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Design Of A Digital Mobile Radio Network For A Mission-Critical Communication

Nkosinathi Nhlanhla Nyawose[1], James Swart[2], Pierre Hertzog[3]
[1,2,3]Department of Electrical, Electronic and Computer Engineering, Central University of Technology, Free State, Private Bag X20539, Bloemfontein, 9300, South Africa
[1]nkosinathi.nyawose@transnet.net
[2]aswart@cut.ac.za
[3]phertzog@cut.ac.za

Abstract
The evolution of mobile communication has shifted from analogue to digital technologies, improving reliability, security, and efficiency. Professional Mobile Radio (PMR) systems have long been essential for Mission-Critical Communications (MCC), particularly in railway operations. However, analogue PMR is becoming obsolete due to spectral inefficiency, poor audio quality, and security concerns. This study explores digital alternatives such as Terrestrial Trunked Radio (TETRA), Long-Term Evolution (LTE), and Digital Mobile Radio (DMR), focusing on DMR as a viable replacement for PMR. A comparative analysis evaluates their suitability, followed by the design and simulation of a DMR pilot site. The findings contribute to knowledge on digital MCC solutions, supporting the adoption of modern communication technologies in railway operations to enhance operational efficiency and safety.
Keywords: *Professional Mobile Radio (PMR), Terrestrial Trunked Radio (TETRA), Long-Term Evolution (LTE). Receive Signal Strength Indicator (RSSI).*

1. INTRODUCTION

The evolution of mobile communication technology has undergone substantial transformations over the past four decades, advancing from the first generation (1G) to the latest fifth-generation (5G) networks [1]. This progress has led to a significant shift from analogue to digital communication technologies, offering enhanced performance in terms of reliability, security, and efficiency [2]. Professional Mobile Radio (PMR) systems, once central to Mission Critical Communications (MCC), have relied on analogue technology for over 25 years. PMR systems, commonly used for MCC, consist of conventional private radio networks that facilitate communication between a base station and multiple mobile radios [3]. These systems have provided essential communication services for public protection and disaster relief (PPDR) agencies, including emergency services such as police, fire, and ambulance teams [4]. The radio communication used in the railway industry is regarded as a MMC system since it directly impacts public safety. The rapid advancement of digital technologies has highlighted the limitations of analogue PMR systems, which are now considered obsolete and inefficient for modern communication demands.

In response to these limitations, several digital technologies have emerged as viable alternatives to traditional PMR systems. Terrestrial Trunked Radio (TETRA), Digital Mobile Radio (DMR), and Long-Term Evolution (LTE) networks have proven to fulfil initial MCC requirements by enhancing voice services with improved availability, security, and reliability [5]. DMR has emerged as a promising replacement for PMR because, unlike other digital radio systems (e.g., TETRA and LTE), it operates within the same channel bandwidth as Frequency Modulation (FM) systems. This allows spectrum license holders to migrate from FM to DMR using the same channel plan [6]. The emergence of these technologies has sparked significant research interest in comparing digital solutions to meet MMC requirements.

The aim of this study is to design and simulate a DMR site as a replacement for an analogue PMR system due to its obsolescence, to evaluate its feasibility and performance in MCC environments. To support this objective, the research will first compare digital communication technologies, including

TETRA, DMR, LTE, to assess their suitability for mission-critical communications. The study will begin with a literature review of these technologies, analysing their capabilities and performance. Following this, the focus will shift to DMR, leading to its detailed evaluation, design, and simulation as a viable alternative to analogue PMR. The results focus on received signal strength levels, illustrating the system's signal performance.

2. LITERATURE REVIEW

The field of telecommunications has experienced significant technological advancements in recent years, driven by increasing demand from both the population and various industries [7]. This demand has also extended to PMR systems, which have traditionally relied on analogue technologies for MMC. These systems have played a crucial role in mission-critical applications, particularly in Public Protection and Disaster Relief (PPDR) agencies and railway operations, where reliable and secure communication is essential. To address the evolving needs of MMC requirements, the discussion will begin with the analogue PMR system, followed by alternative digital technologies that may be considered as alternatives to analogue PMR.

2.1Analogue PMR

Since Guglielmo Marconi (1874–1937) established a radio connection over a few kilometers in 1895, radio technology has undergone significant advancements [2]. This led to analogue communication evolving from one-way AM broadcasts in the 1930s to two-way AM for police, FM adoption in the 1940s, and the introduction of hand-carried radios by the 1950s. By the 1960s, MMC enabled shared RF channels for both voice and analogue signaling [8]. For public safety applications, this analogue communication is known as PMR, a legacy narrowband technology primarily used for mission-critical voice communications. Operating in the Very High Frequency (VHF) and Ultra High Frequency (UHF) bands, PMR has limited data capabilities but remains essential for emergency response and critical operations [9].

