ECE 9038 Report

Abstract

Accurate modeling of wireless multipath fading channels is essential for the design and evaluation of modern communication systems. This report presents a comprehensive study of the Sum-of-Sinusoids (SOS) channel modeling approach, comparing three parameter-computation methods under the COST207 rural four-path scenario. I evaluate each method through time-domain impulse responses, Doppler power spectral density estimates, and bit-error-rate simulations to assess their respective strengths and limitations.

1. Introduction

The rapid proliferation of mobile and wireless applications has led to increasingly stringent requirements on link reliability and spectral efficiency. As the figure 1 shows, in practical deployment scenarios, transmitted radio waves undergo reflection, diffraction, and scattering by buildings, terrain, and other obstacles, resulting in multiple propagation paths between transmitter and receiver [1], [2]. These multipath components introduce time-varying amplitude and phase fluctuations—commonly referred to as small-scale fading—which degrade system performance through deep fades and inter-symbol interference. Under the wide-sense stationary uncorrelated scattering (WSSUS) assumption, a fading channel can be modeled as a time-variant linear system whose impulse response fully characterizes both delay dispersion and Doppler spread phenomena observed at the receiver.

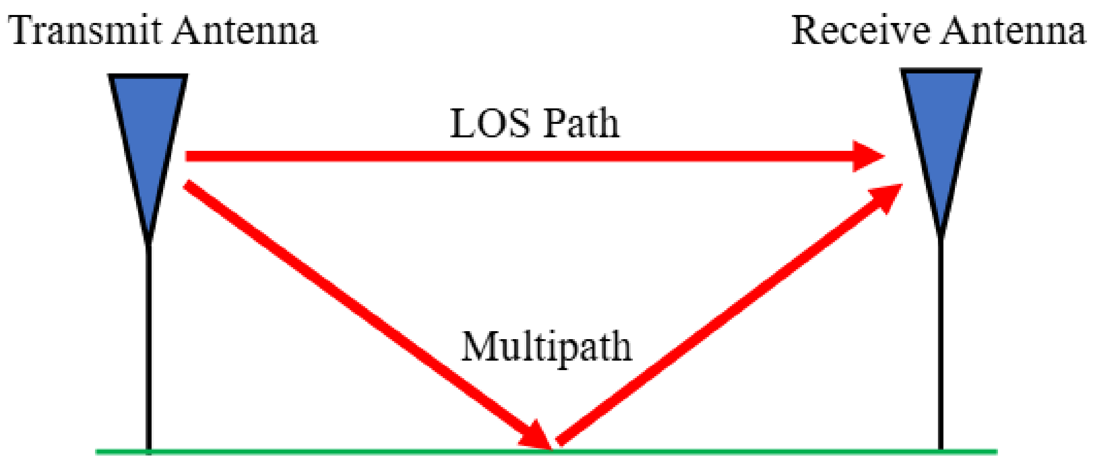


Figure 1. The multipath fading communication scenario according to ellipse model.

Empirical measurement campaigns using channel sounding equipment provide valuable real-world datasets but are often costly, time-consuming, and limited in environmental diversity. In contrast, simulation-based approaches offer a flexible, repeatable framework for studying channel behaviors under controlled parameter settings. The Sum-of-Sinusoids (SOS) method has emerged as a widely adopted simulation technique owing to its capability to replicate the statistical properties of Rayleigh fading in both time and frequency domains. By representing each propagation path as a superposition of sinusoidal components with specified Doppler shifts and random phases, the SOS model allows straightforward incorporation of user-defined Doppler profiles and delay spreads.

In this report, I examine the SOS modeling approach within the context of the COST207 rural four-path channel standard. I begin by reviewing the theoretical foundations of the SOS representation and its equivalence to the tapped-delay-line (TDL) model. Next, I detail three deterministic parameter computation methods—Random-θ, MED, and MEDS—and compare their principles, implementation complexity, and expected performance. Subsequent sections present comprehensive MATLAB-based simulations that evaluate each method's time-domain impulse responses, Doppler power spectral densities, and bit-error-rate performance for both QPSK and OFDM-QPSK systems. Finally, I discuss the strengths, limitations, and potential future directions for enhancing SOS-based channel modeling.

2. Sum-of-Sinusoids Channel Model

The SOS framework models each multipath component as a deterministic superposition of complex sinusoids, enabling fine-grained control over Doppler shifts and phase distributions.

2.1 SOS Repersentation

Each propagation path is modeled as an SOS process [1]:

$$h_i(t) = \sum_{n=1}^{N} g_n \exp\big(j(2\pi f_n t + \phi_n)\big),$$

Here, g_n and φ_n denote the amplitude and initial phase of the n-th sinusoid, and f_n is its Doppler frequency. This construction reproduces Rayleigh fading statistics in both time and frequency domains.

