Leveraging Outage Probability of a Weibull-faded Gamma-shadowed Channel with co-channel Interference for ChatGPT-Driven QoS Prediction

Miloš Popović, Nikola Samardžić, Suad Suljović, Nenad Petrović, Selena Vasić, and Vuk Vujović

Abstract—**In this paper, a model of a wireless receiver based on macro diversity (MD) technique is considered. The system consists of a macro diversity SC receiver (MD SC) that combines the output signals from two micro diversity (mD SC) receivers with *L* input branches. This approach is used to simultaneously reduce the effects of Weibull short-term fading, Gamma long-term fading, and co-channel interference (CCI) on system performance. In this paper, closed-form expressions for the outage probability (P_{out}) of the system for the ratio of the signal-to-interference (SIR) at the outputs of the mD SC and the MD SC receiver, were derived. The system P_{out} of the ratio the signal-to-interference at the output of the MD SC receiver can further be used to calculate the average fading duration (AFD) of the proposed system configuration. Further, we explore the potential of using Large Language Model (LLM)-based trending ChatGPT service to estimate the degree of the Quality of Service (QoS), considering P_{out} as one of the input variables. Finally, we have compared the proposed method to traditional Weka-based machine learning algorithm in predicting the QoS.**

Index terms—**Outage Probability (P_{out}), Selection Combining (SC), Weibull short-term fading, Gamma long-term fading, Gamma co-channel interference (CCI), ChatGPT, Weka.**

I. Introduction

Boosted by the fifth generation (5G) wireless standards, social networking tools and video-sharing platforms, wireless transmission of multimedia content has significantly increased in volume and became dominant part of traffic in data communications. Such wireless communications traffic requires certain QoS standards for the end-users expectations. A high quality of services considers usability, availability, reduced level of connection loss, data rates, packet error probability, and integrity of the service. QoS considers the network ability to provide services from a technical point of view. Designers of wireless networks aim to reach the highest expected QoS, while minimizing deterioration in signal characteristics on its way through the environment affected by fading and shadowing. Therefore, the study of the performance of wireless communication systems and estimating the probability of the system failure is of the fundamental importance to meet the high QoS standards. There are three main types of impairments in wireless channels: short-term fading (multipath propagation), long-term fading (shadowing) and the effect of co-channel interference. The power at the receiver can be predicted using traditional large-scale and small-scale models [1], [2]. Shadowing, as a long-term signal variation is known to follow the Log-normal distribution [3], while short-term variations in the average level of the received signal envelope can be described by several distributions such as Nakagami-q, Rayleigh, Rice, Nakagami-*m*, Weibull, etc [4]. Long-term fading causes slow changes in the level of the average strength of a signal at the reception and is mainly caused by the configuration of the terrain and the environment between the base station and a mobile unit. The stochastic nature of the effects of the environment through which the signal propagates lead to signal attenuation and variations in the mean value of the signal envelope that is, the average strength of the signal. Log-normal and Gamma fading models are often used in literature to model slow fading [5], [6]. Small-scale fading is caused by the constructive and destructive interference of the signal components from multiple paths between the transmitter and the receiver. Different components of the signal can arrive at the receiver at different times, causing interference and rapid variations in signal amplitude and phase. This can cause Inter-Symbol Interference (ISI), where symbols in the transmitted signal overlap and interfere with each other, leading to errors in the received signal and possibly, system outage. The Rayleigh and Rice distributions are comonly used to model statistical changes in the received signal due to multipath propagation. If there are several weaker components and no dominant component of the signal under Non-Line of Sight (NLOS) conditions, with a large number of objects between the transmitter and receiver, signal scattering occurs and Rayleigh fading is the best model proposed in literature. Often, the transmission channels are additionally affected by intersymbol interference [7].

In a situation where there is optical visibility between the transmitter and the receiver (Line-of-Site – LOS conditions), the component of the signal that spreads along this line is dominant to the components obtained by scattering. In such scenario probability density function, cumulative distribution

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M. Popović and N. Samardžić are with the Belgrade Business and Arts Academy of Applied Studies, Belgrade, Serbia (milos.popovic@bpa.edu.rs, nikola.samardzic@bpa.edu.rs). S. Suljović is with the Academy of technical vocational studies Belgrade, Serbia (ssuljovic@atssb.edu.rs). N. Petrović is with the University of Nis, Faculty of Faculty of Electronic Engineering, Nis, Serbia (nenad.petrovic@elfak.ni.ac.rs). S. Vasić is with the Metropolitan University Belgrade, Belgrade, Serbia (selena.vasic@metropolitan.ac.rs). V. Vujović is with the MB University in Belgrade, Belgrade, Serbia (vuk.vujovic@ppf.edu.rs).

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function, channel capacity, and outage probability of the wireless telecommunication system operating in Rice fading channel can be determined [8].

The main contributions of this work are:

- This paper makes an important contribution to wireless communications by merging advanced signal processing with machine learning for predicting Quality of Service (QoS).
- A closed-form expression for the P_{out} of the signal-to-interference ratio at the MD SC receiver output of the communication system affected by Weibull short-term fading, Gamma-shadowing and co-channel interference. The obtained results can be used to find the average fading duration (AFD) of the proposed system.
- We propose a classification-based approach to Quality of Service (QoS) estimation, for the observed system. We utilize the derived outage probability expression as an input variable in our network planning tool.
- We explore the potential of ChatGPT for this purpose. We used Large Language Model (LLM)-based trending ChatGPT service to estimate the degree of the Quality of Service (QoS) of the observed system, considering the calculated P_{out} as one of the input variables.
- Finally, we compare the proposed method to traditional Weka-based machine learning algorithm in predicting the QoS and discuss the findings.

The paper is organized in four sections. Introduction is given in Section I. In Section II, the expression for P_{out} in a channel affected by Weibull fading, Gamma shadowing and Weibull co-channel interference is derived, and numerical results are presented and discussed. In Section III ChatGPT-driven QoS aware network planning for the described communication channel is presented. Finally, in Section IV we have provided the concluding remarks about the results of the work.

II. RELATED RESEARCH

Multiple works explored effects of different combinations of signal impediments such as fading, shadowing or co-channel interference. Co-channel interference CCI can significantly degrade the performance of a communication system by reducing the signal-to-noise ratio (SNR) or signal-to-interference ratio (SIR). This leads to increased error rates, lower data throughput, and degraded QoS. The effect of CCI on the performance of cooperative diversity systems was investigated in [9], assuming optimum combining (OC) technique over Rayleigh fading channels. Nakagami-m fading channels in downlink MIMO-NOMA systems are considered in [10]. In this paper, we explore the specific scenario in a wireless communication channel and aim to integrate the results within the planning methodology for QoS improvement in such system.

