Leveraging Outage Probability of Multi-Branch SC Diversity System in BX Fading and η-μ Interference Channel for ChatGPT-Based QoS Predictions

Suad Suljović, Dejan Milić, Nenad Petrović, Vladimir Petrović, Radiša Stefanović

***Abstract* - In this paper, the mathematical modeling of the SC receiver based on signal-interference, which is used in mobile networks in smart cities in the presence of multiple Beaulieu-Xie (BX) fading and η-μ co-channel interference (CCI) at the level, will be presented. The paper will derive the exact forms of the function for Outage probability (P_{out}) in terms of the normalized signal-to-interference ratio (SIR) for different values of fading and interference parameters. The second part of this paper proposes a new approach that uses the ChatGPT trend to evaluate the Quality of Service (QoS) within our network simulation and planning software environment, considering the P_{out} as one of the input variables.**

Index Terms—Outage probability, Selection combining, BX fading, η-μ channel interference, GPGPU, linear optimization.

I. Introduction

Wireless communications are, nowadays, one of the fastest growing segments of the communications industry. The most successful application of wireless networking is the mobile phone system. Wireless communication systems are designed to deliver a message over a wireless channel. Messages sent are assumed to include a random source and messages received cannot be predicted with certainty. As a result of signal transmission, damage to the wireless channel occurs, including thermal noise, which is expressed as a random factor. Random signals cannot be expressed by a simple mathematical equation and each value of a random signal cannot be predicted with certainty. For this reason, we use probability to express and analyze a random signal [1].

Wireless communication systems are designed to recover received signals that have been damaged by damage to the wireless channel. In order to improve the overall performance of the network in 5G mobile network, Multiple Input and Multi Output Technology (MIMO) is applied [2]. In MIMO systems, there are tens to hundreds of antennas in the receiver and transmitter. Massive MIMO techniques use known channel characteristics to provide superior performance in wireless communications.

For wireless communication, the transmission medium is the radio channel between the transmitter and the receiver. A signal can get from the transmitter to the receiver via several different propagation paths. In some cases there may be line of sight (LOS) between the transmitter and receiver. During the propagation of radio waves between transmitter and receiver, the paths change rapidly due to user mobility and variations in the environment. The result can be a delayed signal, fluctuations in amplitude or phase, or both, causing a significant decrease in u signal strength. With increasing numbers of wireless devices, bandwidth limitation becomes critical factor. The biggest need in today's wireless network communication is to provide reliable high-speed data transmission via unreliable fading and limited interference environments and limited bandwidth.

The three main impairments of signal transmission channels are: short-term fading (multiple spreading), long-term fading (shadowing), and the corrupting effect of co-channel interference [2]. In wireless telecommunication channels, fading is among the dominant factors that significantly affects their characteristics and limits them. So that the error probability in the channel with fading was less than or equal to the predetermined one values, diversity combining is applied in telecommunications. It is one of practically many, effective and widely used techniques in digital communications, for modeling receivers capable of handling the effects fading caused by different signal propagation conditions and improve the overall characteristics of the wireless system. The SC receiver selects the branch with the highest signal-to-interference ratio (SIN), the branch with the strongest signal.

Macro diversity systems are used to reduce the impact slow fading on wireless communication performance system. They can be with two or *L* branches. Micro diversities systems are used to reduce the impact of fast fading on wireless digital telecommunication system. Micro diverse systems may also have two or more branches. The outputs from the micro diversity system are connected to the macro inputs diversities combine, in order to design modules a variety of receivers capable of handling it all interference and

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thus enable the same transmission power transmitter engaged in this case to increase the distance between reception and delivery. Fast fading occurs due to the propagation of the signal, from the transmitter to the receiver, according to multiple paths. This fading is modeled using Rayleigh, Rice, Nakagami-m, Nakagami-q, Weibull and α-r distribution. Fast fading is modeled by the Rayleigh distribution when there is no dominant component and when only the scattering components appear to the receiver. When sketttering appears at the input to the receiver components in the form of more sketering surfaces then for fast fading modeling is used by Weibulova, Nakagami and *α-μ* distribution. Otherwise, to model slow fading Log-normal and Gamma distributions are used.

