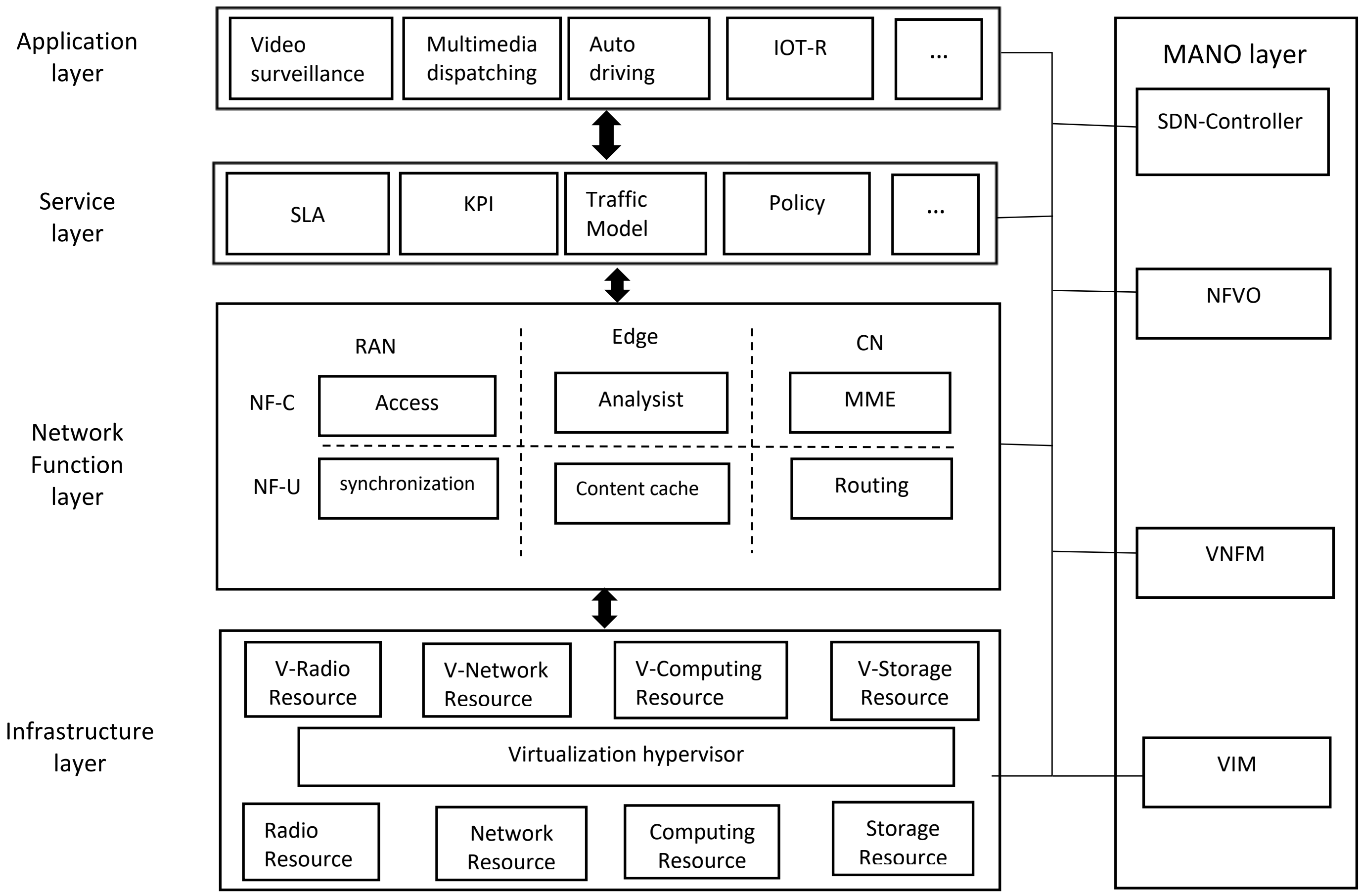

Figure 8: 5G network architecture for railway [24]

2.3 Wireless Network Topologies.

Modern connectivity is based on network topologies, which specify how devices are connected to one another for collaboration, data sharing, and communication. For networks to be effective and resilient, it is essential to comprehend various topologies. In addition to network performance, they control data flow. Star, tree, and mesh topologies are the natural topology options accessible for WSNs in rail applications [1].

