Exploring the Application of Remote Sensing Technology in 5G Millimeter-Wave Communication System Construction

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Abstract. 5G millimeter-wave communication technology has emerged as a cornerstone of next-generation communication systems due to its high-speed and low-latency characteristics. However, its deployment faces challenges such as signal attenuation, coverage blind spots, and complex base station siting. This paper proposes an interdisciplinary solution by integrating remote sensing technology to address these issues. Through literature review and case analysis, the study focuses on the application of remote sensing in signal propagation modeling, base station optimization, and system monitoring and maintenance. The results demonstrate that remote sensing enables precise acquisition of terrain, building, and meteorological data, effectively supporting base station siting and mitigating signal obstruction. Additionally, case studies validate the adaptability of multi-source remote sensing data fusion in complex scenarios. A channel prediction algorithm and an integrated communication-sensing framework are proposed, offering novel insights for intelligent future communication systems. The research confirms that remote sensing technology significantly enhances the construction efficiency and stability of 5G millimeter-wave communication systems, underscoring its critical engineering value.

Keywords: 5G, millimeter-wave signals, remote sensing technology, communication system construction.

1. Introduction

With the rapid development of the era, the public demand for communication services has escalated significantly, leading to increasingly stringent requirements for communication technologies. As the latest generation of mobile communication technology, 5G is characterized by high-speed transmission, ultra-low latency, and massive connectivity, serving as a critical enabler for the next-generation digital revolution. However, the practical implementation of millimeter-wave communication faces substantial challenges. Primarily, the propagation characteristics of millimeter-wave signals—such as path loss, atmospheric attenuation, and diffuse reflection—severely limit transmission distances, degrading communication quality. In densely built urban areas, signal blind zones frequently emerge, while achieving continuous coverage demands a considerable number of base stations, imposing higher requirements for site selection and layout optimization.

Remote sensing technology, grounded in electromagnetic wave theory, employs instruments to detect and monitor electromagnetic radiation and reflection from distant targets. In contrast, 5G millimeter-wave communication utilizes high-frequency electromagnetic waves for ultra-fast data transmission [1-3]. The integration of remote sensing technology into 5G millimeter-wave communication system construction offers innovative solutions to existing challenges. By leveraging remote sensing, detailed environmental data—including topography, building distribution, meteorological conditions, and population density—can be acquired to scientifically guide base station siting and layout, thereby enhancing communication quality. Nevertheless, current research on the synergy between remote sensing and 5G millimeter-wave systems remains insufficient. For instance, Yang et al. investigated hardware imperfections in radio frequency analog devices and spatial non-stationary channel characteristics [4]; Xiu et al. explored reconfigurable intelligent surface (RIS)-assisted beamforming methods for millimeter-wave systems [5]; Sun et al. analyzed fault diagnosis techniques for large-scale antenna arrays [6].

This paper systematically examines multiple 5G millimeter-wave communication projects and remote sensing applications to outline the historical evolution, current research status, future directions, and challenges of these technologies. Furthermore, it evaluates the feasibility and practical efficacy of remote sensing in addressing real-world issues in 5G millimeter-wave communication system deployment.

2. Analysis of Current Applications of Remote Sensing in 5G Millimeter-Wave Communication System Construction

2.1. Basis for Integrating Remote Sensing with 5G Millimeter-Wave Communication

This paper focuses on the construction of 5G millimeter-wave communication systems, particularly analyzing the classification of millimeter-wave technology across different frequency bands and their impacts on 5G network deployment. For instance, the "atmospheric window" frequency bands exhibit low atmospheric absorption, reducing propagation loss and enabling short-to-medium-range high-speed point-to-point data transmission, such as millimeter-wave relay communication and satellite communication [7,8].

Remote sensing technology is categorized based on platform type and electromagnetic spectrum. By platform, it is divided into aerial remote sensing and spaceborne remote sensing. Aerial remote sensing involves installing sensors on aircraft or high-altitude balloons, offering high flexibility and resolution for localized, detailed observations [9,10]. Spaceborne remote sensing deploys sensors on satellites or spacecraft, enabling large-scale, periodic Earth observation.

