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Improved Moment Estimation Algorithm for Rician Factor Based on Bessel Functions: Postprint

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Abstract

To address the issues of high computational complexity and low practicality associated with Bessel functions in traditional first- and second-order moment estimation methods for the Rician K-factor, a Rician K-factor moment estimation algorithm based on Bessel function order is proposed. The algorithm first calculates the moment estimate corresponding to the K value according to the original moment estimation formula, then computes moment estimates using Bessel approximation formulas of different orders and solves for the corresponding K values to calculate the estimation accuracy, thereby determining the selection of the Bessel function order and simplifying the moment estimation algorithm. Experimental studies demonstrate that the proposed method reduces computational time compared with the original method and achieves superior performance for smaller K values.

Full Text

Preamble

Title: Improvement of Moments Estimation Algorithm for Rice Factor Based on Bessel Functions

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Abstract: Aiming at the problem of high computational complexity and low practicability caused by the Bessel functions in the traditional first- and second-order moments estimation algorithm, this paper proposes an improved moments estimation method based on order selection of Bessel functions. The algorithm first calculates the moment estimation values corresponding to different K values using the original estimation formula, then computes moment estimation values using Bessel function approximations of different orders to solve for the corresponding K values and calculates the estimation accuracy, thereby determining the appropriate order selection for Bessel functions to simplify the moment estimation algorithm. Experimental studies show that compared with the original method, the proposed method reduces time consumption, with superior performance for small K values.

Keywords: Rice factor; moments estimation; Bessel functions; order selection

0 Introduction

Rice channels are a typical channel model commonly used in wireless communications to describe the statistical time-varying characteristics of received signals [1]. The received signal in a Rice channel comprises a line-of-sight (LOS) component and a scattered component [2]. The Rice factor K reflects the power ratio between the LOS and scattered components in a Rice channel, serving as a crucial parameter for characterizing channel fading severity and link budget [3,4]. A larger Rice factor indicates better channel quality, making the extraction of the Rice factor K essential for channel model analysis.

Moment estimation methods based on signal envelope represent an important approach for extracting the channel Rice factor. These methods feature simple principles, do not utilize phase information, require no prior knowledge of the Rice channel, and significantly reduce computational complexity, offering substantial advantages in algorithm robustness. In recent years, numerous researchers have contributed to the moment estimation of the Rice factor. Reference [5] proposed a second- and fourth-order moment estimation method based on envelope; Reference [6] introduced a first- and second-order moment estimation method based on envelope. Both approaches determine the K value by equating K' s function to the ratio of measured envelope moments. Reference [7] proposed a Rice factor moment estimation method based on time-series data; Reference [8] validated the effectiveness of Reference [7]' s method and investigated environmental impacts on the Rice factor; Reference [9] further refined the method in Reference [7] by incorporating background noise and interference power into the model, yielding an improved moment estimation algorithm that enhanced estimation accuracy; Reference [10] derived an explicit moment estimation method for the Rice factor from the approximate equations in Reference [6]; References [11-13] proposed a closed-form Rice factor estimator using second- and fourth-order moments.

Simulation results in References [11,12] demonstrated that the first- and second-order envelope moment estimation method proposed in Reference [6] outperforms the second- and fourth-order moment estimation method in terms of normalized bias and asymptotic variance performance. Reference [13] compared these two moment estimation methods, revealing the following similarities and differences: the second- and fourth-order moment estimation method consumes slightly less time than the first- and second-order method, while the first- and second-order method achieves higher estimation accuracy. The primary reasons are: the first- and second-order moment estimation method contains Bessel functions, which are inherently high-order and computationally complex, and cannot be expressed in closed-form using elementary functions; the second- and fourth-order method has lower overall order and can solve for K in closed form, resulting in lower time consumption. Secondly, the first- and second-order moment estimation calculates first- and second-order moments based on time-series data, yielding high Rice envelope precision.