Despite its long-standing and reliable use over the years, analogue PMR networks have notable disadvantages [10], including low audio quality, particularly at longer distances [11], and vulnerability to interception due to analogue voice encryption [12]. These systems also face frequency band limitations, operating within the crowded 136-174 MHz (VHF) and 450-520 MHz (UHF) bands, leading to inefficiencies. Furthermore, analogue systems offer less spectral efficiency as compared to digital systems, which provide enhanced bandwidth and power efficiency [13]. Power efficiency is another concern, as analogue radios generally consume more power than modern digital radios, crucial for portable emergency devices [11]. Additionally, while some digital systems are backward compatible with analogue radios, integrating both into the same network can be complex, limiting the benefits of digital technology [10].

2.2Terrestrial Trunked Radio

TETRA is a digital trunked radio system standardized by the European Telecommunications Standards Institute (ETSI) to meet the needs of PMR users, including public safety agencies [14]. Its air interface employs the Time Division Multiple Access (TDMA) technique, using π/4-shifted Differential Quaternary Phase Shift Keying (π/4-DQPSK) for modulation. Operating on 25 kHz spaced radio frequency carriers, each divided into four time slots, TETRA efficiently provides four communication channels per 25 kHz bandwidth [15]. This optimized spectrum utilization makes TETRA a preferred choice for MMC, ensuring secure and reliable digital voice transmission [12]. Additionally, operating in a low-frequency band enables TETRA to cover longer distances compared to LTE, making it ideal for wide-area public safety and industrial applications [16].

Despite its advantages, TETRA has limitations that impact its widespread adoption. The high costs associated with infrastructure deployment and maintenance present financial challenges. Moreover, its significant power consumption limits battery life in mobile applications, affecting portability and efficiency [12]. Another drawback is TETRA's requirement for a larger channel bandwidth, making spectrum allocation more complex compared to Digital Mobile Radio (DMR) [6]. These factors influence both cost-effectiveness and spectrum efficiency. While TETRA remains a trusted solution for critical communication, advancements in cost management and energy efficiency are essential to ensure its long-term sustainability in evolving communication networks.

2.3Long-Term Evolution

LTE is a high-speed wireless communication standard designed to provide enhanced data transmission rates, reduced latency, and improved spectral efficiency [17]. Initially, LTE was developed primarily for commercial broadband applications and did not account for the requirements of MCC. However, to integrate critical communications into broadband networks, the 3rd Generation Partnership Project (3GPP) introduced Mission Critical Services (MCX) over the LTE standard in Release 13. Founded in 1998, the 3GPP plays a pivotal role in regulating policies and setting specifications for technologies like LTE [18].

One of the advantages of LTE is that it has enhanced data rates by employing Orthogonal Frequency-Division Multiplexing (OFDM) for the downlink and Single-Carrier Frequency-Division Multiple Access (SC-FDMA) for the uplink. These schemes use different modulation techniques, including Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (16-QAM), and 64-QAM. The modulation scheme selected depends on the channel conditions, with higher-order modulations, such as 64-QAM, delivering higher data rates when conditions are favorable [19].

While LTE offers advantages for commercial applications, its use in MCC remains new, with key disadvantages including limited coverage, high costs, and spectrum competition. LTE networks in the 700 MHz band require more sites to match LMR coverage due to propagation characteristics [20], leading to higher infrastructure costs that may be unaffordable for some public administrations [21]. This results in increased capital and operational expenditures, which can be prohibitive for many public sector agencies. Furthermore, MCC users typically representing smaller user bases must compete for spectrum resources with commercial operators, who naturally prioritize services for larger, revenue-generating markets. A key concern lies in LTE's performance under emergency conditions, where it falls short in delivering the low latency, assured Quality of Service (QoS), and user prioritization essential for public safety operations. Unlike LMR systems that provide reliable direct mode operation without network dependence, LTE’s Proximity Services (ProSe) feature remains constrained by limited range and often requires network assistance, undermining its reliability during network outages or infrastructure failures [22] [23].

2.4Digital Mobile Radio

DMR is a digital radio standard developed by the ETSI for PMR, offering reliable and cost-effective voice and data communications for mission-critical applications [24] [25] [26]. It operates in three tiers: Tier I for license-free, low-power devices with a maximum RF power of 0.5 watts, suitable for small coverage areas and emergency applications; Tier II for licensed systems using two-slot Time Division Multiple Access (TDMA) on a 12.5 kHz channel, providing advanced features and IP data services; and Tier III for trunked operations supporting voice, messaging, and packet services, including IPv4 and IPv6 [27].