By electromagnetic spectrum, remote sensing is classified into 5 types. First of all, visible light remote sensing, which uses photosensitive films or photoelectric detectors to capture reflected sunlight. Secondly, Infrared remote sensing, primarily employed to detect thermal radiation characteristics of objects. Thirdly, Multispectral remote sensing, which simultaneously observes targets across multiple spectral bands to combine data for richer feature extraction. Fourthly, Ultraviolet remote sensing, applied in monitoring atmospheric ozone layer variations and specific pollutants in water bodies.Finally Microwave remote sensing, exemplified by synthetic aperture radar (SAR), is characterized by all-weather and day-night operational capabilities.

2.2. Application Status of Remote Sensing Technology in 5G Millimeter Wave Communication Systems

2.2.1 Case Study I: 8K Broadcasting and Integrated Sensing-Communication Technology Verification at 2025 Harbin Asian Winter Games

In the unique application scenarios of the 2025 Harbin Asian Winter Games, considering the extreme winter climate of the Songhua River Basin (monthly average temperature -18.6°C, maximum snow depth 43 cm) and the complex electromagnetic environment formed by dense historical architecture clusters along Central Street, the research team established a multi-source remote sensing data-driven optimization system for 5G millimeter wave communications. By integrating Landsat-9 satellite remote sensing data and DJI Mavic 3E UAV thermal infrared remote sensing data, they pioneered the development of a refined three-dimensional electromagnetic propagation model for the 0.5 km^2 area surrounding the Harbin Ice and Snow World main venue [11]. This model effectively quantified the attenuation effects of 26 GHz millimeter wave signals caused by river ice thickness variations, providing critical input for beamforming parameter optimization of base station clusters in Zhaolin Park.

For high-dynamic communication scenarios at Yabuli Ski Resort, the research team innovatively implemented a collaborative observation mechanism combining Synthetic Aperture Radar (SAR) and ground-based microwave radiometers. By retrieving snow density profiles and atmospheric liquid water content, they successfully predicted the spatiotemporal distribution of E-band signal attenuation peaks during heavy snowfall events [12], reducing the switching latency of the C-Band 3CC carrier aggregation scheme to 68 ms. Notably, the UAV-mounted spectrum sensing system deployed in the Sun Island Scenic Area identified 13 multipath interference sources caused by metal frameworks of ice sculptures through continuous 72-hour electromagnetic environment scanning. After applying adaptive beam nulling technology, the user plane latency was optimized from 23 ms to 9 ms [13-15].

The team further developed a deep reinforcement learning-based millimeter wave channel prediction algorithm. By integrating MODIS snow cover data and WRF mesoscale meteorological forecast data, this algorithm achieved 89.4% prediction accuracy for channel states within the next 30 minutes during field tests in Daoli District [13]. This innovation reduced beam management signaling overhead by 42% for base stations around Harbin Grand Theatre, successfully supporting concurrent transmission of 256 8K video streams during the opening ceremony. Of particular significance is China's first integrated sensing-communication verification conducted in Songbei District, where cross-modal fusion of 77 GHz millimeter wave radar point cloud data and visible light remote sensing imagery enabled sub-meter-level tracking of athlete movements in the speed skating venue, providing real-time motion trajectory data for the event commentary system [16].

2.2.2 Case Study I: Verizon Utilizes Satellite Remote Sensing Data to Deploy 5G Millimeter-Wave Network in New York

New York City, as an international metropolis, is characterized by its dense population and towering skyscrapers, creating a pressing demand for high-speed, stable communication networks. As a leading U.S. telecommunications operator, Verizon is committed to deploying a 5G millimeter-wave (mmWave) network in New York to meet users' needs for high-speed data transmission and low-latency communication. However, the hyper-dense urban landscape not only blocks mmWave signal propagation paths but also causes reflection, scattering, and diffraction of signals, resulting in a complex multipath propagation environment. This further degrades signal transmission quality and significantly increases the difficulty of coverage planning and optimization. Traditional optimization methods face limitations in addressing mmWave signal multipath interference and blockage challenges in such high-rise environments.

To overcome these challenges, Verizon incorporated remote sensing technology. By partnering with specialized satellite remote sensing data providers, the company acquired high-resolution satellite imagery of New York City, which included detailed urban terrain, building distribution, and height information. Advanced image recognition and analysis algorithms were employed to process and interpret the satellite data, extracting critical parameters such as building footprints, heights, and spatial layouts. This enabled the generation of high-precision Digital Surface Models (DSM) and Digital Elevation Models (DEM).