Nakagami-m distribution describes transmission without a dominant component or optical visibility between the transmitter and the receiver. Error performance power line communications in the presence of Nakagami-*m* background noise is considered in [11]. Capacity Analysis for Identically Independently Distributed Nakagami-q (Hoyt) distribution Fading Wireless Communication has been analyzed in [12]. Fading channels with optical visibility between the transmitter and receiver and the formation of only one cluster have been described by Weibull fading in [13]. The signal envelope was modeled using the Weibull distribution. The scattering field is inhomogeneous, with a small number of scattering components, so the central limit theorem does not apply to the sum of components in phase and quadrature. The Weibull random variable is defined by the parameter α which represents nonlinearity of the channel. When $\alpha = 2$, Weibull model reduces to a Rayleigh model, and when α tends to infinity, there is no fading. Outage probability, error probability, and channel capacity of a wireless telecommunication system with Weibull fading, was determined in [14]. The combined probability density of the Weibull random variable and its first derivative is determined using the transformation method. This probability density can be used to calculate the mean number of axial sections of the Weibull random process. The Weibull distribution is widely used across various scientific fields and is a popular statistical model for system reliability analysis. In mobile communications, the Weibull distribution is proposed as the most suitable for describing channels with multi-path signal propagation in an inhomogeneous environment. It is simple, flexible, and provides accurate results for describing communication channels in urban areas when the Rayleigh distribution is insufficient. A new Diversity Scheme in 5G Network at 28 GHz Millimter-wave Frequency is considered [15]. MIMO Weibull fading-affected channel was discussed in [16, 17] within the context of non-orthogonal multiple access techniques (NOMA) targeting next-generation wireless communication system. Authors have analyzed the performance of a downlink multi-user multiple-input multiple-output (MU-MIMO) non-orthogonal multiple access (NOMA) communications system. They considered Weibull-distributed fading channels to account for non-linearities of the propagation medium and to cover, as special cases, important fading scenarios such as Rayleigh and exponential models. Performance metrics such as the outage probability (OP) and the average bit error rate (ABER) were derived. The quality of service (QoS) is one of the main expectations in state-of-the-art wireless systems. The quality of service (QoS) is one of the main expectations in state-of-the-art wireless systems. Evolving multiple access 5G wireless systems considered in [18] are adopting Rayleigh fading channel was adopted within the context of non-orthogonal multiple access techniques (NOMA) targeting next-generation wireless communication system use cases. Novel approaches to implementing diversity techniques for multipath fading channels are explored in [19]. To reduce the influence of fading and improve communication reliability and QoS in wireless systems without increasing transmission power and bandwidth, diversity techniques are employed. These methods involve receiving signals transmitting the same information through two or more uncorrelated or weakly correlated channels and combining them. It is unlikely that attenuation will be high across all channels simultaneously; thus, combining signals from different paths can significantly enhance the signal-to-noise or signal-to-interference ratio at the receiver, improving system performance. Diversity systems can be categorized into frequency, time, spatial, polarization, and angular diversity [20]. Spatial diversity techniques, particularly those using multiple antennas at the receiver input, are used to mitigate the impact of fast and slow fading. Employing diversity combining techniques such as MRC (maximum ratio combining), EGC (equal gain combining), SC (selection combining), and SSC (switch and stay combining) can significantly improve system performance [20].

SC receivers, with two or more inputs, are the simplest for practical implementation. SC receiver selects the signal from the input branch with the highest signal-to-noise ratio (SNR). The advantage of the SC receiver is that only one branch is to be considered and no knowledge of the signal phases of each branch is required. Although SC receivers do not achieve as high a diversity gain as MRC and EGC receivers, [21] they are effective when the input signals are uncorrelated. Outage and error probabilities are lowest under uncorrelated conditions. The variation of a SC receiver performance due to the correlation between antenna signals, over general Weibull fading has been studied in [22].

Macro diversity techniques are described in different fading scenarios, including shadowing as additional impediment [23]. Macro diversity combining simultaneously mitigate the effects of fast and slow fading on system performance. They involve multiple micro diversity systems, each targeting different fading type. Spatial diversity in macro diversity systems often uses antennas spaced at λ/2 intervals (where λ is a wavelength) to eliminate the correlation between channels. Performance analysis of composite fading channels is described in [24].

Research has been done on wireless telecommunication networks performance, by finding the closed-form expressions for the first and second order statistics and outage probability (P_{out}) in different fading environments [25], [26]. P_{out} is defined as the probability that the current value of the equivalent signal-to-noise or signal-to-interference ratio at the receiver output falls below a predetermined threshold, z_{th}. P_{out} is a critical measure of the system performance and is used to control interference levels [27]. It helps designers of wireless communication systems to adjust operating parameters and meet quality of service (QoS) and grade of service (GoS) requirements [28]. Complicated expressions may arise from various mathematical transformations, making them unsuitable for closed-form solutions. Therefore, they are often expanded into series or approximated by other suitable transformations.

The authors of this paper have extended the research done so far to describe a macro diversity system with an SC receiver and two micro diversity SC spatial receivers with L input branches, operating over a Weibull fading and Gamma-shadowed channel, also undergoing Gamma co-channel interference. The receiving antennas of the micro diversity receiver are spaced enough to ensure signal independence. The micro diversity combiner reduces fast fading impact, while the macro diversity combiner mitigates slow fading degradation.

III. Outage Probability in the Presence of Weibull Fading and Gamma CCI

A. Outage Probability at the output of MD SC receiver

In this section, the P_{out} for multi-branch SC receiver in wireless system affected by Weibull fading and Gamma distributed CCI will be derived. We consider a MD SC receiver with a macro diversity (MD) combiner of two micro diversity mD SC output branches. Each mD SC has L inputs. Signals at the inputs of each mDSC are undergoing Gamma shadowing, Weibull multipath fading and Gamma co-channel interference. The model under consideration is shown in Figure 1, where the envelopes of signals and disturbances at the inputs to the mD SC receivers are marked with x_{ij} and y_{ij}, and at the outputs with x_{i} and y_{i} respectively.

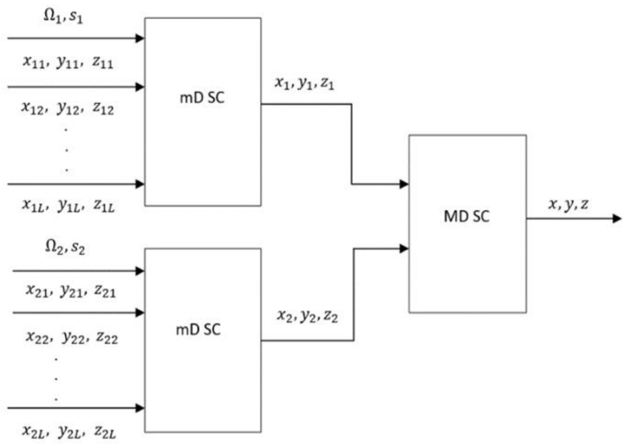

Fig. 1. Model of considered MD receiver

The mD SC combiner is more effective with larger number of branches. It operates by choosing the highest signal to interference ratio from the input. The fading powers Ω_{i} at the inputs to the micro diversity SC receiver have a correlated Gamma distribution. If the power Ω_1 is greater than Ω_2, then the signal from the first micro diversity system is forwarded to the input of the MD SC receiver, and vice-versa.

