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Contribution to the study of single frequency network (SFN) coverage of digital terrestrial television DVB-T2 incorporating Mimo technology

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Abstract

The second-generation digital terrestrial television (DVB-T2) represents a key technology for large-scale audiovisual broadcasting, particularly in environments characterized by high population density and complex topography. One of the major challenges of this standard is the optimization of radio coverage while ensuring high spectral efficiency. Single Frequency Networks (SFNs) address these requirements by allowing multiple transmitters to simultaneously broadcast the same signal on the same frequency. However, SFN operation introduces constraints related to inter-symbol interference and multipath effects, especially in overlapping areas. The integration of MIMO (Multiple Input Multiple Output) technology into the DVB-T2 standard opens new perspectives for improving the robustness, capacity, and coverage of SFN networks. This article provides a contribution to the analytical and functional study of SFN coverage in DVB-T2 incorporating MIMO, relying on fundamental principles, channel modeling, spatial diversity mechanisms, and performance evaluation.

Keywords: DVB-T2; Single Frequency Network (SFN); MIMO; OFDM; Radio Coverage; Digital Terrestrial Television; Spatial Diversity

1. Introduction

The global transition from analog to digital terrestrial television has profoundly transformed audiovisual broadcasting architectures. The DVB-T2 standard, the successor to DVB-T, was designed to provide better spectral efficiency, increased robustness against channel disturbances, and flexibility suited to new multimedia services [4].

In this context, radio coverage is a fundamental parameter determining service accessibility and continuity. Single Frequency Networks (SFNs) have emerged as an effective solution for maximizing the use of the radio spectrum, particularly in highly constrained UHF bands [2]. However, the increase in the number of transmitters and the overlap of signals result in complex phenomena of interference and multipath propagation [3].

Moreover, the introduction of MIMO (Multiple Input Multiple Output) technology into DVB-T2 allows for the exploitation of the spatial dimension of the radio channel to enhance diversity, robustness, and transmission reliability, particularly in SFN environments [1][5].

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2. Single Frequency Networks (SFN) in DVB-T2

2.1. Principle of SFN

A **Single Frequency Network (SFN)** is based on the simultaneous broadcasting of the same signal from multiple synchronized transmitters, all operating on a single frequency. This architecture optimizes spectrum utilization and improves coverage by avoiding interferences related to the use of different frequencies [2][4].

In the context of **DVB-T2**, synchronization relies on very precise temporal references (GPS, atomic clocks), which allow strictly aligned emissions in time and ensure the coherence of the received signal [4]. In both urban and rural environments, the superposition of signals from multiple emission points favors propagation and can generate beneficial constructive effects [3].

The general architecture of a Single Frequency Network (SFN) is illustrated in the figure below:

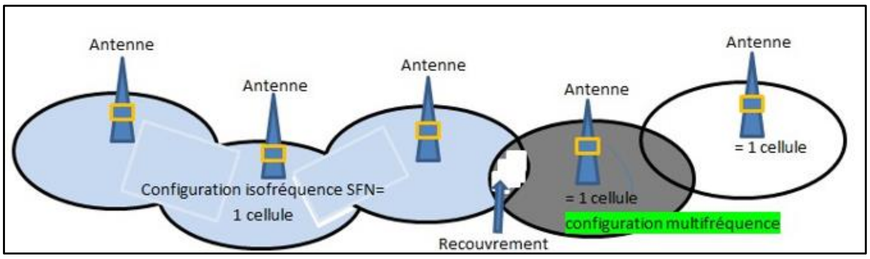

Figure 1 General architecture of a Single Frequency Network (SFN)

2.2. Experimental Bench and Multi-Emitter Transmission Chain

To study SFN coverage, an **experimental bench** comprising a transmission chain involving multiple DVB-T2 transmitters sharing the same frequency is set up. This chain includes the generation of the digital signal, the **OFDM modulation** specific to DVB-T2, and the precise replication and synchronization of the streams to each transmitter [2]. Each transmitter is equipped with amplifiers, filters, and antennas configured to replicate realistic terrain conditions. This setup allows for experimental observation of wave propagation, their superposition, and the dynamics of overlapping areas [3].

The following figure shows the functional diagram of an experimental bench and multi-emitter transmission chain.