In 2015, a new statistical model for the characterization of fading was introduced into the literature: the Beaulieu-Xie (BX) distribution [3] was proposed, which combines the properties of both the Rician and Nakagami distributions, making it the right choice for describing the 5G heterogeneous environment. This fading was presented theoretically [4] and experimentally confirmed [5].

A fading model with an *η*-μ distribution is a signal composed of clusters of multipath waves propagating in an inhomogeneous environment. Within any cluster, the phases of the scattered waves are random with similar delay times. The proposed *η−μ* distribution is a general probability distribution because it contains as special cases most of the linear fading models presented in the available literature: Nakagami-m, exponential, one-sided Gaussian, Rayleigh and Nakagami-q (Hoyt). The η-μ distribution, similar to Nakagami-q or Hoyt, is suitable for use in inhomogeneous propagation environments, where the scattering pattern is non-uniform [6].

In this paper, we consider the 5G mobile network working through BX fading channels and co-channel interference η-μ. One of the basic characteristics analyzed in this paper of the wireless communication system in the environment is the outage probability of system (P_{out}). Moreover, the second part of the paper proposes a Quality of Service (QoS) prediction approach considering the previously calculated P_{out} as one of input variables. The implementation is based on Python Application Programming Interface (API) for novel ChatGPT service, where problem is treated as dialogue between user and chat bot. QoS in wireless communications is significantly dependent on P_{out} as it allows estimation minimum distance between two base stations. The results of this analysis can be used to design an optimal receiver for 5G mobile networks in smart cities when BX fading and η-μ co-channel interference appear at the input of the SC receiver. In a wireless signal transmission channel, it is the probability that a given information rate is not supported and that the actual SIR falls below the target SIR.

II. Outage Probability of Signal to Interference Ratio at the Output of the L-Branch SC Receiver

We consider *L*-branch SC receiver in a channel BX fading and η-μ co-channel interference. The block-diagram of the model is shown in Fig. 1. At the input of the *L*-branch SC receiver (*L=2, 3,..., n*) there are *n* copies of the signal: x_1, x_2, …, x_n. The signals from CCI also appear at the receiver inputsand are denoted by: y_1, y_2, …, y_n, while the corresponding output signal is *y*. The *L*-branch SC receiver chooses the signal with the highest SIR from the input antennas, which will be labelled *z*.

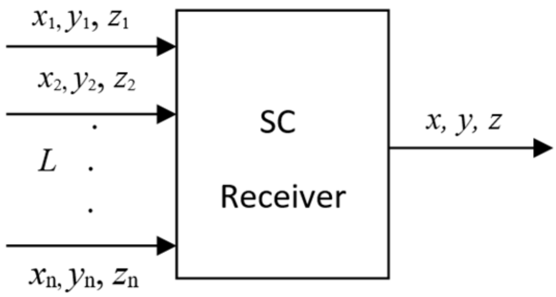

Fig. 1. The model of the SC receiver with *L* branches

Each signal at the input of the receiver has the probability density function (PDF) modelled by the BX distribution [7]:

$$p_{X_i}\left(x_i\right)=2\mathrm{e}^{-\frac{m}{\Omega}\left(x_i^2+\lambda^2\right)}\sum_{i=0}^{\infty}\frac{\lambda^{2i}x_i^{2i+2m-1}}{i!\Gamma\left(i+m\right)}\left(\frac{m}{\Omega_i}\right)^{2i+m} \tag{1}$$

where *Γ(·)* stands for Gamma function, *m* is the parameter that describes the shape, *Ω* represents the average SNR, and λ is the parameter for the location and the height of the mode of the observed signal PDF.

The co-channel interference follows η-μ distribution [8]:

$$p_{y_i}\left(y_i\right)=\frac{4\sqrt{\pi}\,h^{\mu}}{\Gamma\left(\mu\right)}e^{-\frac{2\mu h}{s_i}y_i^2}\sum_{i=0}^{+\infty}\frac{H^{2i}y_i^{4i+4\mu-1}}{\Gamma\left(i+\mu+1/2\right)i!}\left(\frac{\mu}{s_i}\right)^{2i+2\mu} \tag{2}$$

where the variable μ is the number of clusters, *H* is the phase component parameter, *h*-parameter of fading which describes the powers in the phase, while the mean square values of the interferers envelopes are marked with s_i, *i*=1, 2, ..., *L*. The expressions of *h* and *H* are given by [9]:

$$h=\frac{2+\eta^{-1}+\eta}{4}, H=\frac{\eta^{-1}-\eta}{4} \tag{3}$$

The fading parameter *η* is the ratio of the powers in-phase and in quadrature of scattered waves in each multipath cluster, and $0<\eta<\infty$ [10].