SIR-based performance analysis represents quite effective performance criterion since SIR can be measured in a real time for both the base and mobile stations. We discuss the interference-limited system, so we will ignore the effect of noise. The Weibull random variable follows probability density function (PDF) [13]:

$$p_{x_{ij}}(x_{ij}) = \frac{\alpha}{\Omega_i} x_{ij}^{\alpha-1} e^{-\frac{1}{\Omega_i} x_{ij}^{\alpha}}; \; x_{ij} \geq 0; \, i, j = 1,2 \tag{1}$$

where Ω_i are the corresponding mean values ($\Omega_i = \overline{x}_i^2$) of each signal, and α is the nonlinearity of the channel (α>0). It is also reasonable to assume that co-channel interference has the same

Weibull distribution in the same fading environment, with different mean value.

The mean square values of the CCI envelopes are labelled with s_i, i =1, 2, ..., L: s_i= $s_i = \overline{y}_i^2$:

$$p_{y_{ij}}(y_{ij}) = \frac{\alpha}{s_i} y_{ij}^{\alpha-1} \mathrm{e}^{-\frac{1}{s_i} y_{ij}^{\alpha}};\; y_{ij} \ge 0;\, i, j = 1, 2 \tag{2}$$

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

$$z_{ij} = x_{ij} / y_{ij},\; x_{ij} = y_{ij} z_{ij} \tag{3}$$

The ratio of the magnitude of the desired signal and the magnitude of CCI at the i^{th} input branch of the SC receiver is marked with z_i and has a PDF [29] as follows:

$$p_{z_{ij}}\left(z_{ij}\right) = \int_0^{\infty} \mathrm{d}y_{ij}\, y_{ij}\, p_{x_{ij}}\left(z_{ij} y_{ij}\right) p_{y_{ij}}\left(y_{ij}\right) \tag{4}$$

By substituting the expressions (1) and (2) into the expression (4), and further simplifying, we get the PDF of the signal-to-channel interference ratio (SIR) z_{ij} at the input of the SC receiver:

$$p_{z_{ij}}\left(z_{ij}\right) = \frac{\alpha z_{ij}^{\alpha-1} \Omega_i s_i}{\left(s_i z_{ij}^{\alpha} + \Omega_i\right)^2} \tag{5}$$

The cumulative distribution function (CDF) of the SIR of z_{ij} can be expressed as:

$$F_{z_{ij}}\left(z_{ij}\right) = \int_0^{z_{ij}} p_{z_{ij}}(t)\,\mathrm{d}t \tag{6}$$

After substituting the expression (5) into (6), we obtain the CDF of the signal-to-cochannel interference ratio (SIR) z_{ij} at the input of the SC receiver:

$$F_{z_{ij}}\left(z_{ij}\right) = \left(\frac{s_i z_{ij}^{\alpha}}{\left(\Omega_i + s_i z_{ij}^{\alpha}\right)}\right) \tag{7}$$

The mD SC receiver selects the branch with the highest SIR from all input antennas, so the output SIR will be:

$z_i = max\,(z_{11}, z_{12}, \ldots, z_{1L})$, where $j = 1, 2, \ldots, L$.

The CDF of the SIR at the output of the multi-branch mD SC receiver is obtained using the expression [30]:

$$F_{z_i}\left(z_i\right) = \left(F_{z_{ij}}\left(z_{ij}\right)\right)^L \tag{8}$$

By substituting the expression (7) into (8), we can find the CDF of the signal-to-co-channel interference-ratio (SIR) z_i at the mD SC receiver output:

$$F_{z_i}\left(z_i\right) = \left(\frac{s_i z_{ij}^{\alpha}}{\Omega_i + s_i z_{ij}^{\alpha}}\right)^L \tag{9}$$

The signal envelopes at the inputs of the mD SC receivers are marked with Ω_1 and Ω_2. In a Gamma-shadowed channels, the random variables Ω_1 and Ω_2 follow a correlated Gamma distribution [31]:

$$p_{\Omega_1\Omega_2}\left(\Omega_1, \Omega_2, \ldots \Omega_n\right) = \frac{\left(\Omega_1 \Omega_n\right)^{(c-1)/2} \rho^{-(n-1)(c-1)/2}}{\Gamma(c)(1-\rho)^{n-1} \Omega_0^{n+c-1}} \times$$
$$\times \mathrm{e}^{-\frac{1}{\Omega_0(1-\rho)}\left[\Omega_1 + \Omega_n + (1+\rho)\sum_{i=2}^{n-1}\Omega_i\right]} \prod_{i=1}^{n-1} I_{c-1}\left(\frac{2\sqrt{\rho \Omega_i \Omega_{i+1}}}{\Omega_0(1-\rho)}\right) \tag{10}$$

where $I_n(\cdot)$ is the modified Bessel function of the n^{th} order of the first kind, Ω_0 denotes the average value of Ω_1 and Ω_2, and ρ is the correlation coefficient. Parameter c is the order of the Gamma distribution and determines the sharpness of the shadowing. A smaller value of the parameter c indicates the presence of a stronger shadowing effect, while a value of $c \to \infty$ describes a channel with no shadowing. Using the well-known transformation for the modified Bessel function of the n^{th} order of the first kind $I_n(\cdot)$ [32]:

$$I_v(x) = \sum_{k=0}^{\infty} \frac{x^{v+2k}}{2^{v+2k} k!\,\Gamma(v+k+1)}. \tag{11}$$

for the case of a MD SC receiver with two branches, the expression (10) can be represented in the form:

$$p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right) = \frac{1}{\Gamma(c)} \mathrm{e}^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho)}} \sum_{i=0}^{+\infty} \frac{\rho^i \left(\Omega_1\Omega_2\right)^{i+c-1}}{i!\,\Gamma(i+c)\,\Omega_0^{2i+2c}(1-\rho)^{2i+c}} \tag{12}$$

The envelopes of the co-channel interference s_i, i =1,2 at the inputs of the mD SC combiners also follow the Gamma distribution:

$$p_{s_i}\left(s_i\right) = \frac{s_i^{c_1-1}}{\Gamma(c_1)\beta^{c_1}} \mathrm{e}^{-\frac{1}{\beta}s_i},\; s_i \ge 0; \tag{13}$$

where $\beta=E(s^2)$, and c_1 describes the random s-factor severity change parameter ($s_1=s_2=s$).