At the physical layer, DMR employs 4-ary Frequency Shift Keying (4-FSK) modulation and TDMA technology, effectively doubling capacity within existing 12.5 kHz channels while maintaining backward compatibility with analogue systems [28]. It ensures power efficiency, extended battery life, superior audio quality, and system flexibility by enabling simultaneous voice and data transmission, making it increasingly prevalent in public safety and transport sectors, including secondary and low-density railway lines [29].

While DMR offers advantages, it also has drawbacks such as signal degradation in overlap areas where multiple signals are received at different power levels, causing reception issues. Compared to other digital PMR technologies, DMR has lower bit rates, which limits its ability to support high-capacity data applications without significant network upgrades [11]. Furthermore, DMR systems are vulnerable to signal degradation when deployed in complex environments. Urban areas characterized by high-rise buildings, industrial zones filled with metallic structures, and natural terrains such as forests and hills significantly hinder signal propagation. One of the primary causes of this degradation is multipath fading, a phenomenon where transmitted signals reflect off various surfaces, leading to multiple signal paths that arrive at the receiver at different times.

2.5Comparison of Digital PMR technologies

A comparison of digital PMR technologies reveals that DMR offers an ideal solution for medium-scale applications, such as railway communication systems. With a 12.5 kHz channel spacing, DMR ensures efficient spectrum use and is cost-effective. Despite its relatively low data rate of 9.6 kb/s, it is sufficient for voice communication and basic data services. DMR's compatibility with analogue systems also facilitates a smooth transition from older infrastructure, reducing costs.

In comparison, TETRA and LTE offer higher data rates but come with higher implementation costs and are better suited for large-scale systems. While TETRA operates on 25 kHz channels and provides a data rate of up to 28.8 kb/s, it is more expensive than DMR. LTE, with its high-speed capabilities, is designed for large networks, making it an impractical option for the railway sector. Table 1 illustrates the comparison of digital technologies that are potential replacements for analogue radio technology.

Table 1. DMR, TETRA, and LTE Comparison [4]**.**

Technologies	DMR	TETRA	LTE
Frequency bands	VHF and UHF	UHF	Various
Modulation	TDMA (2-slots)	TDMA (4-slots)	OFDMA
Channel spacing	12.5 kHz	25 kHz	Various (e.g., 1.4, 3, 5, 10, 15, 20 MHz)
Data rates	9.6 kb/s	28.8 kb/s	Up to 100 Mb/s (downlink), 50 Mb/s (uplink)
Encryption	Yes	Yes	Yes
Compatible with analog systems	Yes	No	No
Implementation	Small to large	Large	Large
Supported by different manufacturers	Yes	Yes	Yes
System cost (per km^2)	€€	€€€	€€€€

2.6DMR Case studies

Various studies have demonstrated the versatility and reliability of DMR across different applications. Research [11] evaluated DMR for mission-critical applications, comparing it to TETRA in Sardinia's health emergency services. Their study found that DMR provided superior coverage (-110 dBm vs -105 dBm for TETRA) and was the most effective choice for cost savings, spectrum efficiency, and ease of network configuration, making it well-suited for large areas with low to medium traffic.

Similarly, [30] explored the integration of Narrowband Internet of Things (NB-IoT) with DMR to enhance communication reliability, particularly in industrial and emergency scenarios. The system integrates a sensing circuit and an NB-IoT network analyzer at key DMR nodes such as base stations and bidirectional amplifiers to monitor operational parameters including AC current, temperature, RF output, and humidity. The NB-IoT analyzer assesses network stability via RSSI measurements, supporting real-time alerts in the event of abnormal conditions. Their findings demonstrated that this integration improves fault detection and system resilience, reinforcing DMR's suitability for MCC and industrial IoT applications.

Further emphasizing DMR's role in critical communications, [31] analyzed the signal quality of a DMR Tier 3 trunking system along the Makassar–Parepare railway line in Indonesia, where network coverage challenges posed safety risks. Through link budget analysis, radio mobile simulations, and field measurements, they found average Receive Signal Strength Indicator (RSSI) values of -62.49 dBm (calculated), -62.61 dBm (simulated), and -76.47 dBm (measured). With all 36 measurement points meeting ETSI and TAIT standards, their study confirmed the alignment of theoretical and simulated results with field data, offering valuable insights for improving railway communication and safety.

Additionally, a study [29] assessing replacement options for the analogue railway communication system in Russia compared GSM-R, TETRA, and DMR, highlighting DMR as the preferred choice. Owing to its compliance with operational standards and support for cost-effective migration, DMR was found to offer a balanced solution in terms of performance, spectrum efficiency, and deployment simplicity. Building on these insights, the next chapter presents the Research design, which outlines the simulation of a DMR network using WRAP software to evaluate its practical feasibility, signal behavior, and alignment with real-world deployment scenarios.