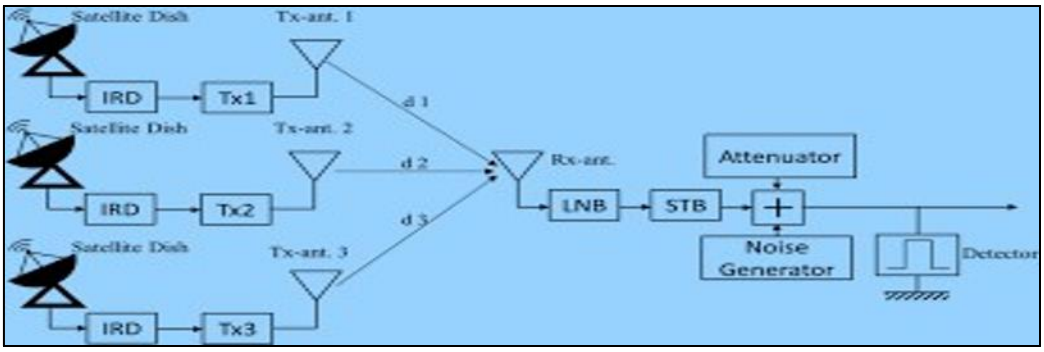

Figure 2 Experimental bench and multi-emitter transmission chain

2.3. Overlapping Areas in SFN Networks

Overlapping areas correspond to regions where signals emitted from multiple transmitters overlap in time and frequency. In an SFN, these zones are crucial as they may generate **inter-signal interference (ISI)** if the temporal synchronization is imperfect or if the propagation delays differ too much [1][3].

The temporal offset between signals must remain less than the duration of the cyclic prefix of the OFDM to allow for constructive interference and take advantage of spatial diversity mechanisms [5]. A fine mapping of these areas helps identify potential gains in coverage and optimize transmitter positioning [3].

The Single Frequency Network (SFN) composed of two synchronized transmitters is represented in the figure below.

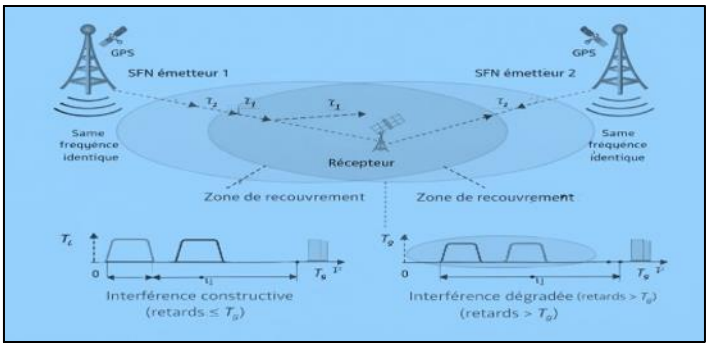

Figure 3 Single frequency network (SFN) composed of two synchronized transmitters

2.4. Mathematical Formulation of Delays in an SFN

In a single frequency network (SFN), the signal received by a terminal results from the superposition of several contributions from spatially distinct synchronized transmitters. From the receiver's perspective, these contributions can be assimilated to **multipath propagation**, provided that their relative delays are compatible with the OFDM structure of the DVB-T2 signal [2][4].

The received baseband signal can be modeled as:

$$r(t) = \sum_{i=1}^{N} h_i \; s(t - \tau_i) \, e^{j\phi_i} + n(t)$$

where:

- $s(t)$ denotes the transmitted OFDM signal
- h_i represents the complex channel gain associated with the (i)-th transmitter
- τ_i is the propagation delay of the signal coming from the (i)-th transmitter
- ϕ_i corresponds to the phase associated with the considered path
- $n(t)$ is the additive white Gaussian noise (AWGN),
- N is the number of SFN transmitters contributing to the received signal.

In an OFDM system, each symbol is preceded by a guard interval of duration (T_g), intended to absorb the effects of multipath and prevent inter-symbol interference (ISI). The fundamental condition for correct reception in an SFN can then be expressed as:

$$\max_i (\tau_i) - \min_i (\tau_i) \leq T_g$$

When this condition is satisfied, the signals received from different transmitters are fully contained within the OFDM observation window and are interpreted by the receiver as useful multipath. They then constructively contribute to the energy of the received symbol, thus improving the effective signal-to-noise ratio.

Conversely, if the maximum delay difference exceeds the duration of the guard interval, part of the symbol energy propagates outside the OFDM window, generating inter-symbol interference.