The macro diversity (MD SC) receiver chooses the output from a micro diversity (mD SC) receiver with higher power to provide service to the user. The outage probability is defined as the probability that the SIR at the receiver is falling below the given threshold value [33], [34]:

$$P_{out}\left(z_{\text{th}}\right) = P_z\left[SIR < z_{\text{th}}\right] = F_z\left(z_{th}\right) \tag{14}$$

where z_{th} is the SIR threshold value, and $F_z(z)$ represents the cumulative distribution function (CDF) for the case when z=z_{th}. The value of the threshold depends on the required quality of services as well as the modulation technique used.

As derived in the Appendix, the expression for the P_{out} of MD SC receiver output signal to interference ratio is:

$$P_{out}(z) = \frac{2(1-\rho)^{c+c_1}}{\Gamma(c)\Gamma(c_1)}\left(\frac{\Omega_0}{\beta z_{ij}^{\alpha}}\right)^{c_1} \sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty} \frac{\rho^{i_1}\Gamma\left(2i_1+i_2+2c\right)}{2^{2i_1+i_2+2c+c_1} i_1!} \times$$
$$\times {}_2F_1\left(2i_1+i_2+2c+c_1, c_1+L, 2i_1+i_2+2c+c_1+L, 1-\frac{\Omega_0(1-\rho)}{2\beta z_{ij}^{\alpha}}\right) \times$$
$$\times \frac{\Gamma\left(2i_1+i_2+2c+c_1\right)\Gamma\left(c_1+L\right)}{\Gamma\left(i_1+c\right)\Gamma\left(2i_1+i_2+2c+c_1+L\right)\left(i_1+c\right)\left(i_1+c+1\right)_{i_2}} \tag{15}$$

Based on the calculations from the equation (15), we present graphical and tabular analysis of the normalized P_{out} of the wireless system in the presence of Weibull fading and Gamma CCI of the entire MD system from Figure 1. The results are illustrated in Figures 2 and 3 and Tables 1 and 2.

B. Analysis of the Influence of the parameters on the Outage Probability of the MD System

Figures 2 and 3 show P_{out} from the signal-interference ratio in relation to the transition threshold z_{th}, at the output of the MD SC receiver. The graphs are generated using Mathematica and Origin software.

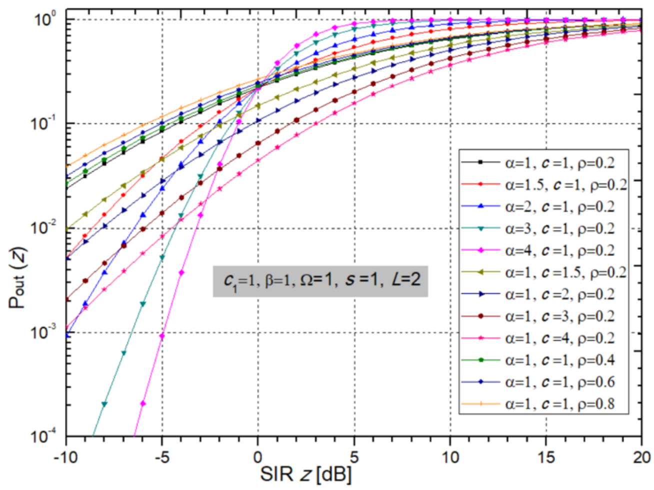

Fig. 2. The P_{out} at the output of the MD SC receiver, for different values of the parameters α, c and ρ

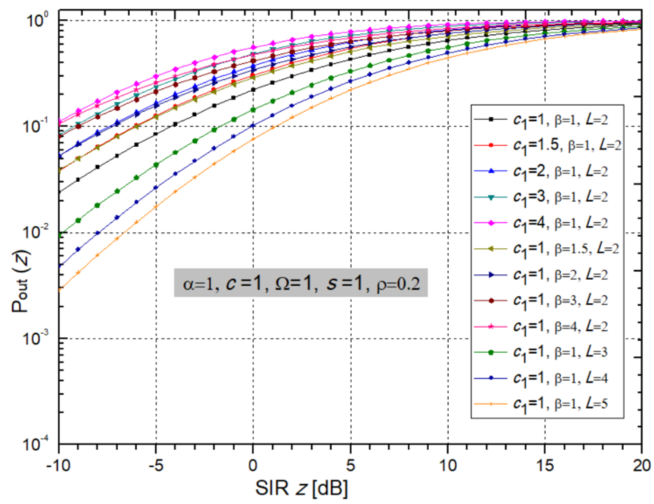

Fig. 3. The P_{out} at the output of the MD SC receiver, for different values of the parameters c_1, β and L changed.

In the Figure 2, we can see that P_{out} decreases with the increase of the parameter α. This is the expected behavior since for higher values of the parameter α the outage probability will be lower, and the system will have better performance. Also, when the parameter c increases, the P_{out} of the system decreases, and the system has better characteristics. When the coefficient ρ increases, the P_{out} increases and the system has performed worse, which is to be expected due to the deteriorating effect of the correlation on the quality of the connection and the errors in the entire system.

From the Figure 3, we observe that due to the increase in the parameters c_1 and β, the P_{out} of the system increases and therefore, the system performance decreases. When the parameter L, the number of branches of the mD SC receivers increases, the P_{out} decreases, and the system has better performance.

This is meaningful as with a larger number of input branches of the mD SC receiver, the chances of choosing the branch with a higher SIR ratio are greater.

In Tables I and II, we present results for the convergence of the expression (15). The convergence can be discussed based on the number of terms of the series needed to add to assure the convergence, that is, the accuracy of expression (15) rounded to the five decimal places. This is the accuracy we defined as the proper for the validity of the results.

Table 1 shows the values of N elements to be added for the convergence of the sequence (15) in relation to the variable z, when the parameters α, c and ρ are changed while the other parameters are kept constant: $c_1 = \Omega_0 = \beta = 1$, $L = 2$, as in the Figure 2.

TABLE I
THE NUMBER OF TERMS IN THE EXPRESSION FOR THE P_{OUT} FOR DIFFERENT VALUES OF THE PARAMETERS α, C AND ρ

Variables	z = -10 dB	z = 0 dB	z = 10 dB
α=1, c=1, ρ=0.2	8	12	16
α=1.5, c=1, ρ=0.2	6	12	16
α=2, c=1, ρ=0.2	5	12	16
α=3, c=1, ρ=0.2	5	12	18
α=4, c=1, ρ=0.2	5	12	18
α=1, c=1.5, ρ=0.2	8	12	17
α=1, c=2, ρ=0.2	7	12	18
α=1, c=3, ρ=0.2	8	15	20
α=1, c=4, ρ=0.2	8	15	20
α=1, c=1, ρ=0.4	8	13	17
α=1, c=1, ρ=0.6	9	16	20
α=1, c=1, ρ=0.8	16	28	40

When the parameter α increases, the number of elements in the sum of the expression (15) decrease and the series converges faster. For values of the coefficient α >2, convergence is achieved and the number of the terms to be added is only 5 for z = -10 dB. Also, for higher values of the parameter α, the number of elements in the sum needed to achieve convergence at z = 0 dB is 12, while at z =10 dB the number of terms in the sum increases and the series converges slower.

