Discussion on Transmission Coverage Engineering in Terrestrial Digital Television Broadcasting Single Frequency Networks (Postprint)

Authors: revolution

Date: 2023-10-08T00:00:00+00:00

Abstract

Digital terrestrial television broadcasting single-frequency systems represent an important component of China's radio and television broadcasting infrastructure. As one of the most prevalent application methodologies in transmission coverage engineering, single-frequency networks not only facilitate highly efficient frequency planning but also enable multi-point radio frequency deployment to resolve blind spot issues in the coverage process, thereby substantially enhancing the coverage rate of digital terrestrial television broadcasting single-frequency networks in transmission coverage projects. Moreover, single-frequency networks can achieve performance characteristics of low radiation, uniform coverage, and minimal pollution, demonstrating excellent efficacy.

Full Text

Abstract

Ground digital television broadcasting single-frequency networks (SFN) constitute a critical component of China's radio and television infrastructure. As one of the most common application methods in transmission coverage engineering, SFN not only enables efficient frequency planning but also utilizes multiple radio frequency points to resolve blind spot issues during coverage, substantially improving the coverage rate of ground digital television broadcast transmission. Moreover, SFN achieves low radiation, uniform coverage, and minimal pollution, demonstrating excellent performance. This paper introduces the system composition and key technologies of ground digital television broadcast SFN, analyzes existing problems in depth, and proposes specific solutions for transmission coverage issues, aiming to provide helpful references for the deployment and optimization of SFN transmission coverage engineering.

Keywords: ground digital television broadcast single-frequency network; transmission coverage; SFN

1. Ground Digital Television Broadcast Single-Frequency Network Fundamentals

Digital terrestrial broadcasting systems transmit digital signals via ground-based broadcast methods. The earliest digital television broadcasting standard, DTTB, was initially adopted in North America and Europe, followed by the establishment of the European DVB-T standard, the American ATSC standard, and Japan's ISDB-T standard. China's ground digital single-frequency broadcasting system started later, but in 2006, China introduced the "Digital Television Terrestrial Broadcasting Transmission System Frame Structure, Channel Coding and Modulation" standard, known as the DTMB standard. In recent years, with continuous development of information technology, digital television technologies have advanced rapidly, and China has gradually transitioned toward the national DTMB and CMMB standards.

A single-frequency network (SFN) refers to the simultaneous transmission of identical signals at the same frequency from multiple transmitters, enabling comprehensive and reliable coverage of service areas. In recent years, with the continuous development of ground digital television broadcasting networks, SFN has been widely deployed and has entered an optimization phase. Since 2002, extensive trials have been conducted across various regions in China, and nationwide SFN coverage has been largely achieved. However, due to regional differences, the actual code rates vary by location. The application of ground digital television broadcast SFN is influenced by numerous factors, and only through in-depth investigation of SFN transmission coverage engineering can we provide a better development platform and broader space for wireless broadcasters.

Electromagnetic waves are classified into direct waves, multipath reflected waves, diffracted waves, and scattered waves. The channel environments for ground digital television broadcasting primarily fall into three categories: Gaussian propagation channels, Rayleigh propagation channels, and Rice propagation channels.

1.1 Propagation Channel Types

1.1.1 Gaussian Propagation Channel This scenario primarily considers Gaussian thermal noise with line-of-sight propagation between transmitting and receiving antennas, free from obstruction, reflection, and scattering. The probability function expression is:

1.1.2 Rayleigh Propagation Channel This model accounts for thermal noise and multipath effects, including electromagnetic wave reflection and scattering. Typical application environments include areas blocked by mountains or buildings. The probability density expression is:

1.1.3 Rice Propagation Channel This model considers the effects of strong received signals alongside low-power delayed signals, while also incorporating thermal noise. Common applicable environments include high-rise apartment complexes and urban streets. The probability density expression is:

1.2 Path Propagation Loss

Path propagation loss refers to the variation in the average level of electromagnetic waves during spatial propagation. For an omnidirectional antenna, radio waves propagate in space as spherical waves diffusing in all directions. The propagation formula is: where L represents path loss, d is the distance between transmitter and receiver, f is the radio wave frequency, and c is the speed of light.

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2. Current Problems in SFN Transmission Coverage Engineering

2.1 Contradiction Between Coverage Range and Overlap Area

For instance, in DVB-T SFN applications, the following problem exists: increasing coverage area and improving coverage overlap areas cannot be simultaneously satisfied. In COFDM environments, although multiple transmission points improve signal strength in blind spots, strong signal overlap regions raise the C/N threshold, degrading signal reception performance. As a contradictory pair, simply increasing the number of transmission points cannot effectively stabilize reception quality. DTMB and CMMB applications encounter similar issues experienced in DVB-T implementations.