3. Research Design

The research design aimed to simulate the DMR radio network site using Wireless Radio Access Planner (WRAP) software, ensuring accurate network planning and performance evaluation. The design process followed a structured approach consisting of three key stages as illustrated in Figure 1:

- Definition of requirements – Identifying technical specifications, site location, and necessary equipment to establish the simulation framework.
- Radio network dimensioning – Performing link budget calculations, determining transmission power, Effective Radiated Power (ERP), and antenna gain to assess network performance.
- Radio propagation model tuning – Using WRAP software for radio coverage simulation and optimization.

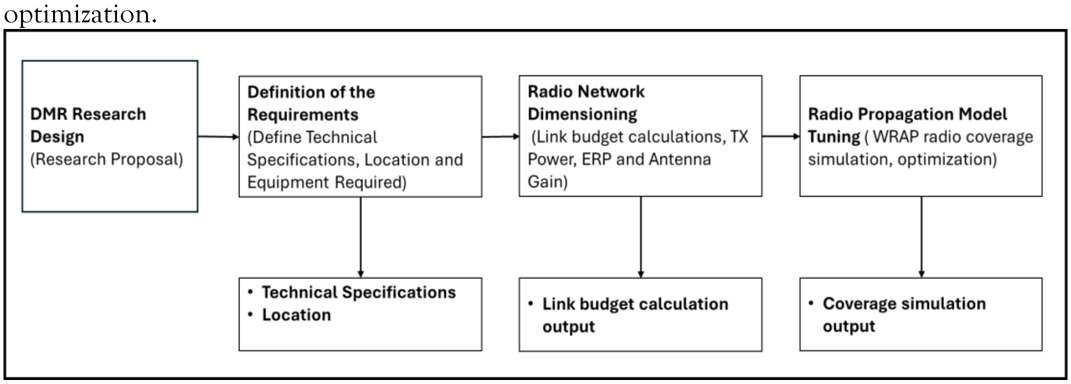

Figure 1. DMR design simulation block diagram.

3.1Definition of Requirements

The initial stage involves identifying and defining the technical and practical requirements for the simulation stage, beginning with the selection of essential equipment and system parameters. The Webb Corner Reflector (CR400) antenna with a gain of 9 dBi was chosen, along with the Tait TB9300 repeater, which supports a maximum power output of 150 W and a receiver sensitivity limit of -119dbm. The feeder system utilizes an LMR 400 coaxial cable with an attenuation rate of 0.089 dB/m, while the Webb Duplexer, with an insertion loss of less than 1.2 dB, is integrated into the setup. Since the design will be simulated for Transnet, which is a South African state-owned company responsible for freight transport and logistics, it needs to comply with certifications prescribed by the Independent Communications Authority of South Africa (ICASA), and thus a 20 W Effective Radiated Power (ERP) was used.

The Muiskraalkop site in Robertson, Western Cape, was selected for its power availability, terrain suitability, existing infrastructure, and road access. The site is strategically positioned to provide optimal line-of-sight coverage, reducing signal degradation due to obstructions. Additionally, its elevation enhances radio wave propagation, ensuring reliable connectivity across the railway corridor. The location allows for efficient signal distribution, optimizing coverage without requiring excessive infrastructure expansion. These factors collectively support sustained communication reliability and future reduced infrastructure costs if the design was piloted.

3.2Radio Network Dimensioning

Network dimensioning is essential for deploying a new network, as it determines the minimum capacity required to meet service agreement specifications [32]. A crucial element of this process is the link budget calculation, which evaluates the power gain and losses from the transmitter to the receiver [31]. In this study, the technical parameters were determined using the Effective Radiated Power (ERP) Equation (1), which combines transmit power and antenna gain.

$$\mathrm{ERP} = \mathrm{PTx} - \mathrm{LTx} + \mathrm{GTx} \tag{1}$$

Where:

- ERP: Effective Radiated Power (dBm)
- PTx: Maximum transmitter power (dB)
- LTx: Loss in the cable or connector at the transmitter (dB)
- GTx: Antenna gain at the transmitter (dBd)

Total transmission losses:

- L (cable): 1.78 dB
- L (Duplexer): 1.2 dB
- L (matching harness): 3 dB

$$\mathrm{LTx(total)} = \mathrm{L\ (cable)} + \mathrm{L\ (matching\ harness)} + \mathrm{L\ (Duplexer)} \tag{2}$$

$$\mathrm{LTx(total)} = 1.78 + 3\mathrm{dB} + 1.2\mathrm{db}$$

$$\mathrm{LTx(total)} = 5.98\ \mathrm{dB}$$

Transmitter Power Calculation:

Given:

- ERP: 20 W
- LTx (total): 5.98 dB
- GTx: 6.86 dBd

First, convert ERP from 20 W to dBm:

$$\mathrm{ERP} = 10 \log \mathrm{P_{mW}} \tag{3}$$

$$\mathrm{ERP} = 10 \log(20 \times 1000) = 43\ \mathrm{dBm}$$

Using the ERP equation, the maximum transmitter power was calculated by rearranging Equation (1) to solve for PTx:

$$\mathrm{PTx} = \mathrm{ERP} + \mathrm{LTx} - \mathrm{GTx} \tag{4}$$

$$\mathrm{PTx} = 43 + 5.98 - 6.86$$

$$\mathrm{PTx} = 42.12\ \mathrm{dBm}$$

To convert dBm to Watts, the following calculation was performed:

$$\mathrm{P_W} = 10^{\left(\frac{\mathrm{P_{dBm}}}{10}\right)} \times 1000 \tag{5}$$

$$\mathrm{P_W} = 10^{\left(\frac{42.12}{10}\right)} \times 1000$$

$$\mathrm{P_W} = 16.34\ \mathrm{W}$$

For simulation purposes in WRAP, power is converted to dBW as follows:

$$\mathrm{P_{dBW}} = 10 \times \log_{10}(\mathrm{PW}) \tag{6}$$

$$\mathrm{P_{dBW}} = 10 \times \log_{10}(16.34) = 12.13\ \mathrm{dBW}$$

ERP value in dBW for accurate use in the WRAP simulation:

$$\mathrm{dBW} = \log_{10}(\mathrm{W}) \tag{7}$$

$$\mathrm{dBW} = \log_{10}(20) = 13\ \mathrm{dBW}$$

The parameters in Table 2 are derived from the calculation of the DMR network design, including an Effective Radiated Power of 13 dBW (43 dBm) and a maximum transmitter power of 16.34 W (12.13 dBW). The system also accounts for transmission losses, while the antenna gain is 6.86 dBd (9 dBi). These calculated values will serve as inputs in the simulation stage to evaluate network performance based on the defined system characteristics.

Table 2. DMR Network radio design dimensioning results.

Parameter	Value
Effective Radiated Power	13 dBW / 43 dBm

Loss in Cable or Connector	1.78 dB
Duplexer Loss	1.2 dB
Matching Harness Loss	3 dB
Antenna Gain	6.86 dBd / 9dBi
Maximum Transmitter Power	16.34 W / 12.13 dBW

3.3Radio Propagation Model Tuning

The final stage of the research design involves tuning the radio propagation model to bridge the gap between simulation and real-world performance. Using the dimensioning results, the WRAP software is configured with parameters such as transmitter power (in dBW), antenna height, radiation pattern, and terrain data. This allows for an accurate simulation of the DMR network's coverage.

4. RESULTS AND DISCUSSION

4.1 Simulated Results

The WRAP simulation software was utilized to predict the performance of the DMR system, generating a signal coverage map that provides a comprehensive visualization of radio coverage. The propagation model selected for the simulation was the Delta-Bullington model with a 90% outdoor coverage reliability setting, which is well-suited for rural and mountainous railway corridors with mixed line-of-sight conditions. The model accounts for diffraction over terrain obstructions, enhancing its accuracy in regions with variable topography. It has also been validated in similar public safety and mission-critical radio communication networks. Figure 2 presents the simulation result from the Muiskraalkop high site, visually representing the simulated signal coverage and its distribution across the designated area. This analysis illustrates how various input parameters influence the RSSI across the designated coverage area.