The ratio z_i of the desired signal and the co-channel interference at the i^{th} branch at the SC receiver input is:

$$z_i=x_i/y_i, x_i=z_iy_i \tag{4}$$

The signal to interference ratio for *i=2, 3,..n* at the output of the SC receiver will be: $z = max\,(z_1, z_2, \ldots z_i)$. The signal z_i has the PDF given by [11]:

$$p_{z_i}\left(z_i\right)=\int_0^{\infty}\mathrm{d}y_iy_ip_{x_i}\left(z_iy_i\right)p_{y_i}\left(y_i\right)=\frac{4\sqrt{\pi}\,h^{\mu}}{\mathrm{e}^{\frac{m}{\Omega}\lambda^2}\Gamma\left(\mu\right)}\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{+\infty}\frac{H^{2i_2}}{i_1!i_2!}\cdot$$
$$\cdot\frac{\lambda^{2i_1}\Omega_i^{2i_2-i_1+2\mu}s_i^{i_1+m}m^{2i_1+m}\mu^{2i_2+2\mu}\Gamma\left(i_1+2i_2+2\mu+m\right)z_i^{2i_1+2m-1}}{\Gamma\left(i_1+m\right)\Gamma\left(i_2+\mu+1/2\right)\left(ms_iz_i^2+2\mu h\Omega_i\right)^{i_1+2i_2+2\mu+m}} \tag{5}$$

By applying expression (5) and further solving, the CDF of the signal is obtained [11]:

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$$F_{z_i}(z_i)=\int_0^{z_i} \mathrm{d}t p_{z_i}(t)=\frac{2\sqrt{\pi}}{\mathrm{e}^{(m/\Omega)\lambda^2}\Gamma(\mu)}\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{+\infty}\frac{H^{2i_2}\lambda^{2i_1}(m/\Omega_i)^{i_1}}{i_1!i_2!2^{2i_2+2\mu}h^{2i_2+\mu}}\cdot$$

$$\cdot\frac{\Gamma(i_1+2i_2+2\mu+m)}{\Gamma(i_1+m)\Gamma(i_2+\mu+1/2)}B_{\frac{ms_iz_i^2}{2\mu h\Omega_i+ms_iz_i^2}}(i_1+m,2i_2+2\mu) \quad (6)$$

where $B_z(a, b)$ is the incomplete Beta function, [12; 8.39]. Using expression (6), the PDF of z at the output of the L-branch SC receiver is calculated by the formula [13]:

$$P_{out}(z)=F_{z_i}(z)=\left(F_{z_i}(z_i)\right)^L=\left(\frac{2\sqrt{\pi}}{\mathrm{e}^{\frac{m}{\Omega}\lambda^2}\Gamma(\mu)}\sum_{i_3=0}^{\infty}\sum_{i_4=0}^{+\infty}\frac{H^{2i_4}\lambda^{2i_3}}{2^{2i_4+2\mu}h^{2i_4+\mu}i_3!}\cdot\right.$$

$$\left.\cdot\frac{\Gamma(i_3+2i_4+2\mu+m)(m/\Omega_i)^{i_3}}{i_4!\Gamma(i_3+m)\Gamma(i_4+\mu+1/2)}B_{\frac{ms_iz_i^2}{2\mu h\Omega_i+ms_iz_i^2}}(i_3+m,2i_4+2\mu)\right)^L \quad (7)$$

III. Analysis of the System Performance

In order to analyze the influence of fading and interference parameters on the respective performance (P_{out}), we generated graphs in Fig. 2 and 3 relative to the output SIR.