When the parameter c increases, for z = 0 dB and z =10 dB a larger number of terms in the sum is needed for the series to converge, and it converges slower, while for z = -10 dB convergence is achieved and accuracy is reached with 8 terms of the series.

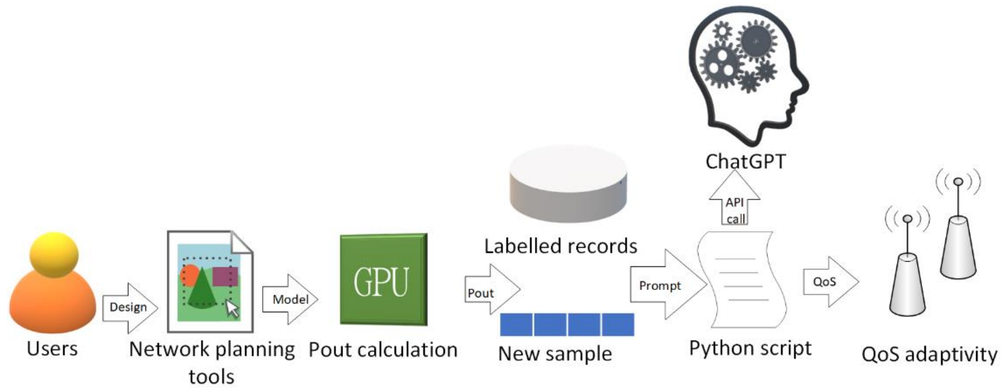

Fig. 4. ChatGPT-driven QoS-aware network planning workflow.

As the parameter ρ (correlation coefficient) increases, more terms are needed and the series converges slower. For example, if the value of the parameter ρ increases from 0.4 to 0.6 at z=0 dB, the number of terms in the expression (15) increases from 13^2=169 to 16^2=256 which slowes down the convergence.

The Table 2 shows the convergence of the expression (15) for P_{out} when the parameters c_1, β and L change, and the parameters $\alpha=1$, $c=1$ and $\rho=0.2$ are kept constant with respect to the variable z [dB].

TABLE II
THE NUMBER OF TERMS IN THE EXPRESSION FOR P_{OUT} FOR DIFFERENT VALUES OF THE PARAMETERS c_1, β AND L

Variables	z = -10 dB	z = 0 dB	z = 10 dB
c_1=1, β=1, L=2	8	12	16
c_1=1.5, β=1, L=2	8	12	16
c_1=2, β=1, L=2	9	12	16
c_1=3, β=1, L=2	9	14	16
c_1=4, β=1, L=2	10	14	17
c_1=1, β=1.5, L=2	9	12	16
c_1=1, β=2, L=2	8	14	16
c_1=1, β=3, L=2	10	14	15
c_1=1, β=4, L=2	10	14	16
c_1=1, β=1, L=3	5	10	14
c_1=1, β=1, L=4	5	10	14
c_1=1, β=1, L=5	5	10	14

As the parameter c_1 increases, for z = -10 dB and z = 0 dB the series converges slower and more terms are needed in each sum, while for z =10 dB the convergence of the expression is achieved and it reaches accuracy to the 5th decimal place when the number of terms in the sum is 16. When the parameter β increases at z = -10 dB, the convergence of the expression is achieved and accuracy is reached to the fifth decimal place with 10 terms in the sum. At z = 0 dB, the number of needed terms is 14, while at z =10 dB 16 terms are needed. By increasing the number of branches L at z = -10 dB, the convergence (and therefore the accuracy) is achieved with 5 terms for all values of the parameter L. However, at z = 0 dB 10 terms and at z = -10 dB 14 terms are needed for convergence of the expression for P_{out}.

IV. ChatGPT-Driven QoS Aware Network Planning

Nowadays, using predictive models relying on machine learning techniques is identified as one of key-enablers when it comes to innovation in next generation wireless and mobile networks [35]. A whole new horizon of innovative usage cases becomes reality, involving proactive response to environment changes and conditions, such as detection of failures and anomalies, estimation of the demand for services and the level of the Quality of Service (QoS). In general, machine learning techniques extract useful patterns and knowledge from large amounts of data. In telco domain, useful data involves various aspects, such as service user number and their activities, usage details, infrastructure parameters and other environment-related factors. However, each time a new prediction-based mechanism is about to be introduced within the system, additional efforts are needed for re-training dataset with either different or updated dataset layout.

In this context, we investigate how the trending ChatGPT [36] service can be leveraged with aim to make network planning more effective, taking into consideration QoS adjustment. Additionally, we incorporate the proposed approach into our smart city mobile network modelling and simulation environment [35]. Despite that the original purpose of ChatGPT is to perform human-alike dialogue, its underlying Large Language Model (LLM), has shown a great potential in many other areas as well, ranging from poetry writing and playing simple board games, to generating computer program code and analyzing huge amounts of data [36]. In this paper, the adoption of ChatGPT targets the prediction of QoS rate, for the wireless system with previously calculated P_{out}, including some other factors. The problem itself is treated as classification. The obtained results will be compared to the results obtained by implementing traditional machine learning technique from Weka library [37] in Java programming language.

The output of classification is categorical and has the following possible values: 1 – malfunction or anomaly; 2 – normal operation; 3 – high performance. Besides the calculated P_{out} value for the described transmission environment, we will consider the following input variables: 1) the base station identifier 2) identifier for the part of the city 3) service consumer count 4) period within day. Moreover, reduction of time required for fading-related calculations is achieved using a GPGPU approach which enables loop parallelization relying on Graphics Processing Unit (GPU) hardware using NVIDIA CUDA, as described in [38]. In this way, more than 60 times faster outage probability calculation was achieved. After that, the outcome of QoS level estimation is considered for the infrastructure tuning parameter. Our goal is to keep QoS at desirable level (underlying adaptability mechanisms are outside of this paper's scope). ChatGPT-enabled workflow of the previously described network planning software environment relying on our past research [35, 38] is illustrated in Figure 4.

When it comes to integrating ChatGPT within network planning environment, we rely on a script written based on our past work [36] and implemented using Python Application Programming Interface (API). Within the programming model, interaction with ChatGPT has form of a dialogue. Users submit prompts consisting of questions and context, which act as a "hint" that would aid generating a more precise result.

