CHAPTER 1
INTRODUCTION

The future of railway transportation relies on leveraging advanced communication systems to enhance safety, reduce operational costs, and innovate passenger services, driving the development of smart railways. The Future Railway Mobile Communications System (FRMCS) aims to establish a unified global standard for railway communications, succeeding GSM-R. While FRMCS will fulfill essential functions, 3GPP technologies like 5G are expected to be the ideal solution to address the comprehensive needs of rail operators.

1.1 Background

Railways have become a crucial mode of transportation worldwide, with rapid advancements in railway development. Today, railway operators are seeking smart, efficient, safe, and reliable systems, driven by technological progress. While GSM-R has been a successful communication system in use for over 20 years, its limited bandwidth and data rate can no longer meet the growing demands of the railway industry, such as multimedia communication, intelligent operations, and maintenance. As a result, GSM-R is expected to become obsolete by 2035, to be replaced by the Future Railway Mobile Communication System (FRMCS) [1–5].

The evolution of railways communication presents many opportunities and challenges, as shown in Fig. 1.1, where FRMCS will be a key enabler of railway digitalization. The rail sector has to develop advanced communication network and critical technologies that guarantee high-quality transmissions for passengers, railway operations, and control systems. Furthermore, the future of railways communication is expected to be accompanied by the escalating user devices, internet of things (IoT) services, artificial intelligence (AI) and machine learning (ML) applications and many more. The fifth-generation (5G) technology may be a promising solution for addressing these issues especially for high-speed railways (HSR) communication. The integration of 5G technology in smart railways is essential for enhancing connectivity, safety, and efficiency [5–7].

Spectrum Utilization Efficiency (SUE) refers to the ratio of information transferred over a distance to the spectrum utilization factor. It is an important aspect to consider for the development of intelligent future railway systems and for the

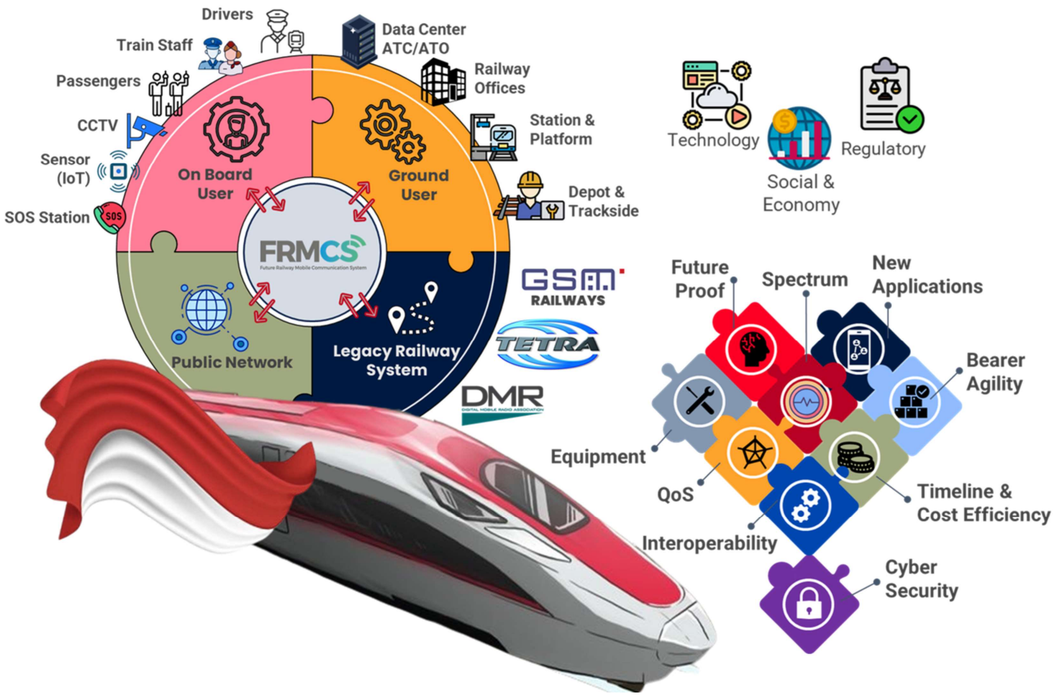

Fig. 1.1 The challenges and applications of FRMCS in several areas.

economic management of spectrum, as recommended by the ITU - Handbook on National Spectrum Management [8]. Defining the efficiency of spectrum use is crucial for comparing and assessing the benefits of new or improved technologies. In the context of migrating from GSM-R to FRMCS 5G-Railways in Indonesia, a precise analysis is needed, particularly in terms of spectrum efficiency, technology alignment, and regulation.

Indonesia's telecommunications regulatory framework has yet to establish dedicated frequency spectrum allocations for the Future Railway Mobile Communications System (FRMCS), creating a significant planning challenge for railway modernization efforts. This gap in spectrum policy necessitates extensive radiofrequency studies to determine viable frequency bands that can accommodate FRMCS requirements. A well-planned frequency allocation is essential for ensuring reliable and efficient railway communications, which directly impacts the safety and operational efficiency of Indonesia's rail network.