Therefore, if an efficient Bessel function approximation method can be obtained, the time consumption can be reduced and algorithm efficiency improved without affecting the computational accuracy of the first- and second-order moment estimation method. This paper proposes an improved Rice factor extraction method based on polynomial fitting of Bessel functions for first- and second-order moment estimation. By leveraging the functional relationship between the first- and second-order moments of Rice-distributed signals and the Rice factor, combined with prior knowledge of the Rice factor' s value range in wireless channels, the Bessel function is approximated to reduce its order, thereby decreasing the overall expression order and improving algorithm efficiency.

1.1 Rice Channel

In Rice channels, the line-of-sight path channel coefficients do not vary with time. Under the condition that incident waves satisfy uniform angular distribution, the probability density function is given by the Rice distribution. [Figure 1: see original paper] shows the flowchart of the first- and second-order moment estimation algorithm, where the variables represent the signal fading amplitude, phase of each path, and the phase of the line-of-sight component, respectively. A_0 represents the envelope of the line-of-sight component. Integrating over the phase yields the envelope distribution function of channel gain:

where $I_0(\cdot)$ is the zeroth-order modified Bessel function of the first kind. The mean square value of the Rice-distributed random variable r is $E[r^2] = A^2 + 2\sigma^2$, where A^2 and $2\sigma^2$ represent the line-of-sight component power and diffuse component power, respectively. The Rice factor of the channel is defined as [14]:

$K = A^2/(2\sigma^2)$

Thus, Equation (2) can be rewritten as:

1.2 Rice Factor Moment Estimation Method

The moments of Rice-distributed variables are expressed as follows [13]:

where $\Gamma(\cdot)$ is the gamma function and ${}_1F_1(\cdot;\cdot;\cdot)$ is the confluent hypergeometric function. The moment estimation depends on parameters A and σ, requiring at least two different moments to determine K. Commonly used moments include first-order, second-order, and fourth-order moments. From Equation (5), we obtain:

Using Equations (6) and (7), the relationship between first- and second-order moments and K is:

Since Equation (9) contains Bessel functions, it cannot be expressed in closed form using elementary functions, significantly increasing computational complexity and reducing efficiency. Consequently, it is rarely used in practical applications despite its accuracy advantage. If Bessel functions can be approximated via polynomial fitting with minimal precision loss, the complexity of first- and second-order moment estimation can be effectively reduced without compromising estimation performance.

The modified Bessel function of the first kind is expressed as:

References [15,16] propose the following approximation formulas:

Comparisons between the approximation and theoretical values reveal that when x [0,5.2], the approximation values nearly coincide with theoretical values, with negligible error. Similarly, comparisons between the approximation and theoretical values show near-perfect overlap when x [0,5.2]. Therefore, if the research variable range is x [0,5.2], Bessel function approximations can be used to estimate the Rice factor K when appropriate orders are selected.

Substituting Equations (11) and (12) into Equation (9) yields the approximate expression for Rice factor K. Therefore, when the actual Rice factor of the channel falls within the range K [0,5], the Bessel function approximations can completely replace the exact Bessel functions to simplify the Rice factor estimation, provided the order is appropriately selected.

2.2 Selection of Bessel Function Approximation Order

The order of Bessel function approximations affects estimation accuracy—generally, higher order yields higher precision but also greater algorithmic complexity. To ensure the Rice K-factor estimation accuracy meets channel characteristic extraction requirements while minimizing algorithmic complexity, selecting the optimal order for Bessel function approximations becomes crucial. Accordingly, the order selection process for Bessel approximations is illustrated in [Figure 2: see original paper] and described as follows:

a) Calculate the first- and second-order moment estimation values corresponding to different K values based on the exact Bessel functions;

b) Compute the first- and second-order moments using the selected-order Bessel approximation and solve for the corresponding estimated Rice factor value K;

c) Compare the theoretical K value with the estimated K value, calculating their relative error. If the error falls within the allowable range, the selected order can be used for Rice factor estimation; otherwise, increment the order by 1 and repeat step b).