Regarding the usage limitations, in API mode, user has to be provided a valid OpenAI token that includes billing information in order to be generated on manufacturer's website. Per-usage charging model is applied, resulting with spending of a total of $0.02 for approximately 750 words contained in both the prompt and result. For QoS estimation the following prompt structure for the (question, context) pair is submitted to ChatGPT service relying on our Python script for the data record classification:

$$Question: \textbf{Classify}\left(Pout_i\, UserCount_i\, BStation_i\, Location_i\, Period_i\right) \quad (16)$$

$$Context: \textbf{Label}QoSi\textbf{is}\left(Pout_i\, UserCounts_i\, BStation_i Location_i\, Period_i\right) \quad (17)$$

In this case, context consists of labelled record with known QoS level value. On the other side, the aim of the question is to ask for QoS degree level of the record which is previously unseen by the model. Table III shows the outcome of the experiments for the ChatGPT-driven QoS degree prediction, considering the following aspects: 1) minimal context size – smallest feasible number of labelled observations required for successful classification 2) accuracy – average percentage of correctly classified samples per 100 prompts for context of minimal size 3) processing time – amount of time required for classification of a single new sample. Evaluation was done for 5000 samples exported from simulation environment [37, 35].

In shown experiments, fine tuning or training of the underlying GPT-4 model were not performed, as it requires significant time, resources and could also involve additional costs[1]. Instead, the context-based approach was adopted where annotated samples with known outcome are provided as part of the prompt, as given in (17).

The experiments were performed for the following scenarios including the outcomes of our previous works: 1) outage probability (P_{out}) of MD SC receiver within Weibull fading gamma-shadowed environment with co-channel interference (derived in this paper) 2) channel capacity (*CC*) of macro diversity MIMO system in gamma-shadowed Nakagami-m fading channel [39] 3) level crossing rate (*LCR*) of L-branch SC receiver in k-μ fading and Nakagami-m interference channel [40]. For these three scenarios, the datasets had the same layout, apart from the performance metric, which is P_{out} in the first, *CC* in the second and *LCR* in the third case. Table III includes the results for the mentioned aspects from the perspective of these three different scenarios (each of them denoted with the corresponding number 1-3).

TABLE III
THE CHATGPT-DRIVEN METHOD FOR QOS ESTIMATION

Aspect	***Outcome***	
Procesing time [s]	1	2.16 s
	2	2.11 s
	3	2.09 s
Minimal context [integer]	1	4
	2	4
	3	5
Accuracy [%]	1	95%
	2	93%
	3	90%

Regarding the execution time, it was around 2 seconds for all the three scenarios, with no significant variety. Moreover, the minimal context for the first two scenarios is the same, while for the third one it requires at least one more sample. Considering this outcome, it can be concluded that small amount of data inside context is needed for successful prediction using the proposed approach. Finally, when it comes to accuracy, in all the proposed scenarios we have value higher than 90%, which is satisfiable outcome for practical applications, while the first scenario exhibits the highest value.

TABLE IV
THE WEKA-BASED QOS ESTIMATION APPROACH

Algorithm		***Training* [s]**	**Accuracy [%]**
Ibk	1	1.96	85%
	2	2.01	81%
	3	1.93	78%
DecisionStump	1	1.28	83%
	2	1.17	79%
	3	1.31	77%
J48	1	0.94	91%
	2	0.83	88%
	3	0.92	89%
DecisionTable	1	4.24	95%
	2	4.04	91%
	3	4.01	87%

Table IV provides an overview of results obtained in case of traditional Weka-based approach for various classification algorithms. In this case, evaluation was done on 5000 records (75% training, 25% test). Considering the traditional approach,

[1] https://platform.openai.com/docs/guides/fine-tuning/create-a-fine-tuned-model

decision table exhibits the highest classification performance in terms of accuracy value with an evident longer training time.

However, in the case of all Weka-based approaches, the time required for classification of single observation is still shorter for about two orders of magnitude. When it comes to accuracy in case of traditional approach, *DecisionTable* algorithm adoption leads to the highest value for all of the three presented scenarios, but with the longest training time. On the other side, *J48* has slightly lower accuracy, but much faster execution time. Finally, both *iBk* and *DecisionStump* lead to lower accuracy than the previous two, while their execution time is shorter than *DecisionTable*, but longer than *J48*.

Observing the experiment results from Tables III and IV, we can notice that, in general, the traditional approach seems faster, which could be justified by the fact that ChatGPT involves online service access. Weka is executed locally in our experiments while the number of labelled records required for training of traditional algorithms is significantly larger, as ChatGPT was initially pre-trained on comprehensive textual data content, which depicts the state of World Wide Web until 2021. Therefore, only a few labelled observations were sufficient for successful classification.

Additional explanation of the workflow from Fig. 4 leveraging ChatGPT is provided as pseudo-code in Table V. As input, identifier of the user-created model is provided, together with the name of the labelled dataset file and number of samples that represent context. In the first step, the model is loaded based on the given id. On the other side, the desired number of samples with known outcomes are loaded as context from the dataset. Afterwards, the parameters relevant to outage probability calculation are extracted from the parsed model. In the fourth step, outage probability is calculated leveraging the extracted parameters within formula (15). In the next step, question for ChatGPT from (16) is parametrized taking into account both the model parameters and calculated P_{out}. Afterwards, the parametrized question is prompted against ChatGPT using the context as described in (17), which results with the estimated QoS value which is returned.

TABLE V
CHATGPT-DRIVEN QOS ESTIMATION METHOD

Input: model_id, labelled dataset, num_samples
Output: qos_value
Steps:
1. model:=LoadModel(model_id);
2. context_hint:=load(labelled dataset, num_samples);
3. performance_parameters:=Parse(model);
4. Pout:=CalculatePout(performance_parameters); (15)
5. parametrized_question:=ParametrizeQuestion(question(16), Pout, parameters);
6. qos_value:=PromptGPT(parametrized_question, context_hint (17);
7. return qos_value;
8. End

V. CONCLUDING REMARKS

This paper presents the analysis of the MD SC system with two mD SC receivers with L input branches and one MD SC receiver with two inputs undergoing Weibull fading and Gamma CCI in a correlated Gamma shadowed channel. For this case, the performance of the proposed P_{out} system was calculated in relation to the SIR ratio. Numerical results were graphically and tabularly presented and analyzed for different values of the system parameters. This enabled a better insight into the analysis of the wireless telecommunication system in a described fading environment. Based on the results, we conclude that the system operates better with the increase of the parameters α, c and L, while its performance significantly worsens with the increase of the parameters ρ, β and c_1 which also increases the probability of the system outage.

In the second part of the research, we leveraged the derived P_{out} expression as one of the input variables in the QoS prediction model based on ChatGPT. We compared the results to the traditional approach implemented in Weka. According to the outcomes, it can be noticed that the ChatGPT-approach is slower than traditional method and hence not suitable for time-critical applications. On the other side, this novel method needs smaller amount of labelled records, which allows for higher level of flexibility as it does not require re-training, even in the case of dataset layout modifications. For traditional approach, *DecisionTable* method exhibited the highest accuracy value.

In our future work, we are planning to adopt a similar ChatGPT-based approach for an estimation of fading type based on signal-related measurements. The method will introduce the ability to select the appropriate receiver type in a case of identified scenario. Additionally, LLM fine tuning method will be also applied aiming to improve the accuracy of the achieved results based on large amount of already annotated data provided as input. Finally, we would also explore open-source locally deployable LLMs as alternatives to commercial ChatGPT, such as Llama 3[2].