2.3.1 Star topology

The star topology is a simple and easy-to-achieve network structure where a coordinator is the center node, connecting devices like routers and end devices. However, it is not suitable for large-scale applications due to its limitations and the potential impact of the center node's failure on the entire network [7]. The advantages of the star topology include short network delay time, a simple structure, and easy maintenance and the disadvantages include low line utilization and heavy central node load [12]. In the railway industry, the star topology, has a single base station that can send and receive messages to multiple remote sensor nodes, resulting in fewer transmissions and collisions and low communication latency. However, it requires the base station to be within the transmission range of all nodes, and is not robust due to its dependence on a single base station [1].

2.3.2 Tree topology

Unlike star topology, tree topology allows for deployment without being constrained by the coordinator. It is a more adaptable network structure. Routers can be used to adopt sub-devices to extend it [7]. The root node of the tree network serves client nodes and lower-level nodes. The tree network is a hierarchy of nodes. All levels of nodes allow for grouping and scaling. When a sensor node is within transmission range of its parent node or other nodes, messages can be sent through the tree's branches to the root [1]. The substantial dependence of each node on the root is a drawback of tree topology, despite its benefits of simplicity, ease of maintenance, and ease of expansion [12].

2.3.3 Mesh topology

Similar to a tree topology, the mesh topology is a flexible network layout that enables routers to connect without first forwarding messages to the parent device. It is an amplified star topology that enables router nodes to configure communication flows to aggregate at a single location. A star or tree network, however, cannot be extended to a mesh network [7]. This permits indirect communication with nodes that are outside of their communication range, multi-hop communication, and low transmission power. The network includes fault tolerance and is easily expandable [1].

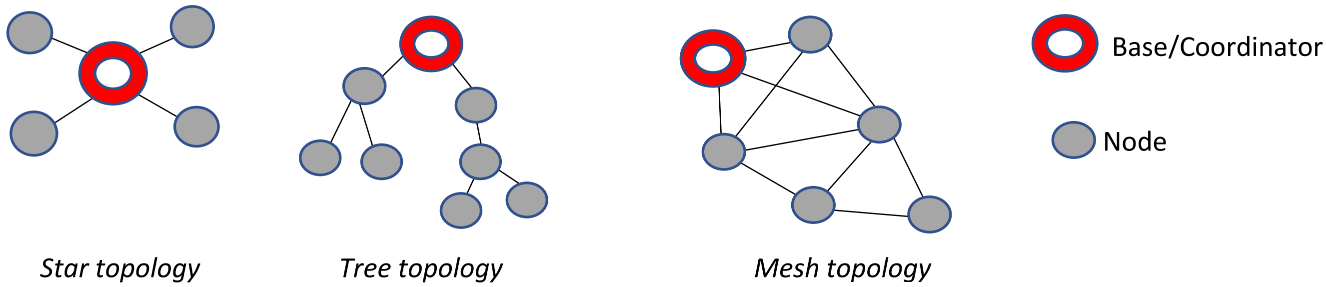

Figure 9: Network topologies [1, 7]

3. Applications of WSNs in the Railway industry

A. WSNs in Railway Signaling Systems

Supervisors currently receive warning messages about faults but struggle to obtain specific information about signaling equipment. A real-time monitoring and maintenance system is needed to address this issue. Mass transit systems often have inefficiencies, such as waiting for passengers, indirect routes, and inconsistent schedules. The Wireless Sensor Network-based Signaling scheme aims to eliminate these wastes by providing efficient signaling and accurate train location management [8].

B. WSNs prevent Rail Car Slippage and Derailments.

Wireless sensors Networks are utilized in the common anti-slippage systems, such as the Anti-Runway Prevention System (ARPS), which was developed on track skates. The data is detected and communicated over a radio frequency network through a micro-power wireless communication module. By enabling fewer derailment accidents and lowering the possibility of human mistake that may be induced by carelessness in the operations, the technology improves the safety of the railway stations. As a result of the system's automatic recording and analysis of the anti-runaway function's condition, employment expenses are also greatly reduced [6].