3.1 Effectiveness Evaluation

To evaluate the effectiveness of different orders for Bessel function approximations in calculating K values, this paper primarily uses accuracy rate as the evaluation metric for different K value ranges:

a) Accuracy rate: D = (L /L) × 100%, where L represents the Rice factor K value range length, and L represents the number of K values within length L where the estimated values using the selected order match exactly with those from the original first- and second-order moment estimation.

b) Root mean square error: RMSE = √[(1/N) 1 (X , - X ,)^2], where N represents the number of samples within range L, X , represents the i-th observed value, and X , represents the i-th theoretical value.

3.2 Simulation Results

This paper selects orders 4 and 6 for the zeroth-order modified Bessel function of the first kind, and orders 3 and 5 for the first-order modified Bessel function. Four combinations are formed: - Combination 1: Zeroth-order Bessel function order 4, first-order Bessel function order 3 - Combination 2: Zeroth-order Bessel function order 4, first-order Bessel function order 5 - Combination 3: Zeroth-order Bessel function order 6, first-order Bessel function order 3 - Combination 4: Zeroth-order Bessel function order 6, first-order Bessel function order 5

The corresponding Rice factor K values are solved using the approximate moment estimation values and compared with the original K values. presents the root mean square errors for the four combinations across different K value ranges.

Table 1 Root Mean Square Errors for Four Combinations Across Different Ranges

Range	Combination 1	Combination 2	Combination 3	Combination 4
(0,2)	0	0	0	0
(0,4)	0.5760	0	0.5760	0
(0,5)	-	-	-	-

Table 2 Accuracy Rates for Four Combinations Across Different Ranges (%)

Range	Combination 1	Combination 2	Combination 3	Combination 4
(0,2)	100	100	100	100
(0,4)	99.8	100	99.8	100
(0,5)	99.2	99.8	99.2	99.8

As shown in [Figure 6: see original paper], Table 1, and Table 2, within the interval K [0,2], all four combinations achieve zero root mean square error and 100% accuracy. Within K [0,4], Combination 1 exhibits the largest RMSE, Combination 3 follows, with both showing identical accuracy rates. Combination 2 outperforms Combinations 1 and 3 in both RMSE and accuracy, while Combination 4 achieves zero RMSE and 100% accuracy, enabling completely accurate K estimation in this interval. Within K [0,5], RMSE values increase and accuracy decreases compared to the previous intervals, with Combination 4 remaining superior to the others.

3.3 Complexity Analysis

The maximum orders for Combinations 1-4 are 4, 5, 6, and 6, respectively. To ensure Bessel function calculation accuracy, this paper selects order 10 as reference [2], with step size 0.2. Within K [0,2], all combinations achieve zero RMSE. Within K [0,4], Combination 4' s calculations match the original first- and second-order moment calculations, while Combinations 2, 3, and 1 show progressively decreasing accuracy. As K values increase, curves for Combinations 1-4 deviate from theoretical values, with Combination 1 deviating most and Combination 4 deviating least, demonstrating optimal performance.

Table 3 Computational Time for Four Combination Algorithms and Original Algorithm (ms)

Range	Original	Combination 1	Combination 2	Combination 3	Combination 4
(0,2)	45.2	12.3	15.6	18.9	22.1
(0,4)	87.5	24.7	31.2	37.8	44.2
(0,5)	112.3	31.8	40.1	48.6	56.8

Table 3 demonstrates that all four combination algorithms require significantly less computation time than the original first- and second-order moment estimation algorithm. By selecting appropriate Bessel function orders based on the K interval, the computational complexity of the moment estimation algorithm is reduced, achieving algorithmic optimization.

4 Conclusion

Addressing the high computational complexity caused by high-order Bessel functions in first- and second-order moment estimation formulas, this paper proposes a Rice K-factor first- and second-order moment estimation algorithm based on order selection for Bessel function approximations. Through simulation experiments on four different combinations constructed in this paper, it is verified that within the K value range of 0-4, the selected orders for Bessel approximations can be lower than theoretically required orders while maintaining estimation accuracy, reducing algorithm runtime and improving timeliness. This achieves algorithmic improvement.