APPENDIX

MD SC receiver selects mD SC branch with higher signal level, to improve the received signal quality and enable better system performance. Therefore, P_{out} of SIR ratio at output of MD SC receiver is expressed as [25]:

$$P_{out}(z) = \int_0^{+\infty} ds_1\, p_{s_1}(s_1) \int_0^{+\infty} d\Omega_1 \int_0^{\Omega_1} d\Omega_2 F_{x_1|\Omega_1 s_1}(z_1)\, p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) +$$
$$+ \int_0^{+\infty} ds_2\, p_{s_2}(s_2) \int_0^{+\infty} d\Omega_2 \int_0^{\Omega_2} d\Omega_1 F_{x_2|\Omega_2 s_2}(z_2)\, p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) =$$
$$= 2\int_0^{+\infty} ds_1\, p_{s_1}(s_1) \int_0^{+\infty} d\Omega_1 \int_0^{\Omega_1} d\Omega_2 F_{x_1|\Omega_1 s_1}(z_1)\, p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) \quad \text{(A1)}$$

After substitution of the equations (9), (12) and (13) into (A1), we obtain the expression for: $P_{out}(z)$:

$$P_{out}(z) = \frac{2\left(z_{ij}{}^{\alpha}\right)^L}{\Gamma(c)\Gamma(c_1)\beta^{c_1}} \sum_{i_1=0}^{+\infty} \frac{\rho^{i_1}}{i_1!\,\Gamma(i_1+c)\,\Omega_0{}^{2i_1+2c}(1-\rho)^{2i_1+c}} \times$$
$$\times \int_0^{+\infty} ds_1 s_1^{L+c_1-1} e^{-\frac{1}{\beta}s_1} \int_0^{+\infty} d\Omega_1 \frac{\Omega_1{}^{i_1+c-1} e^{-\frac{\Omega_1}{\Omega_0(1-\rho)}}}{\left(\Omega_1 + s_1 z_{ij}{}^{\alpha}\right)^L} \int_0^{\Omega_1} d\Omega_2 \Omega_2{}^{i_1+c-1} e^{-\frac{\Omega_2}{\Omega_0(1-\rho)}} \quad \text{(A2)}$$

[2] https://llama.meta.com/llama3/

Solving the integral I_1 in expression (A2), we obtain the following form:

$$I_1 = \int_0^{\Omega_1} \mathrm{d}\Omega_2 \Omega_2^{i_1+c-1} \mathrm{e}^{-\frac{\Omega_2}{\Omega_0(1-\rho)}} = \left(\Omega_0 (1-\rho)\right)^{i_1+c} \times$$

$$\times \gamma\left(i_1 + c, \frac{\Omega_1}{\Omega_0 (1-\rho)}\right) \quad \text{(A3)}$$

where $\gamma(a, x)$ is lower incomplete Gamma function [38; 6.5.2]:

$$\gamma(\alpha, x) = \int_0^x \mathrm{e}^{-t} t^{\alpha-1} \mathrm{d}t \quad \text{(A4)}$$

Using the form for the lower incomplete Gamma function [29]:

$$\gamma(a, x) = \frac{1}{a} x^a \mathrm{e}^{-x} {}_1F_1(1, a+1, x) = \frac{1}{a} x^a \mathrm{e}^{-x} \sum_{j=0}^{+\infty} \frac{x^j}{(1+a)_j} \quad \text{(A5)}$$

where ${}_1F_1$ is the Kumar confluent hyper geometric function, and $(a)_n$ denoting the Pochhammer symbol, we can write the integral I_1 in the following form:

$$I_1 = \frac{1}{i_1 + c} \mathrm{e}^{-\frac{\Omega_1}{\Omega_0(1-\rho)}} \sum_{i_2=0}^{+\infty} \frac{\Omega_1^{i_1+i_2+c}}{(i_1+c+1)_{i_2} \left(\Omega_0(1-\rho)\right)^{i_2}} \quad \text{(A6)}$$

Substituting expression (A6) into (A2), we obtain the following expression:

$$P_{out}(z) = \frac{2}{\Gamma(c)\Gamma(c_1)\beta^{c_1}} \sum_{i_1=0}^{+\infty} \sum_{i_2=0}^{+\infty} \frac{\rho^{i_1}}{i_1!\,\Gamma(i_1+c)} \times$$

$$\times \frac{1}{\Omega_0^{2i_1+i_2+2c} (1-\rho)^{2i_1+i_2+c} (i_1+c)(i_1+c+1)_{i_2}} \times$$

$$\times \int_0^{+\infty} \mathrm{d}s_1 s_1^{c_1-1} \mathrm{e}^{-\frac{1}{\beta}s_1} \int_0^{+\infty} \mathrm{d}\Omega_1 \frac{\Omega_1^{2i_1+i_2+2c-1} \mathrm{e}^{-\frac{2}{\Omega_0(1-\rho)}\Omega_1}}{\left(1 + \left(1/s_1 z_{ij}^{\alpha}\right)\Omega_1\right)^L} \quad \text{(A7)}$$

Using the following expression [35; 3.383]:

$$\int_0^{+\infty} \frac{x^{q-1}\mathrm{e}^{-px}}{(1+ax)^v} \mathrm{d}x = a^{-q}\Gamma(q)\Psi\left(q, q+1-v, \frac{p}{a}\right) \quad \text{(A8)}$$

where: $\psi(s, d, t)$ is confluent hyper geometric function, integral I_2 from (A7) can be written in the following form:

$$I_2 = \int_0^{+\infty} \mathrm{d}\Omega_1 \frac{\Omega_1^{2i_1+i_2+2c-1} \mathrm{e}^{-\frac{2}{\Omega_0(1-\rho)}\Omega_1}}{\left(1 + \left(1/s_1 z_{ij}^{\alpha}\right)\Omega_1\right)^L} = \left(s_1 z_{ij}^{\alpha}\right)^{2i_1+i_2+2c} \Gamma(2i_1+i_2+2c) \times$$

$$\times \Psi\left(2i_1+i_2+2c, 2i_1+i_2+2c-L+1, \frac{2s_1 z_{ij}^{\alpha}}{\Omega_0(1-\rho)}\right) \quad \text{(A9)}$$