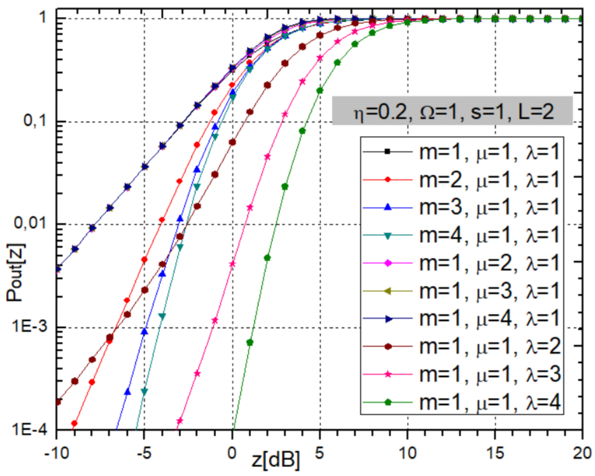

Fig.2. Normalized P_{out} of L-branch SC receiver considering different values of fading parameters m, μ and λ

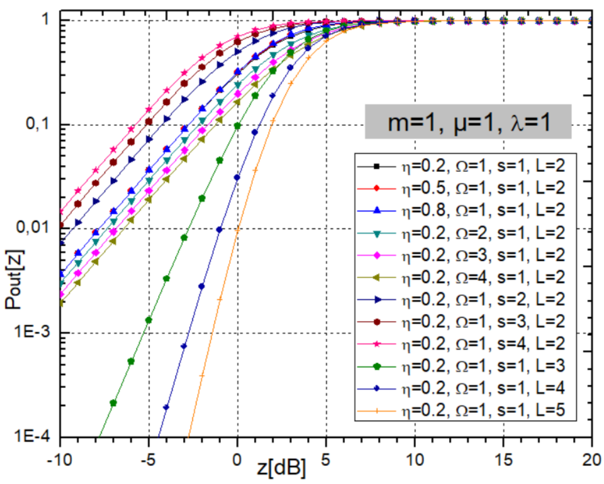

Fig.3. Normalized P_{out} of L-branch SC receiver considering different values of fading parameters η, Ω, s and the number of branches L

A graphical analysis of P_{out} at the SC receiver outputs is given in Fig. 2 and 3, where $\Omega_1=\Omega_2=\ldots\Omega_n$, and $s_1=s_2=\ldots s_n$; The correlation between the input branches in the SC receiver is not considered for this case. The graphic presentation was made using the Mathematica and Origin software packages, for cases with two or more input branches of the SC receiver.

Fig. 2 shows that P_{out} is constant when the parameter μ is increasing, and when the parameters m and λ are increasing, P_{out} decreases and the system has better performance. From graph 3, we see that due to the increase in the η parameter P_{out} is constant, while when the Ω and L parameters P_{out} increases, the system has better performance. When the parameter s_i increases, then there is an increase in P_{out} as seen in Fig. 3 and the system has worse performance.

In addition to the graphical representations, tables 1 and 2 are also given for the convergence of expression (7), in which the necessary number of members of the series that should be summed to achieve the desired precision of the expression, rounded to the fifth decimal place, is calculated and shown.

Table 1. Number of terms that should be added in expression (7) P_{out} in order to reach accuracy at 5th significant digit, when parameters m, μ and λ change, and oder parameters are: η=0.2, Ω=1, s=1, L=2 (Fig.2).

	z=-10 dB	z=0 dB	z=10 dB
m=1, μ=1, λ=1	9	14	14
m=2, μ=1, λ=1	5	13	13
m=3, μ=1, λ=1	5	14	15
m=4, μ=1, λ=1	5	14	15
m=1, μ=2, λ=1	11	17	16
m=1, μ=3, λ=1	13	19	19
m=1, μ=4, λ=1	14	21	21
m=1, μ=1, λ=2	5	13	15
m=1, μ=1, λ=3	5	13	25
m=1, μ=1, λ=4	5	9	36

Table 2. Number of terms that should be added in expression (7) P_{out} in order to reach accuracy at 5th significant digit, when parameters η, Ω, s and L change, and oder parameters are: m=1, μ=1, λ=1 (Fig.3).

	z=-10 dB	z=0 dB	z=10 dB
η=0.2, Ω=1, s=1, L=2	9	14	14
η=0.5, Ω=1, s=1, L=2	5	5	8
η=0.8, Ω=1, s=1, L=2	5	5	8
η=0.2, Ω=2, s=1, L=2	9	13	14
η=0.2, Ω=3, s=1, L=2	8	13	14
η=0.2, Ω=4, s=1, L=2	9	13	14
η=0.2, Ω=1, s=2, L=2	9	13	14
η=0.2, Ω=1, s=3, L=2	10	14	14
η=0.2, Ω=1, s=4, L=2	11	14	14
η=0.2, Ω=1, s=1, L=3	5	13	14
η=0.2, Ω=1, s=1, L=4	5	13	15
η=0.2, Ω=1, s=1, L=5	5	11	15