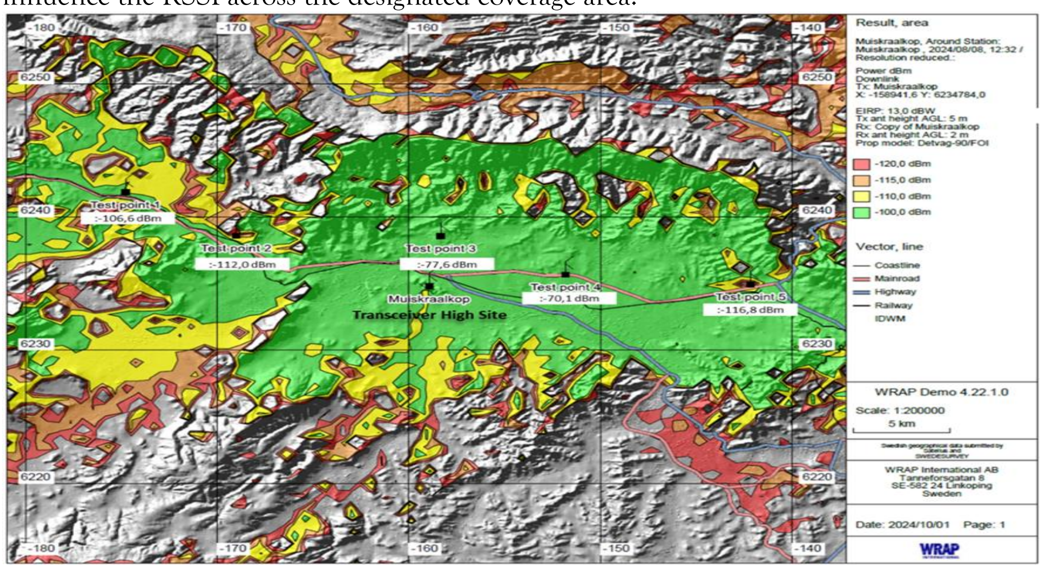

Figure 2. DMR WRAP Coverage Simulated Results.

The simulated results from WRAP showed good coverage across the railway, with RSSI levels varying based on terrain and propagation conditions. Test Points 3 (-77.6 dBm) and 4 (-70.1 dBm) exhibited strong signal levels due to direct line-of-sight with the transceiver. In contrast, Test Points 2 (-112.0 dBm) and 5 (-116.8 dBm) recorded weaker signals due to terrain obstructions. Test Point 1 (-106.6 dBm) displayed intermediate coverage, highlighting the impact of partial obstructions on signal strength. Although some test points recorded moderate RSSI levels, the overall signal strength along the railway remains strong, with areas above -100 dBm appearing in green on the coverage map.

The strongest signals are observed in areas with a direct line-of-sight to the Muiskraalkop transceiver high site, while weaker signals appear in regions with elevated terrain or dense vegetation. This distribution highlights the impact of terrain variations, where obstructions contribute to signal degradation, whereas open landscapes with minimal interference provide better communication reliability. The results from Test Points 1 to 5, along with observed signal levels along the railway, indicate that the coverage meets the DMR Tait TB9300 repeater specifications. With an acceptable RSSI limit of -119 dBm, all measured test points fall within this range, confirming adequate coverage across the railway.

4.2 Practical Results

To validate the simulation results, a pilot DMR site was deployed at the Muiskraalkop high site, and RSSI measurements were recorded at five test points using a Hytera PD785 handheld radio. Strong signal levels were observed at Test Points 3 (-81 dBm) and 4 (-72 dBm), where direct line-of-sight prevailed. In contrast, weaker signals at Points 2 (-114 dBm) and 5 (-119 dBm) were due to elevated terrain and vegetation. All measurements fell within the receiver sensitivity threshold of -119 dBm, confirming adequate coverage. The practical results, shown in Figure 3, align closely with the simulated predictions and support the validity of the WRAP-based coverage model.

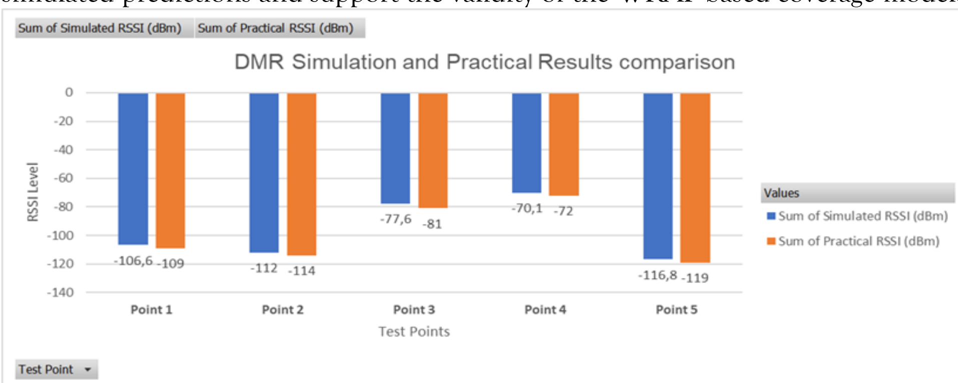

Figure 3. Comparison of Simulated and Practical RSSI Results at Test Points.

5. CONCLUSIONS

This study demonstrates the feasibility of transitioning from analogue PMR to DMR for MMC. Literature findings indicate that DMR provides improved spectral efficiency, enhanced security, and better audio quality compared to analogue PMR, making it a suitable choice for MCC applications and compared to alternatives such as TETRA and LTE, DMR offers a cost-effective and practical solution for railway operations.

The WRAP simulation confirms that the Muiskraalkop high site provides acceptable DMR coverage along the railway. Strongest signals were observed at Test Points 3 (-77.6 dBm) and 4 (-70.1 dBm) due to direct line-of-sight, while weaker signals at Test Points 2 (-112.0 dBm) and 5 (-116.8 dBm) resulted from terrain obstructions. Test Point 1 (-106.6 dBm) showed intermediate coverage. All points (1-5) fall within the Tait TB9300 repeater's acceptable RSSI limit of -119 dBm, demonstrating sufficient coverage for reliable communication.