References

[1] Leturc X, Ciblat P, Martret C J L. Estimation of the Ricean K-factor from noisy complex channel coefficients [C]// Proc of Asilomar Conference on Signals, Systems and Computers. 2017: 1092-1096.

[2] Salah M B B, Samet A. Moment-based joint estimation of Ricean K-factor and SNR over linearly-modulated wireless SIMO channels [M]. Kluwer Academic Publishers, 2016.

[3] Bousnina I, Bellili F, Samet A, et al. Joint estimation of the Ricean K-factor and the SNR for SIMO systems using higher order statistics [C]// Proc of IEEE Global Telecommunications Conference. 2011: 1-5.

[4] Chen Y, Beaulieu N C. Estimation of Ricean K parameter and local average SNR from noisy correlated channel samples [J]. IEEE Trans on Wireless Communications, 2007, 6 (2): 640-648.

[5] Rastogi P K, Holt O. On detecting reflections in presence of scattering from amplitude statistics with application to D region partial reflections [J]. Radio Science, 2016, 16 (6): 1431-1443.

[6] Talukdar K K, Lawing W D. Estimation of the parameters of the Rice distribution [J]. Journal of the Acoustical Society of America, 1991, 89 (3): 1193-1197.

[7] Greenstein L J, Michelson D G, Erceg V. Moment-method estimation of the Ricean K-factor [J]. IEEE Communications Letters, 1999, 3 (6): 175-176.

[8] Greenstein L J, Ghassemzadeh S S, Erceg V, et al. Ricean K-factors in narrow-band fixed wireless channels: theory, experiments, and statistical models [J]. IEEE Trans on Vehicular Technology, 2009, 58 (8): 4000-4012.

[9] Xing P, Zhang T, Zeng X. A modified algorithm of Ricean factor K estimation for L-DACS1 system [C]// Proc of International Symposium on Microwave, Antenna, Propagation and Emc Technologies for Wireless Communications. 2013: 6-10.

[10] Azemi G, Senadji B, Boashash B. Estimating the Ricean K-parameter for mobile communication applications [C]// Proc of the 7th International Sympo-

sium on Signal Processing & Its Applications. 2003: 311-314.

[11] Tepedelenlioglu C, Abdi A, Giannakis G B, et al. Performance analysis of moment-based estimators for the K parameter of the Rice fading distribution [C]// Proc of International Conference on Acoustics, Speech, and Signal Processing. 2001: 2521-2524.

[12] Tepedelenlioglu C, Abdi A, Giannakis G B. The Ricean K factor: estimation and performance analysis [J]. IEEE Trans on Wireless Communications, 2003, 2 (4): 799-810.

[13] Kong Deqiang, Liu Zuoxue, Cui Can, et al. Ricean factor estimation and performance analysis [C]// Proc of international forum on computer science technology and applications. 2009: 27-30.

[14] Aejaz S M H, Haselmayr W, Springer A. RSSI-based parameter estimation for Rician fading environments on wireless sensor nodes [C]// Proc of International Workshop on Factory Communication Systems. 2017: 1-7.

[15] Zhuang Mingjie. Implementation method of wireless Rice fading channels with computer simulation [J]. Chinese Journal of Radio Science, 2004, 19 (5): 632-637.

[16] Lee J S and Miller L E. CDMA System Engineering Handbook [M]. Beijing: People' s Posts and Telecommunications Publishing House, 2002.

[17] Sasaoka N, Adachi Y, Itoh Y. K factor estimation for MIMO multipath channels [C]// Proc of International Conference on Digital Signal Processing. 2015: 1081-1084.

[18] Saito K, Takada J I, Kim M. Dense multipath component characteristics in 11GHz-band Indoor environments [C]// Proc of the 10th European Conference on Antennas & Propagation, 2016: 1-3.

[19] Tariq S A M, Despins C, Affes S, et al. Experimental results of Rician K-factor and co-polarization ratio of 60 GHz wireless channel in an underground mine gallery [C]// Proc of International Conference on Ubiquitous Wireless Broadband. 2015: 1-5.

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