2.2 Tapped-Delay-Line (TDL) Equivalence

By superimposing delayed and weighted SOS gains, the overall channel impulse response assumes a tapped-delay-line form [3]:

$$h(\tau, t) = \sum_{i} a_i \, h_i(t) \, \delta(\tau - \tau_i).$$

where a_i and τ_i represent the power gain and delay of the i-th path, and $\delta()$ enforces the path-specific delay. This TDL representation underpins many digital channel simulators.

3. Parameter Computation Methods

Here compares three deterministic methods for selecting Doppler frequencies f_n and initial phases Φ_n, as shown in Table I [4]:

Method	**Principle**	**Advantages**	**Disadvantages**
Random-θ	Random arrival angles θ_n	Simple implementation	Significant statistical variability
MED	Equally spaced angles in $[0,2\pi)$	Low computational complexity	Moderate spectral fit
MEDS	Inversion of theoretical CDF for exact Doppler placement	Best match to theoretical spectrum	More complex to implement

Table I. Characteristics of three computation methods

4. Simulation Setup

- **SOS configuration:** N= 128 sinusoids, maximum Doppler shift f_d=70 Hz, sampling rate f_s = 5000 Hz, duration T = 10s, same as in the paper [1].
- **COST207 rural channel:** Four propagation paths with delays [0, 0.2, 0.4, 0.6] µs and normalized powers [1, 0.63, 0.10, 0.01], same as in the paper [1].

5. Results and Analysis

5.1 Time-Domain Impulse Response Comparison

I generated three-dimensional plots of |h(t)|) for each method, as shown in Figure 2, Figure 3, Figure 4:

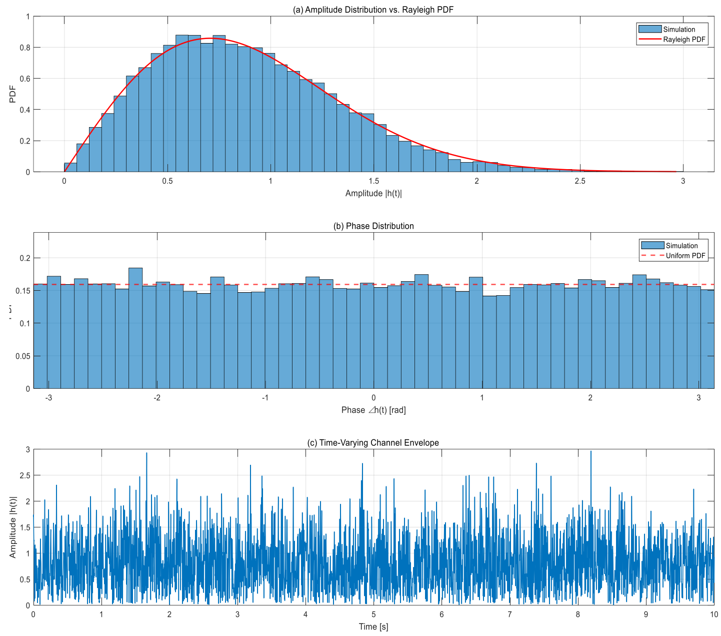


Figure 2. Amplitude&phase diagram for jake's method

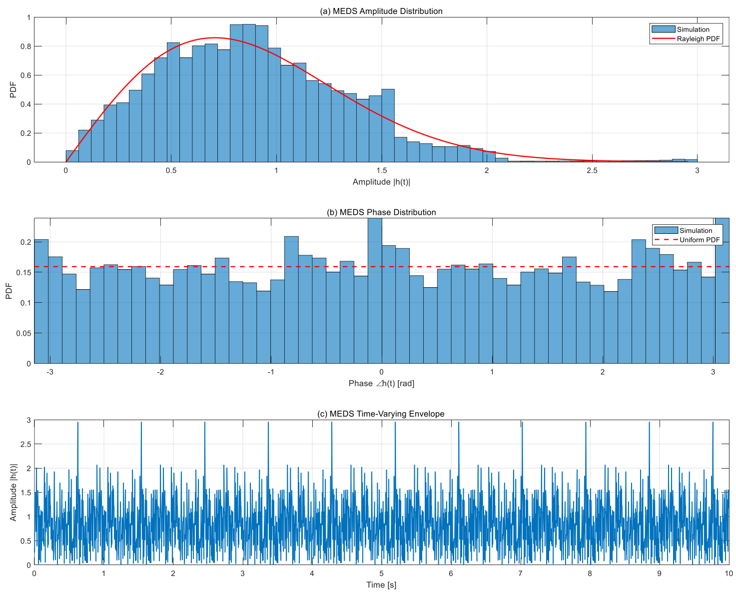


Figure 3. Amplitude&phase diagram for MEDS method

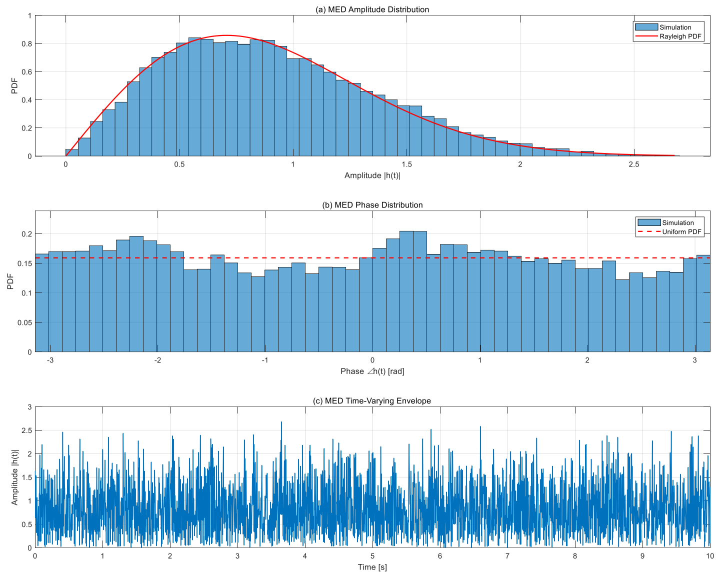


Figure 4. Amplitude&phase diagram for MED method

From the figures, we can know that:

- **Random-θ:** Exhibits large temporal fluctuations and lacks statistical stability.
- **MED:** Displays periodic patterns determined by equally spaced angles.
- **MEDS:** Produces more uniform fluctuations, closely adhering to theoretical statistics.

5.2 Doppler Power Spectral Density (PSD) Comparison

Applying Welch’s method, I compared the estimated PSDs against the theoretical Jakes spectrum (Figure 5):

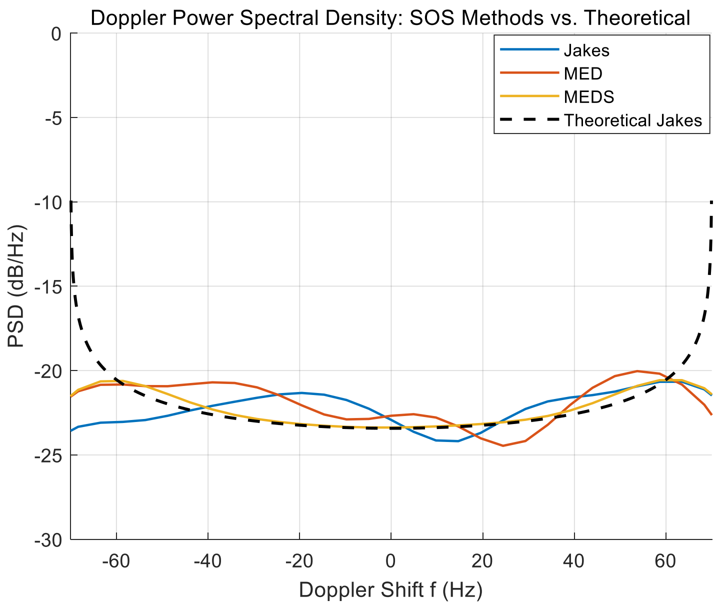


Figure 5. Doppler PSD comparison

From the figures, we can know that:

- **MEDS** aligns most closely with the theoretical curve.
- **MED** shows acceptable fit with minor deviations.
- **Random-θ** suffers from sampling noise and large spectral variance.

5.3 Scattering function

I compared the estimated Scattering function of three methods under the condition of COST207 (Figure 6):