This situation leads to a significant degradation of system performance, resulting in an increase in bit error rate (BER) and a reduction in coverage probability. This mathematical formulation is a fundamental criterion for planning DVB-T2 SFN networks, conditioning the choice of guard interval duration, transmitter spacing, and optimization of coverage, particularly in critical overlap zones.

3. MIMO Technology Applied to DVB-T2

MIMO (Multiple Input Multiple Output) technology utilizes multiple antennas at both the transmission and reception stages to enhance the capacity and robustness of the radio link. When applied to **DVB-T2**, it exploits **spatial diversity** and **spatial multiplexing** to improve data rates and coverage [5].

MIMO compensates for the effects of **multipath fading**, which are characteristic of terrestrial channels [1]. Each antenna emits distinct coded and synchronized streams in **OFDM**, thereby optimizing spectral efficiency [2]. The key principle involves decomposing the radio channel into several partially independent sub-channels, allowing either a gain in quality via diversity or an increase in data rate via spatial multiplexing, depending on the chosen architecture [3].

This approach is particularly relevant in **SFN environments**, where overlapping signals can otherwise degrade performance. By leveraging spatial diversity, MIMO strengthens transmission reliability and ensures more consistent coverage [1][3][5].

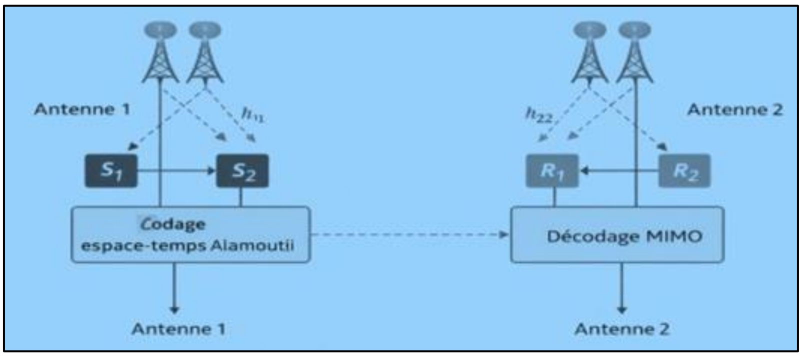

Figure 4 MIMO scheme in the DVB-T2 standard

4. Analysis of SFN DVB-T2 Coverage with MIMO

The study of MIMO configurations in an SFN DVB-T2 environment encompasses the following cases:

- SISO (Single Input Single Output): reference configuration without spatial diversity, sensitive to interference and fading.
- SIMO (Single Input Multiple Output): multi-antenna receiver, improves robustness through reception diversity.
- MISO (Multiple Input Single Output): multi-antenna transmission, adds diversity in emission.
- Complete MIMO (Multiple Input Multiple Output): diversity in both transmission and reception, more complex but offering maximum gains.

The comparison focuses on indicators such as the bit error rate (BER), effective capacity, and resilience in SFN overlapping areas. The use of MIMO significantly alleviates constraints related to delays and reduces inter-source interference effects by ensuring a better spatial distribution of the signal. The SISO, SIMO, MISO, and MIMO configurations exhibit different performance levels in terms of robustness, coverage, and spectral efficiency.

The following figure compares the different antenna configurations (SISO, SIMO, MISO, and MIMO) and highlights the potential gains provided by spatial diversity in wireless communication systems.