Future research may explore the integration of DMR with complementary technologies such as LTE, 5G, and the Internet of Things (IoT). Hybrid DMR-LTE systems could support higher data rates, while 5G and IoT convergence may enable intelligent monitoring, redundancy, and real-time diagnostics. Such advancements would modernize mission-critical communications and ensure resilience and scalability for evolving railway network demands.

BIBLIOGRAPHY

[1] S. Yrjölä, M. Matinmikko-Blue and P. Ahokangas, "The Evolution of Mobile Communications," in *The Changing World of Mobile Communications: 5G, 6G and the Future of Digital Services*, Cham, Springer International Publishing, 2023, pp. 13 - 43.

[2] A. Kouwen, M. Scanlon, K.-K. R. Choo and N.-A. Le-Khac, "Digital forensic investigation of two-way radio communication," *Digital Investigation,* vol. 26, no. 1, pp. 77-86, 2018.

[3] K. O. Olasupo, I. Kostanic and O. E. Olasupo, "Investigation of the Impact of Heterogeneous Traffic on Performance of LTE-based Mission Critical Communication Networks," in *Proceedings of the 8th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON 2017)*, Vancouver, 2017.

[4] T. D. Katsilieris and T. E. Karafasoulis, "Capacity and Coverage Planning of DMR Trunking Radio Network for PPDR Services," in *Proceedings of the 24th International Conference on Circuits, Systems, Communications and Computers (CSCC 2020)*, Chania, 2020.

[5] F. Neto, J. Granjal and V. Pereira, "A Survey on Security Approaches on PPDR Systems Toward 5G and Beyond," *IEEE Access,* vol. 10, no. 1, pp. 117119-117140, 2022.

[6] A. Fongen, "Integration of Digital Mobile Radio in a Sensor Network," in *Proceedings of the Sixteenth International Conference on Sensor Technologies and Applications (SENSORCOMM 2022)*, Lisbon, 2022.

[7] M. Ayad, R. Alkanhel, K. Saoudi , M. Benziane, S. Medjedoub and S. S. M. Ghoneim, "Evaluation of Radio Communication Links of 4G Systems," *Sensors,* vol. 22, no. 1, pp. 1-17, 2022.

[8] M. Ulema, Fundamentals of Public Safety Networks and Critical Communications Systems, Piscataway: Wiley- IEE Press, 2018.

[9] A. Kumbhar, F. Koohifar, I. Güven and B. Mueller, "A Survey on Legacy and Emerging Technologies for Public Safety Communications," *IEEE Communications Surveys & Tutorials,* vol. 19, no. 1, pp. 97-124, 2017.

[10] V. K. Joshi and T. Kavitha, "Efficient methods to improve power bandwidth measurement of ETSI low bandwidth digital mobile radio," *Measurement: Sensors,* vol. 27, no. 1, pp. 1-7, 2023.

[11] T. Onali, M. Sole and D. D. Giusto, "DMR networks for health emergency management: A case study," in *Proceedings of the 7th International Wireless Communications and Mobile Computing Conference (IWCMC 2011)*, Istanbul, 2011.

[12] M. Hanchate, R. Patil, T. Marathe, S. Srivastava, P. Dhivare and S. Singh, "Terrestrial Trunked Radio," *Elixir International Journal,* vol. 93, no. 1, pp. 39668-39671, 2016.

[13] K. Kunavut, "An Overview of Digital Trunked Radio: Technologies and Standards," *The Journal of Industrial Technology,* vol. 10, no. 2, pp. 111-121, 2014.

[14] S. Heleno, C. A. Fernandes, J. M. Felício, C. Salem, R. Caldeirinha and N. Leonor, "Development of TETRA Radio Backhaul Network Redundancy Plan for Disaster Recovery in Mission Critical Communications," in *Proceedings of the 17th European Conference on Antennas and Propagation (EuCAP 2023)*, Florence, 2023.

[15] M. G. Chavez, L. Goratti, T. Rashe and D. Boru, "The Evolutionary Role of Communication Technologies in Public Safety Networks," in *Wireless Public Safety Networks Volume 1: Overview and Challenges*, Elsevier, Amsterdam, 2015, pp. 21-48.

[16] L.-S. Hsiao and I.-L. Lin, "Integrating 5G and Terrestrial Trunked Radio into Railway Communication System for Railway Safety and Information Security," *Sensors and Materials,* vol. 36, no. 3, pp. 1275-1285, 2024.