When the parameter m increases for all values of z [dB], the convergence of the expression is achieved and the number of elements in the sum is limited to 5, 14 and 15. With the increase of the parameter μ, for all values of z [dB] a larger number of terms is required and the series converges more slowly. When the parameter λ increases for $z=0$ [dB], the number of elements in the expression that need to be added in order to achieve convergence decreases and the series converges faster, and for $z=10$ [dB] for the expression to converge, the number of elements that need to be added increases and the series converges more slowly.

Moreover, when the parameter η increases, for all values of z [dB], the convergence of the expression is achieved and the number of elements in the sum is limited to 5, 5 and 8.

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Also when the parameter Ω increases for all values of z [dB], the convergence of the expression and the number of elements in the sum is achieved is limited to 9, 13 and 14. Furthermore, in case of parameter s increase, the number of elements in the expression is limited for all values $z=0$ [dB] and z=10 [dB] and weighs 14, while for $z=-10$ [dB] the number of elements increases and the sequence converges more slowly. When we increase the number of branches L, the required number of elements that need to be added in order to achieve the convergence of the expression in the series decreases for z=0 [dB] and the series converges faster, and for $z=10$ [dB] the convergence of the expression is achieved and then the number of terms in the expression tends to 15.

From Tables 1 and 2, we can conclude that when the parameters m, μ, λ increase for $z=0$ [db] and $z=10$ [dB], the number of terms in each sum that needs to be added in order to obtain the accuracy of the expression to the 5th decimal place is higher and a series of slower converging. When the parameters η, Ω, s and L=2 increase, the number of terms that need to be added for $z=0$ [db] and $z=10$ [dB] in order to achieve convergence to the 5th decimal is smaller and the series converges faster.

IV. Planning and simulation environment relying on ChatGPT-based QoS predictions

Nowadays, further innovation within state-of-art wireless and mobile networks, together with development of next generation systems relies, among other novelties on adoption of machine learning models [15]. Therefore, they enable predicting values and extraction of useful knowledge from enormous amount of raw data, making possible scenarios such as network failure prevention, recovery from anomalies and adaptive infrastructure adjustment for QoS improvement [15].

This paper explores the potential for usage of trending ChatGPT originally created to mimic human-alike conversation in case of network-related predictions. Precisely, it will take network state records as input and estimate QoS level. We will treat the problem as classification, considering that outcome is categorical and represents one of the possible QoS levels: 0 – malfunction (failure or anomaly); 1 – low; 2 – acceptable 3 – high. The previously determined P_{out} is considered as one of the nput variables, among the others: count of service users, base station and area of interest identifiers. Experiment data is taken from out network planning and simulation environment [15, 16] and dataset header given in Table 3.

Table 3. QoS estimation dataset layout.

P_{out}	*User count*	*Base station id*	*Area id*	*QoS*

When it comes to implementation, Python API for Chat Generative Pre-trained Transformer, widely known as ChatGPT is leveraged. It represents an AI-driven tool designed to act as chatbot capable of imitating human-alike conversations in form of a dialogue. Users provide question and optionally, context as inputs. Context represents specific information or additional facts, acting as „hint“ to ChatGPT in order to provide more precise answer. The underlying large language model (LLM) was trained on enormous amount of information in textual form, capturing the state of World Wide Web around 2021. ChatGPT was launched publicly by OpenAI organization in November 2022, and led to huge public attention due to its power of question answering in various forms across different domains – from writing poetry to generating programming code and playing games [17]. It is accessible for free using web browser, Application Programming Interface (API) usage is charged per request (1000 request tokens circa $0.02). In order to use Python, JavaScript or any other API for ChatGPT, OpenAI token is obligatory and registration procedure involves providing payment information.