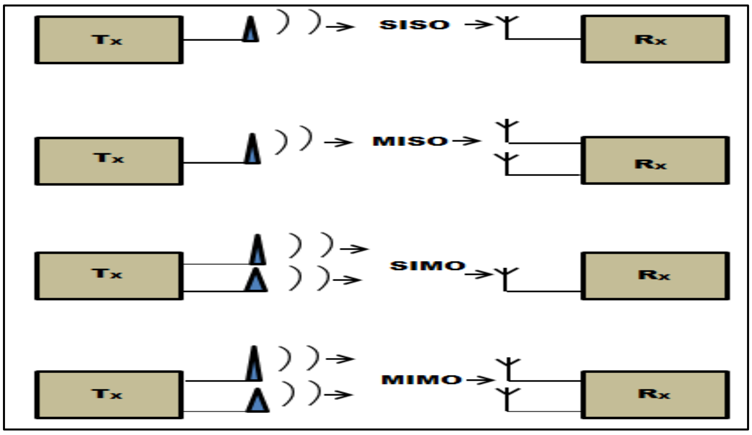

Figure 5 Comparison of SISO, SIMO, MISO, and MIMO configurations

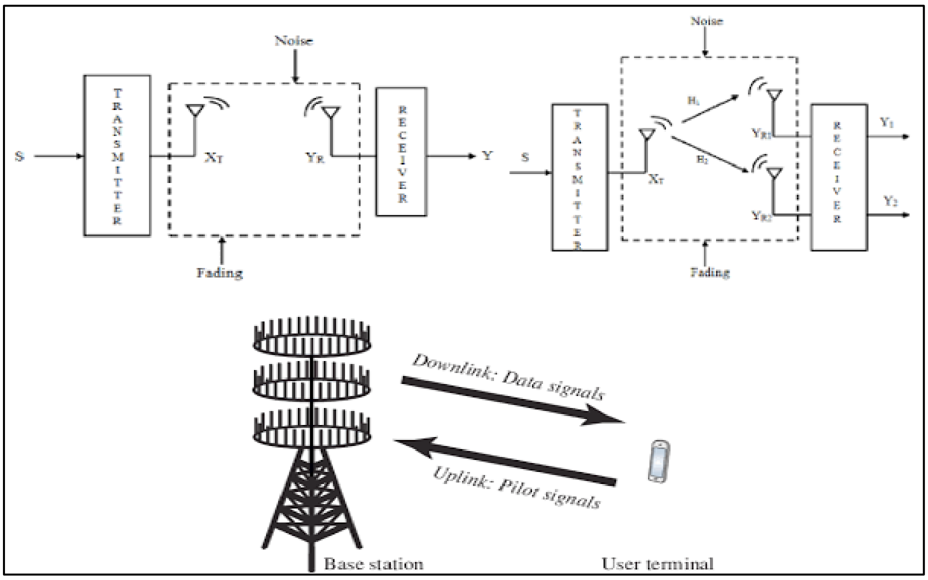

Figure 6 Antenna techniques (SISO, SIMO, MISO, MIMO)

The SISO, SIMO, MISO, and MIMO antenna configurations differ based on the number of antennas used at the transmission and reception stages, which directly influences the robustness of the transmission, radio coverage, and spectral efficiency of the system.

As illustrated in Figure 5, the SISO (Single Input Single Output) configuration, using a single antenna for both transmission and reception, represents the simplest architecture. However, it exhibits low robustness against fading and interference, limiting its performance in challenging propagation environments.

The SIMO (Single Input Multiple Output) configuration enhances reception reliability by utilizing multiple antennas on the receiver side. The signals received by these antennas are combined to reduce the impact of noise and fading, resulting in better reception quality without modifying the transmitter.

In contrast, the MISO (Multiple Input Single Output) configuration employs multiple antennas at transmission to send the same signal to a receiver equipped with a single antenna. This technique improves coverage and robustness of the radio link, notably through emission diversity.

Finally, the MIMO (Multiple Input Multiple Output) configuration, presented in Figures 5 and 6, combines multiple antennas for both transmission and reception. It fully exploits the spatial diversity of the radio channel, offering the highest gains in terms of robustness, coverage, and spectral efficiency. In DVB-T2 systems, MIMO is primarily used to enhance the reliability of transmission and stability of coverage, particularly in SFN environments.

5. Performance and Evaluation Indicators

The evaluation of SFN DVB-T2 coverage incorporating MIMO relies on key indicators:

- The bit error rate (BER), which measures the reliability of the digital stream.
- The signal-to-noise ratio (SNR), essential for assessing the quality of reception.
- Channel capacity (in bits/s/Hz), an indicator of achieved spectral efficiency.
- Robustness against temporal and spatial interferences, analyzed through propagation models and simulations.
- Effective geographical coverage, mapped in urban and rural areas.

Results show that incorporating MIMO in an SFN DVB-T2 improves the consistency of coverage and the quality perceived by the user, particularly in complex overlapping areas.

6. Conclusion

The addition of MIMO technology to SFN DVB-T2 networks represents a significant advancement for digital terrestrial television. It helps mitigate constraints related to propagation delays and spatial interferences in a multi-emitter context. The experimental bench and delay modeling provide a detailed understanding of phenomena affecting coverage. The analysis of different MIMO configurations highlights a tangible improvement in link quality and coverage, paving the way for more efficient broadcasting solutions to meet the increasing demands of digital.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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