C. WSNs Identify and evaluate the railway system

Researchers have developed systems for analyzing train carriages, wagons, and engines using wireless sensor networks. These systems measure vibration, provide weight, speed, and integrity assessments, and measure strain and temperature. Sensor-enabled ambient-intelligent telemetry for trains (SEAIT) is used for unpowered freight wagons. A wear detection system for train wheels is also developed for wheel condition assessment [26].

D. WSNs facilitate heavy haul transportation

Railway freights are used for large haul transportation. By putting air pressure sensors, accelerometers, and ultrasonic sensors along the track, wireless sensor networks increase traffic volume and decrease the need for maintenance and inspections. If a leading locomotive brakes, relay nodes on the train or track transmit the information to other locomotives, allowing them to set brakes accordingly [6].

E. WSNs Forecast Track Inclinations and deflections

A preliminary series of experiments has been conducted to confirm that the wireless sensors may be used to predict track inclinations in order to assure train stability, passenger comfort, optimize track efficiency, and determine preventive maintenance. Track inclines can be connected to deflections or used to assess condition directly [9].

F. WSNs employed in WSRDDS systems.

Wireless communication and self-organizing networks enable real-time transmission of sensing device information, making wireless sensor networks ideal for real-time rail defect detection. Researchers have established WSN models for railway safety, laying the foundation for wireless sensor-based rail defect detection systems (WSRDDS) systems [12]. Zhan developed a wireless sensor system for rail fastener detection [27].

G. Improved railway security

Railway systems need online monitoring for security and safety. WSN integration with CCTV, digital video recording, and media management systems provides more effective monitoring and faster response times for video-based intrusions [10]. With the aid of these wireless sensors, unauthorized entry may be stopped, urban vandalism can be averted, the true condition of the tracks can be seen, and false alerts can be disregarded.

Table 1: Shows the different sensors used in WSN.

	Type of Sensor	Description	Usage
1.	Magnetoelectric	When a magnetic field is applied, they cause an electric polarization in the material. Since they are powered by induction, they are passive and don't need a power source (battery).[1]	They can be used to analyze magnetic fields in current-carrying electrical wires[1] and to monitor the current by doing so.[6]
2.	Fiber Optical Sensors	FBG(Fiber Bragg Gratings)and interferometry are two different techniques of this sensor, where FBG controls high resolution strains and interferometry handles quasi-distributed strains.[11] They have remarkable sensitivity, are resistant to electromagnetic interference.[1]	The FOC is a tool for measuring temperature, strain, and acceleration [6]and can work in challenging environments.[11] They are appropriate for usage in electrified railway and close to power lines where EMI is high since they are impervious to it.[1] They have the capacity to gauge consistently distributed physical values along the length of the fibre, such as displacements, inclinations, and strains. Possibility of long-term monitoring, extensive measurements (up to several km), and early detection of threats related to infrastructure damage.[11]
3.	Strain gauges	They are cost-effective, straightforward, accurate, and tiny in size.[1], [12]	They are used to detect minor surface and embedded defects such as pitting, fatigue splitting, impact damage[26], damaged or missing fasteners[12], and so on. They measure local stresses and provide a signal that reflects the strain given to the sensor, and they frequently assess the vertical and lateral force delivered to the rail between two sleepers at train passes.[1]
4.	Accelerometer	They are sturdy, reliable, simple to calibrate, and inexpensive, with compact size[1], and low precision.[12]	They detect surface defects/rail defects[12], faulty wheels and bearings, track geometry anomalies, and acceleration. [11]They assess vibrations on infrastructure such as metal tracks or bridge girders, as well as lateral accelerations of mechanics such as wheels.[1] Commonly used in combination with strain gauges. They have been used to measure the vibration of railway tracks, other infrastructure pieces, including train wheels. [6]
5.	Gyroscope	It has a rotating wheel/disc which uses the operating principle of conservation of angular momentum.	It measures the angular velocity of the train around the exes.[13] They are suitable for analyzing carriages, chassis, and bogies since they are integrated into inspection programmes that measure the rotation of vehicles around axes in the train, namely longitudinal, lateral, and vertical accelerations as well as pitch, roll, and yaw.[1]
6.	Inclinometers	It calculates the degree to which an item slopes, tilts, rises, or depresses in relation to gravity.	They identify alterations in the slope of railway infrastructures.[6] In order to spot sabotage or broken bonds, they also measure settlement, monitor twist, and monitor ties. Additionally, the angular tilt with respect to an artificial horizon is used to calculate the slope angle. By monitoring inclination changes, they can identify distortion in railway structures.[1]
7.	Temperature sensors	Temperature sensors come in a wide variety and are divided into 4 classes with their respective temperature ranges i.e., Thermocouple(-190 to 1821^{0}C), Resistance Temperature Detector (RTD)(-200 to 850^{0}C), Thermistor(-90 to 130^{0}C) and Integrated Circuit temp. sensor(-55 to 150^{0}C)[7]	Temperature sensors are used in railway applications to track the temperatures of the ambient (air temperature), the rail bed or train chassis, and the mechanics.[1]
8.	Piezoelectric	They are typically employed in research because of their alleged increased accuracy; they are durable, able to tolerate adverse weather conditions, and they can supply a significant quantity of energy[1]; nonetheless, they are relatively expensive[13]	They are employed to gauge pressure, vibration, shock, and strain. When under mechanical stress, such as that put on the track or sleepers by a passing train, piezoelectric materials have the ability to generate electricity.[1]