1.2 Problem Identification

The lack of clear spectrum allocation by regulatory authorities is a critical challenge for FRMCS implementation in Indonesia, creating uncertainty that needs comprehensive planning and analysis. This regulatory gap necessitates a thorough harmonization effort with international FRMCS spectrum standards, particularly focusing on the 1900 MHz band's availability and suitability for Indonesian railway communications. A detailed analysis of Spectrum Utilization Efficiency (SUE) for FRMCS is essential to ensure effective use of the limited spectrum resources and to justify the proposed frequency allocation.

Additionally, the substantial initial investment required for FRMCS infrastructure deployment demands a comprehensive feasibility study to evaluate the financial viability of the project. This economic assessment must be complemented by a thorough investigation of investment challenges and risk management strategies, considering factors such as implementation costs, potential technical obstacles, and long-term operational sustainability. These comprehensive studies will help determine if implementing FRMCS in the 1900 MHz band is technically and economically viable for Indonesia's railways.

1.3 Research Objectives

The researches on the Indonesian FRMCS channel model have been conducted several times. The previous studies analyzed the FRMCS performance by emphasizing its reliability on Doppler effects and overcoming interference with the existing GSM cellular network [9, 10]. Additionally, the performance of channel capacity and outage probability is examined, showcasing a trade-off between frequency and path loss of 900 and 1900 MHz for FRMCS [11].

Spectrum allocation is the major challenge in the migration phase to FRMCS that should be addressed to create a firm network deployment. The harmonized frequency bands for FRMCS are now under standardization in 3GPP. The proper consideration needs to be given to the co-existence of the GSM-R and FRMCS radio-frequency allocation. The cost overrun might be occurred due to the lacking of radio-frequency spectrum, reflecting on the GSM-R based high-speed train project in Indonesia [12].

This thesis proposes a comprehensively analysis on spectrum utilization efficiency of 1900 MHz for 5G-Railways in Indonesia through regulatory, technological, and economic perspectives. The regulatory perspective helps in the policy recommendation of the 1900 MHz and its benefits for the government, railway operators, and relevant stakeholders. The technology perspective helps identify the challenges involved in implementing 5G-Railways while the economic perspective helps identify the trade-off between the required cost investment and spectrum efficiency.

1.4 Scope of Work

The following assumptions form the foundation of this thesis:

1. The study area of this thesis is the island of Java, which has the largest population and the longest railway track in Indonesia.

2. To determine maximum allowable path loss, the analysis employs both Urban Macro (UMa) and Rural Macro (RMa) propagation models, assuming outdoor-to-outdoor (O2O) with non line of sight (NLOS) scheme.

3. The number of base stations required is calculated only based on coverage, as a basis for conducting an economic feasibility analysis.

4. The technical and economic assessment of FRMCS deployment focuses on the 1900 MHz band, using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) to determine its viability.

5. The scope of infrastructure sharing in this analysis covers just towers and transmission systems, while the railway operator will fund all other necessary components through capital expenditure, including radio equipment and related accessories.

1.5 Research Methodology

In general, this thesis is organized into four work packages (WP) to ensure the production of high-quality outcomes:

1. WP 1: Study of literature.
   This thesis explores fundamental concepts and theories from various sources, including books, research papers, journals, and other materials, focusing on spectrum utilization efficiency, investment feasibility analysis, and regulatory frameworks for spectrum management.

2. WP 2: Calculation of cell radius and the required number of base stations based on coverage planning.
   The cell radius is calculated based on the minimum allowable path loss (MAPL) for each specific propagation model. By applying this calculation, the required cell size is determined, which then allows for the estimation of the number of base stations needed to cover the entire study area effectively.

3. WP 3: Assessment of the correlation between spectrum utilization efficiency, cell radius, and frequency reuse factor.
   This thesis examines different frequency reuse factors and cell radius, analyzing how each impacts the overall spectrum efficiency. It then explores the relationship between these factors and the resulting efficiency of spectrum utilization, identifying how variations in frequency reuse and cell size affect performance.

4. WP 4: Analysis of the investment feasibility for implementing FRMCS.
   This thesis assesses the economic viability of investing in FRMCS through various simulation scenarios, analyzing the results using NPV, IRR, and PP methods.

1.6 Structure of The Thesis

The rest of this thesis is organized as follows:

- **CHAPTER 2 : BASIC CONCEPT**
  This chapter describes the theoretical foundation and relevant literature supporting this thesis research.

- **CHAPTER 3 : SYSTEM MODEL AND DESIGN**
  This chapter explains the system model, including the parameters and variables used in the thesis, as well as the research methodology and design.

- **CHAPTER 4 : EVALUATION AND ANALYSIS**
  This chapter outlines the results of the thesis, starting with the cell radius and the number of base stations required. It also assesses the feasibility of implementing FRMCS in Indonesia. Additionally, the chapter includes sensitivity and risk analysis to evaluate the reliability of the feasibility study's results.

- **CHAPTER 5 : CONCLUSION**
  This chapter describes the conclusions of the thesis and discusses possible improvements for future work.