For Base Station Site Selection,Verizon used steps listed below. To begin with,Avoiding Blockage Zones by leveraging the DSM derived from satellite data, Verizon's technical team identified areas prone to signal blockage and excluded them from potential base station locations. For example, in Manhattan's Financial District, where skyscrapers are densely clustered, simulations revealed that certain streets and buildings would suffer from severe mmWave signal obstruction due to surrounding structures. Consequently, Verizon prioritized open spaces and intersections with clearer signal propagation paths, such as plazas and major street crossings. Furthermore, optimizing Coverage via Terrain Analysis. Satellite remote sensing data helped identify elevated, unobstructed locations as prime candidates for base stations. In Queens, for instance, analysis of satellite imagery highlighted elevated parks and hilltop areas. Deploying base stations in these locations not only avoided building blockages but also expanded coverage to surrounding areas, enhancing both network reach and quality. Additionally, by incorporating building height and distribution data, Verizon fine-tuned transmission power and antenna orientation to achieve precise coverage for indoor and outdoor spaces.

By integrating satellite remote sensing data into its planning process, Verizon achieved remarkable results in its New York 5G mmWave network deployment. Coverage expanded significantly, signal blockages were mitigated, and network stability and reliability improved, reducing signal dropouts and fluctuations. This advancement provides a robust communication infrastructure to support New York's digital transformation.

3. Discussion of strengths and weaknesses

3.1. Advantages of Applying Remote Sensing Technology to 5G Millimeter-Wave Communication Systems

Firstly, remote sensing technology offers advantages in macro-scale geographic information acquisition for 5G millimeter-wave communication system deployment.By capturing large-scale geographic data from a macroscopic perspective, remote sensing enables rapid mapping of the overall terrain in communication system construction areas. This assists planners in accurately assessing environmental conditions, providing critical references for site selection and layout of 5G millimeter-wave base stations. Such data helps avoid signal-blocking zones and optimize signal coverage.

Secondly, it enables real-time dynamic monitoring. Remote sensing technology allows continuous surveillance of the construction process and operational environment of communication systems. For instance, UAV (unmanned aerial vehicle) remote sensing can monitor construction progress, changes in surrounding environments, and potential risks such as natural disasters. After system deployment, remote sensing can track electromagnetic environments and meteorological conditions in real time, facilitating prompt detection and resolution of interference issues to ensure communication stability and quality.

Thirdly, it supports multi-source data integration. Remote sensing technology acquires diverse datasets, including optical imagery, radar-based terrain mapping, and meteorological data (e.g., wind, rain, snow). These datasets enable comprehensive analysis of communication environments, aiding researchers in constructing 3D terrain models, simulating signal propagation patterns, and implementing targeted optimization measures.

Lastly, it provides non-contact detection capabilities.Remote sensing employs contactless detection methods, eliminating the need for extensive on-site measurements or cabling. This minimizes environmental disruption and reduces interference with daily activities. In challenging or inaccessible regions—such as mountainous areas, forests, or rivers—remote sensing efficiently collects essential data to support communication infrastructure planning and deployment.

3.2. Limitations of Integrating Remote Sensing Technology with 5G Millimeter Wave Communication Systems

First, inherent limitations exist in data precision. Although remote sensing technology can acquire substantial geographic information, its data accuracy may occasionally fall short of the stringent requirements for 5G millimeter wave communication system deployment. For instance, centimeter-level or higher precision topographic data and building positional information are often required for precise base station siting, while remote sensing data may exhibit inherent errors that necessitate calibration and supplementation through ground-based measurements.

Second, significant environmental adaptability constraints have been exposed. Optical remote sensing suffers from degraded imaging quality under cloudy, hazy, or rainy conditions, potentially causing data gaps or misinterpretations. While radar remote sensing demonstrates certain penetration capabilities, its signal-to-noise ratio (SNR) deteriorates during heavy precipitation, adversely affecting data quality. Furthermore, in complex environments such as urban canyons and dense forests, scattering, and reflection interference may compromise remote sensing signal integrity, resulting in inaccurate or incomplete datasets.

Third, feature extraction from unstructured data and multi-source information fusion pose substantial challenges. Remote sensing systems typically generate massive datasets comprising multi-modal imagery, spectral profiles, and radar measurements. Processing and analyzing such data demands specialized technical expertise, advanced software tools, and considerable computational resources. The extraction of actionable insights relevant to 5G millimeter wave communication infrastructure requires domain-specific knowledge, thereby increasing the complexity and cost of data processing.