Table 2: Summary Of Acronyms

Acronym	Definition		Acronym	Definition
BS	*Base station*		**MSC**	*Mobile Switching Centre*
BSC	*Base station Controller*		**NF**	*Network Function*
BTS	*Base Transceiver Stations*		**NFVO**	*Network Functions Virtualization Orchestrator*
CN	*Core Network*		**PHY**	*Physical Layer*
EPC	*Evolved Packet Core*		**RAN**	*Radio Access Network*
HLR	*Home Location Register*		**RF**	*Radio frequency*
HSS	*Home Subscriber Server*		**RFCOMM**	*Radio frequency communication*
IMS	*IP Multimedia Subsystem*		**SDN**	*Software-Defined Networking*
IN	*Intelligent Network*		**SDP**	*Service Delivery Platform*
IOT-R	*Internet of Things for railways*		**SGSN**	*Serving GPRS Support Node*
IP	*Internet Protocol*		**SLA**	*Service Level Agreement*
KPI	*Key Performance Indicator*		**TCP**	*Transmission Control Protocol*
LLC	*Logical Link Connection*		**TCS**	*Telecommunications Connectivity Services*
MAC	*Media Access Control protocol*		**UDP**	*User Datagram Protocol*
MANO	*Management and Orchestration*		**URLCC**	*Ultrareliable low latency communication*
MLME	*Media Access Control (MAC) Sublayer Management Entity*		**VIM**	*Virtualized Infrastructure Manager*
MS	*Mobile Station*		**VNFM**	*Virtual Network Function Manager*

4. Challenges faced by WSN

- Wireless sensor networks require large nodes for effective sensor field, requiring comprehensive management architecture for monitoring, parameter configuration, and updating systems. Scalability issues can degrade performance.[7]
- WSNs face challenges in railway applications due to rapid data generation, complex sensor behavior, noisy sensor data, and potential sensor defects.[1]

- The main challenge is determining the best measurement technologies for reliable, accurate, and cost-effective condition monitoring in harsh environments. Sensor data may contain errors, exacerbate communication failures.[1]
- Interference from neighboring wireless systems can significantly reduce WSN performance, as conventional avoidance mechanisms struggle due to low computation capability.[7]
- Wireless social networks (WSNs) face security risks due to their wireless nature, requiring proper mechanisms and encryption for data distribution.[7]
- The wireless sensor nodes are constrained in a number of ways, including in terms of power supply, memory size, computational ability, and wireless channel bandwidth.[7]

5. Conclusions and ideas for future work.

The use of wireless sensor networking (WSN) in railway monitoring systems is essential for improving infrastructure growth and it also guarantees secure and safe rail transport operations but in spite of that, comprehensive studies and the integration of artificial intelligence in the railway industry still fall short in this field of research. With reference to the other articles and reviews, it is noted that a continuous source of energy is required for data gathering, and the energy source for sensors affects how they operate. Future researchers and engineers should put a lot of emphasis on developing unique wireless sensor system solutions for practical applications, combining sensors for high-precision detection, putting into use large data managements and incorporating technology to extract meaningful information, generation of databases etc. Future research on railway status monitoring will concentrate on comprehensive, integrated systems that provide information and alerts in real-time. Developing systems that prevent intrusion, eavesdropping, and data theft because cyber security is very crucial.