[17] M. O. Odida, "The Evolution of Mobile Communication: A Comprehensive Survey on 5G Technology," *Journal of Sensor Networks and Data Communications,* vol. 4, no. 1, pp. 1-11, 2024.

[18] A. Santiago, A. D. De Cerio, A. Sanch and F. Liberal, "Analysis of Mission Critical Services Radio Access Network Capacity Limitations Over 5G," *IEEE Access,* vol. 12, no. 1, pp. 6191 - 6203, 2024.

[19] S. Parasher and S. Kumar, "Effects of Various Digital Modulation Methods on LTE System Over Orthogonal Frequency Division Multiplexed AWGN : A Review," in *Proceedings of the 2022 International Conference on Advances in Computing, Communication and Materials (ICACCM 2022)*, Dehradun, 2022.

[20] A. U. Chaudhry and R. H. Hafez, "LMR and LTE for public safety in 700 MHz spectrum," *Wireless communications and mobile computing,* vol. 2019, no. 1, pp. 1-17, 2019.

[21] R. Ferrus, O. Sallent, G. Baldini and L. Goratti, "LTE: the technology driver for future public safety communications," *IEEE Communications Magazine ,* vol. 51, no. 10, pp. 154-161, 2013.

[22] F. Jameel, Z. Hamid, F. Jabeen, S. Zeadally and M. A. Javed, "A Survey of Device-to-Device Communications: Research Issues and Challenges," *IEEE Communications Surveys & Tutorials,* vol. 21, no. 3, p. 2520–2543, 2019.

[23] X. Wang, M. Chen, T. Taleb, A. Jamalipo and V. C. Leung, "Device-to-Device Communication in LTE: ProSe Challenges and Evaluation," *EEE Communications Magazine,* vol. 52, no. 6, p. 86–92, 2014.

[24] A. Goeritno, N. Andriana , Indriya, I. Setyawibawa and D. Suhartono, "Application-based Simulation on the Digital Trunking Radio Communication System to Predict the Area Coverage," *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI),* vol. 8, no. 2, pp. 256-268, 2022.

[25] W. Wang, L. Zhu, T. H. Luan and C. Li, "DoIP: A Parallel Protocol Conversion Gateway for DMR over Internet Protocol," in *Proceedings of the 97th IEEE Vehicular Technology Conference (VTC2023-Spring),*, Florence, 2023.

[26] M. Ulema, "Overview of Digital Mobile Radio (DMR) Technology," in *Fundamentals of Public Safety Networks and Critical Communications Systems: Technologies, Deployment, and Management*, Hoboken, Wiley-IEEE Press, 2019, pp. 107-120.

[27] K. Jin-Guk, S. Kwang-Bok, . S. Chol-Uk and K. Man-Ho, "Simultaneous wireless power and data transfer based on 4FSK modulation using the four splitting frequencies of series–parallel combined resonant circuit-based system," *Journal of Electrical Engineering,* vol. 105, no. 2, pp. 1307-1315, 2023.

[28] H. Ghannadrezaii, J.-F. Bousquet and J. Craig, "Outage Probability Analysis to Address Interference Vulnerabilities in Digital Mobile Radio Networks," in *Proceedings of the IEEE International Workshop Technical Committee on Communications Quality and Reliability (CQR 2021)*, Naples, 2021.

[29] A. B. Nikitin, I. V. Kushpil , J. M. Kokurin and V. A. Sharov , "New method of trains movement for low-density railway lines of JSC Russian Railways," *Transport Automation Research,* vol. 4, no. 4, pp. 561-579, 2018.

[30] Y. W. Lo, M. H. Tsoi, C.-F. Chow and S. W. Y. Mung, "An NB-IoT Monitoring System for Digital Mobile Radio With Industrial IoT Performance and Reliability Evaluation," *IEEE Sensors Journal,* vol. 25, no. 3, pp. 5337 - 5348, 2025.

[31] M. A. S. Firmansyah, D. A. Feryando and A. P. E. Wibowo, "Comparative Analysis of DMR (Digital Mobile Radio) Tier 3 Performance Based on RSSI Parameters at the Rammang-Rammang Site," in *Proceedings of the 2nd International Conference on Railway and Transportation 2023 (ICORT 2023)*, Chandipur, 2023.

[32] W. Jiang, "Cellular traffic prediction with machine learning: A survey," *Expert Systems with Applications,* vol. 201, no. 3, 2022.

Authors

Nkosinathi Nhlanhla Nyawose
MEng electrical engineering student at the Central University of Technology, Free State.

Prof James Swart
Received his DTech in 2011 and is an Associate Professor at the Central University of Technology.

Prof Pierre Hertzog
Received his DTech in 2004 and is an Associate Professor at the Central University of Technology.