Substituting the expression (A9) into (A7), we obtain the following form for P_{out} at the output of the MD SC receiver:

$$P_{out}(z) = \frac{2}{\Gamma(c)\Gamma(c_1)\beta^{c_1}} \sum_{i_1=0}^{+\infty} \sum_{i_2=0}^{+\infty} \frac{\rho^{i_1} \left(z_{ij}^{\alpha}\right)^{2i_1+i_2+2c}}{\Gamma(i_1+c)\Omega_0^{2i_1+i_2+2c} (i_1+c)} \times$$

$$\times \frac{\Gamma(2i_1+i_2+2c)}{i_1!(1-\rho)^{2i_1+i_2+c} (i_1+c+1)_{i_2}} \int_0^{+\infty} \mathrm{d}s_1 s_1^{2i_1+i_2+2c+c_1-1} \mathrm{e}^{-\frac{1}{\beta}s_1} \times$$

$$\times \Psi\left(2i_1+i_2+2c, 2i_1+i_2+2c-L+1, \frac{2s_1 z_{ij}^{\alpha}}{\Omega_0(1-\rho)}\right) \quad \text{(A10)}$$

Using substitution $2s_1 z_{ij}^{\alpha} / \Omega_0(1-\rho) = n$, the expression in term (A10) becomes:

$$P_{out}(z) = \frac{2(1-\rho)^{c+c_1}}{\Gamma(c)\Gamma(c_1)} \left(\frac{\Omega_0}{\beta z_{ij}^{\alpha}}\right)^{c_1} \sum_{i_1=0}^{+\infty} \sum_{i_2=0}^{+\infty} \frac{\rho^{i_1}}{2^{2i_1+i_2+2c+c_1} i_1!} \times$$

$$\times \frac{\Gamma(2i_1+i_2+2c)}{\Gamma(i_1+c)(i_1+c)(i_1+c+1)_{i_2}} \int_0^{+\infty} \mathrm{d}n n^{2i_1+i_2+2c+c_1-1} \times$$

$$\times \mathrm{e}^{-\frac{\Omega_0(1-\rho)}{2\beta z_{ij}^{\alpha}}n} \Psi(2i_1+i_2+2c, 2i_1+i_2+2c-L+1, n) \quad \text{(A11)}$$

By using the expression [30; 7.621]:

$$\int_0^{+\infty} t^{b-1} \mathrm{e}^{-st} \Psi(a, d, t) \mathrm{d}t = \frac{\Gamma(b)\Gamma(b-d+1)}{\Gamma(a+b-d+1)} \times$$

$$\times {}_2F_1(b, b-d+1, a+b-d+1, 1-s) \quad \text{(A12)}$$

integral I_3 from the expression (A11) can be written as:

$$I_3 = \int_0^{+\infty} \mathrm{d}n n^{2i_1+i_2+2c+c_1-1} \mathrm{e}^{-\frac{\Omega_0(1-\rho)}{2\beta z_{ij}^{\alpha}}n} \Psi(2i_1+i_2+2c, 2i_1+i_2+2c-L+1, n) =$$

$$= \frac{\Gamma(2i_1+i_2+2c+c_1)\Gamma(c_1+L)}{\Gamma(2i_1+i_2+2c+c_1+L)} {}_2F_1\Big(2i_1+i_2+2c+c_1, c_1+L,$$

$$2i_1+i_2+2c+c_1+L, 1 - \frac{\Omega_0(1-\rho)}{2\beta z_{ij}^{\alpha}}\Big) \quad \text{(A13)}$$

Finally, after replacing expression (A13) in expression (A11), we get the final form for P_{out} of SIR ratio at output of MD SC receiver in (15).

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Miloš Popović was born in Priština, Serbia, in 1985. He currently resides and works in Belgrade, where he completed his Master's studies at Singidunum University, earning the title of Master of Science in Information Technology in 2010. In 2017 he obtained a PhD in Computer Science from the same University. Since 2009, Author has been employed as a teaching assistant at the Belgrade Business and Arts Academy of Applied Studies. There, he lectures on various subjects, including computer architecture and operating systems, business process management, and information technologies in business. His contributions to academia include co-authoring seven scientific papers and, in 2023, writing a book on the Internet of Things. Author's research interests span the field of natural and mathematical sciences, with a particular focus on information and communication technologies and artificial intelligence.

Samardzic Nikola, born in 1994 in Belgrade. In 2018 he earned his Bachelor's degree in Information Technology from the University "Union-Nikola Tesla". He pursued master's studies at the Higher School of Academic Studies "Dositej," specializing in Computer Science. In 2019, he defended his master's thesis and now holds the title of Master of Computer Science. Currently, he is enrolled in doctoral studies at the Business and Legal Faculty of the University "MB" in the field of Advanced Information Technologies. He is employed at the Belgrade Academy of Business and Arts, within the Department of Business and IT Studies, working as an assistant at the Information Technology Chair.

Suad N. Suljović was born on January 8, 1975 in Tutin, Republic of Serbia. In 1999 he graduated from the Faculty of Electrical Engineering in Pristina, Department of Electronics and Telecommunications. In 2009 he completed master's studies at the Faculty of Electronics in Nis, the Department of Telecommunications and in 2019 defended a Doctoral dissertation: "Analysis of performance improvement in relay communication systems from the aspect of diversity combining techniques" at the same Faculty. He is a professor at the Academy of Applied Technical Studies Belgrade, Serbia. His research activity is focused on wireless communications, optical and satellite signal transmission, computer networks, programming and databases. He is author of more than 100 papers published in journals of international importance or referenced at international and national symposia and conferences.

Nenad Petrović was born in Pirot, Serbia, in 1992. He is a teaching assistant at the Faculty of Electronic Engineering, University of Niš, Serbia. He received his bachelor's degree in the area of Electrical Engineering and Computer Science and his master's degree in Computer Science and Engineering comes from Politecnico di Milano, Milan, Italy. He has been occasionally working as an ICT analyst/consultant in TELCO,e-commerce, machine learning and DevOps areas. Nenad is the author of around 150 research publications (conference papers, journal articles, and book chapters) with both national and international recognition and is the holder of 4 IcETRAN Conference Best Young Paper Awards (1 in 2018, 2 in 2019, and 1 in 2022) and WEBIST 2023 Best Poster Award. His main research interests cover model-driven engineering, semantic technology, IoT, and large language models.

Vasic Selena, born in 1971 in Aleksinac, holds BC in Electrical Engineering from Electronic faculty, University of Nis. She completed her master's and doctoral studies at the University of Nis, Department for Telecommunications. Her primary area of research is applied mathematics in telecommunications and signal detection in wireless communications. She is author of more than 50 papers published in national and international journals or referenced at national or international forums and conferences.
Since 2008 she has worked as a professor and researcher at the Faculty of Information Technologies, Metropolitan University in Belgrade.

Vuk B. Vujović was born in Pristina, Serbia in 1974. He graduated from the Faculty of Electrical Engineering, Department of Electronics and Telecommunications at the University of Pristina in 2001. He received his doctorate in electrical engineering at Alfa BK University, Belgrade, Serbia in 2021. From 2016 to 2021, he was an assistant at the Faculty of Information Technologies of Alfa BK University. Since 2022, he works as an assistant professor at the Department of Information Technologies at the University of MB. He is the author of more than 30 scientific papers. His research interests include the use of ICT in construction, the development of business intelligence in companies.