References

[1] V. J. Hodge, S. O'Keefe, M. Weeks, and A. Moulds, "Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 3, pp. 1088–1106, Jun. 2015, doi: 10.1109/TITS.2014.2366512.

[2] "Timeline: The world's deadliest train crashes." Accessed: Aug. 21, 2023. [Online]. Available: https://www.aljazeera.com/news/2023/6/3/timeline-what-are-the-worlds-deadliest-train-crashes

[3] Civil and Infrastructure Engineering Discipline, School of Engineering, RMIT University, Australia, A. Falamarzi, S. Moridpour, Civil and Infrastructure Engineering Discipline, School of Engineering, RMIT University, Australia, M. Nazem, and Civil and Infrastructure Engineering Discipline, School of Engineering, RMIT University, Australia, "A Review on Existing Sensors and Devices for Inspecting Railway Infrastructure," *J. Kejuruter.*, vol. 31, no. 1, pp. 1–10, Apr. 2019, doi: 10.17576/jkukm-2019-31(1)-01.

[4] S. Al-Sarawi, M. Anbar, K. Alieyan, and M. Alzubaidi, "Internet of Things (IoT) communication protocols: Review," in *2017 8th International Conference on Information Technology (ICIT)*, Amman, Jordan: IEEE, May 2017, pp. 685–690. doi: 10.1109/ICITECH.2017.8079928.

[5] C. Saad, B. Mostafa, E. Ahmadi, and H. Abderrahmane, "Comparative Performance Analysis of Wireless Communication Protocols for Intelligent Sensors and Their Applications," *Int. J. Adv. Comput. Sci. Appl.*, vol. 5, no. 4, 2014, doi: 10.14569/IJACSA.2014.050413.

[6] H. Alawad and S. Kaewunruen, "Wireless Sensor Networks: Toward Smarter Railway Stations," *Infrastructures*, vol. 3, no. 3, Art. no. 3, Sep. 2018, doi: 10.3390/infrastructures3030024.

[7] S.-H. Yang, *Wireless Sensor Networks: Principles, Design and Applications*. in Signals and Communication Technology. London: Springer London, 2014. doi: 10.1007/978-1-4471-5505-8.

[8] J. Grover and Anjali, "Wireless Sensor Network in Railway Signalling System," in *2015 Fifth International Conference on Communication Systems and Network Technologies*, Gwalior, India: IEEE, Apr. 2015, pp. 308–313. doi: 10.1109/CSNT.2015.28.

[9] E. Aboelela, W. Edberg, C. Papakonstantinou, and V. Vokkarane, "Wireless Sensor Network Based Model for Secure Railway Operations," in *2006 IEEE International Performance Computing and Communications Conference*, Phoenix, AX, USA: IEEE, 2006, pp. 623–628. doi: 10.1109/.2006.1629461.

[10] G. M. Shafiullah, A. Gyasi-Agyei, and P. Wolfs, "Survey of Wireless Communications Applications in the Railway Industry," in *The 2nd International Conference on Wireless Broadband and Ultra Wideband Communications (AusWireless 2007)*, Aug. 2007, pp. 65–65. doi: 10.1109/AUSWIRELESS.2007.74.

[11] C. Du, S. Dutta, P. Kurup, T. Yu, and X. Wang, "A review of railway infrastructure monitoring using fiber optic sensors," *Sens. Actuators Phys.*, vol. 303, p. 111728, Mar. 2020, doi: 10.1016/j.sna.2019.111728.

[12] Y. Zhao *et al.*, "A Review on Rail Defect Detection Systems Based on Wireless Sensors," *Sensors*, vol. 22, no. 17, p. 6409, Aug. 2022, doi: 10.3390/s22176409.