Python code excerpt used for classification-based QoS level is given within Fig. 4. For our experiments, the form of questions and context is given as follows:

$$\textit{Question: } \textbf{\textit{Classify}}\ \textit{(CC User BS Area)} \tag{8}$$

$$\textit{Context: } \textbf{\textit{Label}}\ QoSi = (CC_i\ \ Users_i\ \ BS_i\ Area_i) \tag{9}$$

```
API_KEY = "YOUR_KEY"
API_ENDPOINT = "https://api.openai.com/v1/chat/completions"

def estimate_qos(context, record, model="gpt-4", temperature=0.1, max_tokens=None):
    headers = {
        "Content-Type": "application/json",
        "Authorization": f"Bearer {API_KEY}",
    }

`     messages = [
        {"role": "system", "content": f"{context}"},
        {"role": "user", "content": f"Classify {record}"}
     ]

    data = {
        "model": model,
        "messages": messages,
        "temperature": temperature,
    }

    if max_tokens is not None:
        data["max_tokens"] = max_tokens

    response = requests.post(API_ENDPOINT, headers=headers, data=json.dumps(data))

    if response.status_code == 200:
        return response.json()["choices"][0]["message"]["content"]
```

Fig.4. Python API calls to ChatGPT for QoS prediction

As it can be seen from Fig. 4, apart from question (record to be analyzed) and context (set of labelled records), there are two more additional parameters: 1) *temperature* – value denoting the randomness of generated answer, which we prefer to be smaller value, as more deterministic behavior is preferred in our case than in traditional chat scenario 2) *max_tokens* – limits the maximal cost of each request by defining the upper bound of characters used within the question and answer together.

Furthermore, underlying prediction-based network adjustment workflow for QoS improvement is given in Fig. 5. In the first step, network model representation within our tool for mobile network planning and simulation [15, 16] is created by user. Additionally, this model is processed and P_{out} calculated for the selected scenario of BX fading and η-μ co-channel interference. This step is performed leveraging GPU hardware and NVIDIA CUDA in order to speed-up the calculations by loop parallelization [16]. Moreover, record for QoS level determination is constructed considering other factors from model into account and forwarded to ChatGPT for classification using the previously shown Python code. Depending on the achieved outcome for QoS estimation, corresponding action can be taken, such as turning additional modules on in case of too many users or turning off and performing migration of services when malfunction occurs.

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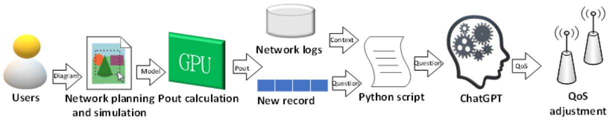

Fig. 5. Overview of QoS estimation-based adjustment workflow.

Finally, results of evaluation are given in Table 4. The following aspects were considered: 1) execution time–duration of classifying a single record; 2) minimal context size–least amount of records in context for successfull classification; 3) accuracy–percentage of corectly classified records per 100 requests for minimal context size.

Table 4. Experiment and evaluation results.

Aspect	Value
Execution time	2.81 s
Minimal context	5
Accuracy	90%

According to the achieved results, the proposed approach seems promising when it comes to classificaiton-based QoS estimation. Even for the smallest context size, it shows satisfiable accuracy. However, due to the processing time on the order of a second, which was expected due to the online ChatGPT service usage (but not locally), it is still not suitable for strict real-time scenarios.

V. Conclusion

Outage probability (P_{out}) is one of the most important measures for the reliability in wireless transmitting channel. The mobile system performs better for the lower values of P_{out}. In this work, we examined a harshly degraded transmission conditions, under effects of BX fading and $\eta-\mu$ co-channel interference in mobile networks in smart cities, where a wireless system performance could be severely degraded. For the given conditions of a channel with a small-scale *BX* fading and $\eta-\mu$ CCI, the expression for P_{out} is calculated for the case of L-branch SC diversity receiver.

Based on the analytical results and graphical representation of P_{out} in terms of different fading and interference parameters we have concluded that the system performs better for the greater number of branches (L), as the receiver can choose the branch with highest signal-to-interference-ratio (SIR), and transfer it to the user. Also, it can be noticed that better performance is achieved for bigger values of the SIR, larger number of clusters μ and larger ratio of the powers in-phase and in quadrature of scattered waves in each multipath cluster defined by the parameter η.

Additionally, in the second part we showed how P_{out} value can be leveraged among inputs for QoS prediction relying on novel ChatGPT. The obtained results seem promising, but still not suitable for real-time usage. However, adoption of ChatGPT and similar LLM-based solutions opens many horizons for future works when it comes to smart parameter tuning and infrastructure adaptation based on automatic fading type classification using real measurements as input.

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