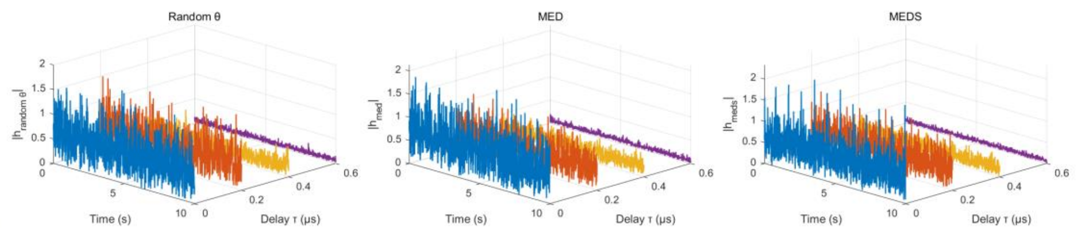
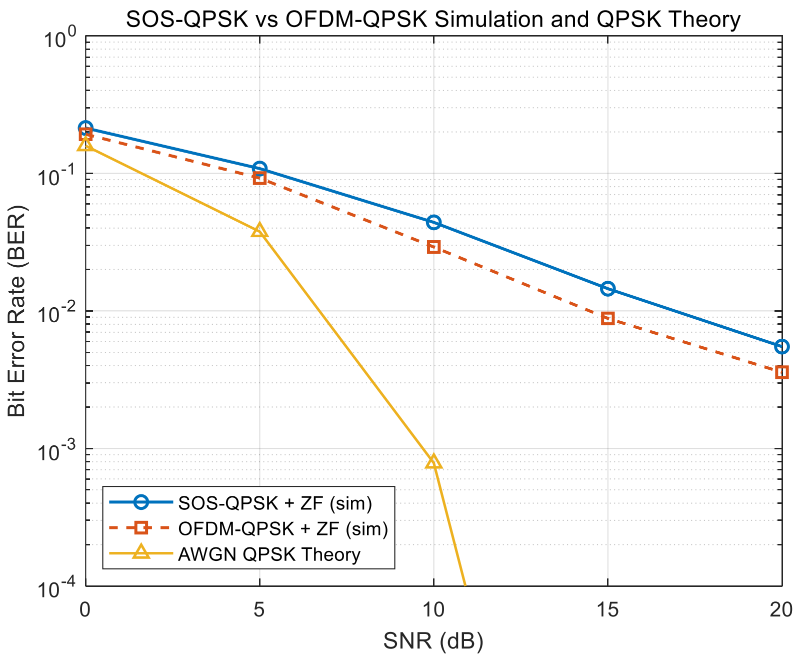


Figure 6. Scattering function of different methods

What worth noticing is that when tau=0, it becomes the Rice type.

5.4 Bit-Error-Rate (BER) Performance

Figure 7. evaluates SOS-QPSK and OFDM-QPSK under the COST207 channel, juxtaposed with the theoretical AWGN QPSK limit:



This shows that while SOS-based fading cannot be eliminated, OFDM provides a robust way to combat multipath without requiring much complexity.

However, compared with the results in the paper, the ber performance of my simulation results is poor, which may be because my channel estimation, equalization and coding parts can be further optimized.

6. Discussion

The finite sinusoidal representation inherent in SOS modeling can introduce periodic artefacts, causing repeat patterns that may not fully capture the randomness of real-world fading. Mitigation strategies such as phase randomization or hybridizing deterministic and stochastic approaches can help reduce these biases. While the MEDS method provides the best conformity to the theoretical Doppler spectrum, its reliance on CDF inversion and increased computational demands may limit its suitability for rapid or resource-constrained simulations. Conversely, the MED approach balances spectral accuracy and simplicity, making it a practical choice for initial algorithm tests and broad parameter sweeps. Overall, practitioners must weigh the need for spectral fidelity against implementation complexity and simulation speed when selecting between Random-θ, MED, and MEDS for their specific evaluation objectives [5].

7. Conclusions and Future Work

1. The SOS framework effectively reproduces key statistical features of multipath fading.
2. Among deterministic methods, MEDS offers the highest spectral fidelity; MED provides a trade-off between complexity and performance.
3. OFDM effectively mitigates multipath effects but incurs an approximate 3 dB performance penalty relative to AWGN.

Future work will pursue the following directions. First, we plan to design hybrid channel models that seamlessly integrate SOS-generated taps with empirically measured impulse responses, thereby mitigating periodic artefacts and capturing non-stationary channel phenomena. Second, we will develop adaptive parameter estimation techniques—leveraging pilot-assisted measurements and machine learning algorithms—to infer Doppler spread and delay profiles in real time, enabling dynamic channel emulation within software-defined radio environments. Third, we aim to accelerate SOS simulation through parallel computing frameworks, including GPU and FPGA implementations, to facilitate large-scale Monte Carlo analyses and support real-time channel reproduction. Finally, extending the SOS methodology to multi-antenna (MIMO) and frequency-selective fading scenarios will further validate its versatility across advanced wireless communication systems.

Reference

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[2] [1] J. D. Parsons, and A. S. Bajwa, “Wideband characterisation of fading mobile radio channels,” Communications Radar & Signal Processing Iee Proceedings F, vol. 129, no. 2, pp. 95-101, 1982.

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