2.2 Security Risks in Synchronization

For DTMB, CMMB, and DVB-T SFN systems, frequency and time synchronization are typically achieved through SFN adapters. In DVB-T applications, GPS provides reference frequency and pulse signals to drive cascade oscillators. The SFN adapter inserts MIP packets into the MPEG-2 stream, which are then distributed to transmission stations via PDN to achieve synchronization. However, in practical applications, standalone GPS systems are prone to information loss, causing overall SFN system confusion and creating significant security vulnerabilities in the synchronization chain.

2.3 Problems in Link Transmission

Code stream transmission represents a critical issue in SFN. SFN requires strict simultaneity, identical frequency, and identical code stream. This is typically addressed through MIP packet processing to achieve time synchronization. The arrival position of MIP packets is closely related to SFN synchronization. Code stream recovery and transmission must guarantee absolute timing, and PCR values and null packets cannot be arbitrarily altered. Current SFN code streams are typically transmitted via direct optical cable, SDH networks, or microwave. While optical cable networks offer simple and reliable methods, they require dedicated fiber, increasing costs and limiting applicability to urban SFN transmission. For SDH networks, DVB-C is typically employed, but ASI and DS3 adapters are incompatible with SFN. Consequently, microwave transmission requires optical cable backup.

[Figure 2: see original paper] Reference Configuration Parameters [Figure 3: see original paper] DVB-T Signal Co-Channel Protection Ratio Against DVB-T Signal (dB)

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4. SFN Transmission Coverage Engineering

4.1 Frequency Selection

For DVB-T implementation system parameters, actual planning requires corresponding configuration as shown in Figure 1 [Figure 1: see original paper]. For all possible frequency selections, the following steps are necessary:

1. First, select a reference station and choose a candidate channel, then calculate the harmful field of the selected station location, and finally identify all reference analog stations with harmful fields exceeding the set threshold.
2. Among the analog stations selected in step 1, adjust ERP values based on the analog stations' harmful field strength values, and further process and filter corresponding analog stations by comparing distances between analog and digital stations.
3. For analog stations filtered in step 2, analyze interference from digital stations to analog stations.
4. Treat the assigned digital station as the desired receiving station. First analyze harmful fields, then examine interference between assigned digital and analog stations, considering both digital and analog EPR values.

4.2 Transmission Mode Selection

For DVB-T application planning, three configuration methods exist: RPC1, RPC2, and RPC3. The main parameter items, parameters, and reception methods are shown in Figure 1 [Figure 1: see original paper]. The 2K mode can construct small SFNs, offering fast synchronization and strong anti-interference capability, while the 8K mode provides stable synchronization and strong anti-delay capability. The net bit rates possible in DVB-T systems under different modulation modes are shown in Figure 4 [Figure 4: see original paper]. DVB-T co-channel protection ratio values vary across different channels and modulation schemes, as detailed in Figure 3 [Figure 3: see original paper].

Representative transmission mode combinations are shown in Figure 5 [Figure 5: see original paper]. Generally, for SFNs with coverage radius less than 37.54 km, modes 1 and 3 in Figure 6 [Figure 6: see original paper] can be used, typically employing PN945 as the frame header, though this approach has large frame header overhead and lower error correction coding rates. For SFNs with coverage radius less than 16.68 km, modes 5 and 6 are generally adopted. Mode 6 uses 64QAM to achieve high net payload rates when multipath channel performance is poor. Mode 5 uses 16QAM with higher error correction coding rates and has now been widely applied. For SFNs with coverage radius less than 23.61 km, modes 2, 4, and 7 are typically selected. All three modes have a coding efficiency of 0.8. Mode 7 has lower modulation than mode 4, while mode 2 has the lowest C/N threshold and is generally applied to mobile services. For small SFN selection, the goal is to reduce overlap areas from a wireless perspective.

4.3 Synchronization Mode Selection

[Figure 7: see original paper] SFN Networking Mode

In multi-carrier systems, resistance to frequency drift is relatively weak. GPS is used for synchronization while establishing a high-stability local oscillator. This approach uses GPS as a frequency reference, allowing transmitters to emit at the fundamental frequency for stable system operation. When the main transmission point receives high-quality signals from the transmitter, it feeds them to a frequency converter to transform the signal into an intermediate frequency, which is then filtered and amplified. This method proves highly effective for blind spot coverage.

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5. Conclusion

This paper examined SFN transmission coverage engineering for ground digital television broadcasting from four perspectives: SFN fundamentals, current problems in SFN transmission coverage engineering, SFN transmission coverage planning, and SFN transmission coverage implementation. In an era of resource constraints, SFN can significantly improve frequency resource utilization efficiency, ensure stable and reliable signal reception, and guarantee the reliability of transmission coverage areas.

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(Author affiliation: Inner Mongolia Press, Publication, Radio, Film and Television Bureau, Hulunbuir Broadcast Transmission Center)

Note: Figure translations are in progress. See original paper for figures.