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ENHANCING EFFICIENCY OF SATELLITE TELEMETRY CHANNELS IN RAILWAY MONITORING APPLICATIONS

The efficiency, reliability, and safety of modern railway infrastructure increasingly depend on the continuous acquisition of accurate telemetry data regarding the technical condition of rolling stock, locomotive subsystems, track infrastructure, and operating parameters. As the industry transitions toward intelligent transport technologies and data-driven operational management, there is a growing need for monitoring systems capable of providing uninterrupted connectivity to mobile railway objects moving across large territories, including remote regions with limited or no terrestrial communication coverage. Satellite communication technologies therefore become a key component for ensuring long-range, stable, and accessible telemetry services in railway applications.

However, satellite communication systems present several limitations, such as high transmission costs, restricted bandwidth, increased communication latency, and energy constraints on board the monitored object. These challenges highlight the necessity of optimizing the processes of telemetry data collection, preprocessing, aggregation, prioritization, and transmission. Effective optimization strategies make it possible to reduce communication load, improve data relevance, and enhance the responsiveness of railway monitoring systems.

A promising direction involves the use of adaptive models for forming telemetry packets, which adjust the volume, frequency, and structure of transmitted data based on the operating mode of the rolling stock, the dynamics of the monitored parameters, the current state of satellite channels, and the criticality of the information. Intelligent methods enable significant reductions in data traffic through techniques such as sensor-level data filtering, temporal data compression, event-triggered reporting, and selective transmission of critical diagnostic indicators in real time. This approach is particularly relevant for parameters associated with vibration diagnostics, axle temperature monitoring, brake system performance, diesel-generator operation, and locomotive control subsystems.

Energy-efficient communication protocols represent another essential component of optimization. Lightweight IoT-class protocols such as MQTT-SN or CoAP, as well as specialized narrowband transport protocols, help minimize overhead and reduce energy consumption of onboard telemetry modules. Embedding machine learning–based predictive analytics directly on the rolling stock further decreases communication load by transmitting only diagnostic

events, anomaly alerts, or predictive maintenance indicators instead of large volumes of raw sensor data.

A substantial improvement in performance can also be achieved through the use of hybrid communication architectures that combine satellite channels with terrestrial GSM/LTE/5G networks. Automated channel selection mechanisms allow the system to dynamically choose the most efficient link based on signal quality, availability, cost, and current network load. Such hybrid systems ensure reliable delivery of telemetry data while reducing overall communication expenses and increasing operational flexibility.

On the ground infrastructure side, advanced methods for processing large-scale telemetry datasets enable improved diagnostics, anomaly detection, and forecasting of technical failures. Machine-learning models can identify hidden patterns in long-term operational data, detect abnormal behavior of locomotive components in early stages, and support predictive maintenance strategies. This allows operators to reduce downtime, extend equipment life, and increase the safety and efficiency of railway.

The conducted research includes a systematic analysis of modern satellite monitoring architectures and identifies the key bottlenecks in telemetry transmission processes. A comprehensive optimization framework is proposed, which integrates: Adaptive telemetry packet formation based on parameter priority and operating conditions; Onboard preprocessing and predictive modelling to reduce the volume of transmitted data; Intelligent communication channel management within hybrid satellite–terrestrial systems; Use of lightweight telemetry protocols to decrease overhead and latency; Cybersecurity measures such as lightweight encryption and secure authentication mechanisms.

These approaches collectively improve the performance of satellite-based monitoring systems, reduce operational costs, enhance communication reliability, and provide stable access to mission-critical data required for decision-making in railway.

In conclusion, optimizing the processes of telemetry data collection and transmission is a crucial factor in the digital transformation of the railway sector. Adaptive, energy-efficient, and intelligent monitoring systems form the technological foundation for predictive analytics, real-time diagnostics, and advanced decision-support tools. The development and deployment of such systems pave the way for safer, more efficient, and more resilient railway transport infrastructures capable of meeting the demands of modern mobility and long-distance operational environments.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ СУПУТНИКОВИХ ТЕЛЕМЕТРІЧНИХ КАНАЛІВ ДЛЯ МОНІТОРИНГУ НА ЗАЛІЗНИЦІ

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