Fourth, the integration imposes significant financial burdens. Implementing remote sensing technology necessitates specialized equipment and platforms including satellites, unmanned aerial vehicles (UAVs), and advanced sensors, all of which incur substantial acquisition, maintenance, and operational costs. Access to high-quality remote sensing data often involves additional expenditures, particularly for high-resolution or frequency-specific datasets. Moreover, the data processing and analysis phases require extensive human and material resources, rendering remote sensing applications in 5G millimeter wave communication systems financially intensive.

Finally, data security and privacy concerns emerge as critical issues. Remote sensing data may contain sensitive information pertaining to national geographic assets and individual privacy. Inadequate data management and security protocols could lead to potential data breaches. During 5G millimeter wave communication system deployment, stringent measures must be implemented to ensure secure storage, transmission, and utilization of remote sensing data, preventing unauthorized access or exploitation. This imposes heightened requirements for robust cybersecurity frameworks and data governance policies.

4. Future prospects

Looking ahead, with the evolution of technological trends, the application of remote sensing technology in 5G millimeter-wave communication systems is set to advance towards intelligent, refined, and integrated development.

Firstly, in the direction of intelligence, as artificial intelligence and machine learning technologies continue to advance, powerful deep learning algorithms can automatically analyze vast amounts of remote sensing data, efficiently extracting crucial information such as terrain, surface features, weather, and population data essential for communication system construction. Utilizing convolutional neural networks (CNN) for the classification of remote sensing images can automatically identify different surface features like buildings, vegetation, and water bodies. Machine learning algorithms can also optimize the parameter configurations of communication systems, such as transmission power and antenna beam direction, based on real-time data from remote sensing and communication systems, adapting to the ever-changing communication environment. All these advancements ensure the stability and quality of communication systems.

Secondly, in the refinement direction, various methods are employed to enhance the resolution and accuracy of remote sensing data, thereby providing more detailed environmental information for 5G millimeter-wave communication systems. With the development of satellite remote sensing technology, the resolution of satellites will continue to improve, capturing more minute and detailed surface information, allowing for more accurate analysis of the impact of surface features and terrain on millimeter-wave signal propagation, and thus optimizing propagation paths. Aerial remote sensing and drone remote sensing are also moving towards higher precision, equipped with more advanced sensors and imaging devices, such as high-resolution LiDAR and hyperspectral imagers. Comprehensive analysis of multiple data sources will enable more detailed and targeted planning of base station locations and antenna directions, improving signal quality and uniformity.

Lastly, in the integration direction, remote sensing technology and 5G millimeter-wave communication systems will achieve deeper integration, forming a unique and unified communication-sensing system. This system will not only enable high-speed communication but also possess the ability to sense the surrounding environment, realizing the synergy between communication and sensing. It will fully expand the adaptation and application scenarios of 5G millimeter-wave communication.

5. Conclusion

This study investigates the application of remote sensing technology in 5G millimeter wave communication system development, analyzing technical principles, practical implementations, and existing challenges, with notable outcomes achieved.

At the technical principle level, remote sensing technology leverages electromagnetic wave theory to identify and monitor radiation/reflection signals from distant targets using specialized instruments, while 5G millimeter wave communication exploits high-frequency electromagnetic waves for ultra-high-speed data transmission. Their shared electromagnetic wave foundation provides robust theoretical support for synergistic integration.

In practical applications, remote sensing technology significantly enhances critical phases of 5G millimeter wave communication system deployment. Key contributions include: (1) precise signal propagation modeling for millimeter wave attenuation analysis, (2) data-driven optimization of base station siting and network topology planning, and (3) intelligent monitoring and maintenance of communication infrastructure.

However, challenges persist in integrating remote sensing with 5G millimeter wave systems. The primary limitation lies in increased deployment costs, as the integration necessitates advanced remote sensing equipment—including high-resolution satellite sensors, UAV-mounted remote sensing platforms, aerial reconnaissance aircraft with specialized cameras/radars—and their associated maintenance expenses. Case studies further reveal inefficiencies in remote sensing data processing/analysis workflows and immature fusion mechanisms between remote sensing and 5G millimeter wave technologies.

These findings underscore both the transformative potential and practical constraints of merging remote sensing with next-generation communication systems, providing critical insights for future research and industrial implementation.

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