[13] D. Milne *et al.*, "Proving MEMS Technologies for Smarter Railway Infrastructure," *Procedia Eng.*, vol. 143, pp. 1077–1084, 2016, doi: 10.1016/j.proeng.2016.06.222.

[14] J.-S. Lee, Y.-W. Su, and C.-C. Shen, "A Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi," in *IECON 2007 - 33rd Annual Conference of the IEEE Industrial Electronics Society*, Taipei, Taiwan: IEEE, 2007, pp. 46–51. doi: 10.1109/IECON.2007.4460126.

[15] N. V. R. Kumar, C. Bhuvana, and S. Anushya, "Comparison of ZigBee and Bluetooth wireless technologies-survey," in *2017 International Conference on Information Communication and Embedded Systems (ICICES)*, Chennai, India: IEEE, Feb. 2017, pp. 1–4. doi: 10.1109/ICICES.2017.8070716.

[16] M. Sofi, "Bluetooth Protocol in Internet of Things (IoT), Security Challenges and a Comparison with Wi-Fi Protocol: A Review," *Int. J. Eng. Res.*, vol. V5, Nov. 2016, doi: 10.17577/IJERTV5IS110266.

[17] M. Tolani, Sunny, R. K. Singh, K. Shubham, and R. Kumar, "Two-Layer Optimized Railway Monitoring System Using Wi-Fi and ZigBee Interfaced Wireless Sensor Network," *IEEE Sens. J.*, vol. 17, no. 7, pp. 2241–2248, Apr. 2017, doi: 10.1109/JSEN.2017.2658730.

[18] "WiFi protocol stack," FutureLearn. Accessed: Sep. 19, 2023. [Online]. Available: https://www.futurelearn.com/info/blog

[19] C. M. Ramya, M. Shanmugaraj, and R. Prabakaran, "Study on ZigBee technology," in *2011 3rd International Conference on Electronics Computer Technology*, Kanyakumari, India: IEEE, Apr. 2011, pp. 297–301. doi: 10.1109/ICECTECH.2011.5942102.

[20] "Discover Zigbee Protocol 3.0." Accessed: Aug. 23, 2023. [Online]. Available: https://www.digi.com/solutions/by-technology/zigbee-wireless-standard

[21] G. Tingting and S. Bin, "A high-speed railway mobile communication system based on LTE," in *2010 International Conference on Electronics and Information Engineering*, Kyoto, Japan: IEEE, Aug. 2010, pp. V1-414-V1-417. doi: 10.1109/ICEIE.2010.5559665.

[22] R. He *et al.*, "High-Speed Railway Communications: From GSM-R to LTE-R," *IEEE Veh. Technol. Mag.*, vol. 11, no. 3, pp. 49–58, Sep. 2016, doi: 10.1109/MVT.2016.2564446.

[23] R. Xue, Z. Ma, X. Ma, and M. Dai, “5G Enabling Technologies in Rail,” in *2020 2nd International Conference on Information Technology and Computer Application (ITCA)*, Guangzhou, China: IEEE, Dec. 2020, pp. 372–375. doi: 10.1109/ITCA52113.2020.00084.

[24] B. Ai, A. F. Molisch, M. Rupp, and Z.-D. Zhong, “5G Key Technologies for Smart Railways,” *Proc. IEEE*, vol. 108, no. 6, pp. 856–893, Jun. 2020, doi: 10.1109/JPROC.2020.2988595.

[25] J. G. Andrews *et al.*, “What Will 5G Be?” arXiv, May 12, 2014. Accessed: Sep. 23, 2023. [Online]. Available: http://arxiv.org/abs/1405.2957

[26] S. Mustapha, Y. Lu, C.-T. Ng, and P. Malinowski, “Sensor Networks for Structures Health Monitoring: Placement, Implementations, and Challenges—A Review,” *Vibration*, vol. 4, no. 3, pp. 551–584, Jul. 2021, doi: 10.3390/vibration4030033.

[27] Z. Zhan *et al.*, “Wireless Rail Fastener Looseness Detection Based on MEMS Accelerometer and Vibration Entropy,” *IEEE Sens. J.*, vol. 20, no. 6, pp. 3226–3234, Mar. 2020, doi: 10.1109/JSEN.2019.2955378.