Model of microwave link channel with adaptive modulation under the fading conditions

Irina Stepanets, [1,*],and *Sergei Odoevskii* [2]

[1] Deutsche Telekom, Integrated Active Access, Landgrabenweg 151, 53227 Bonn, Germany
[2] The State Marine Technical University St. Petersburg, Lotsmanskaya Ulitsa, 3, 190121 St. Petersburg, Russian Federation

Abstract. Higher throughput requirements of the radio access network (RAN) of 5th generation (5G) network lead in turn to even more higher capacity require-ments of wireless backhaul segment. Current research proposes a model of microwave link channel with adaptive modulation under the fading condi-tions. This model allows to estimate maximum possible throughput with re-quired bit error probability (BEP) for channel with adaptive modulation un-der fading conditions. The contribution of the current research is the consid-eration of the 5G requirements on higher throughput and fading conditions in microwave link. Whereby this fading is assumed as a process with Rice distribution.

1 1 Introduction

The key characteristic of the channel in the wireless transport segment of the 5th generation (5G) communication network is higher data transmission capacity, which should ensure the transmission of data streams coming from the radio access net-works. Therefore, the throughput of the wireless transport segment in 5G should be by orders higher than in radio access networks. The requirements of the ETSI organization define the communication channel speed of the wireless segment up to 100 Gbps [1-4]. To ensure high data rates, it is necessary to use quadrature amplitude modulation (QAM) modulation schemes of higher orders M, than in previous communication generations. M denotes the dimension of the QAM constellation, or the total number of variants of symbol positions in the constellation, while M=2L, where L is the number of bits in one symbol. In current wireless transport systems based on microwave links, QAM dimensions are used up to M=4096.

However, due to changes of external conditions and channel conditions, the constant application of high QAM modulation schemes can lead to data loss. Therefore, the use of adaptive QAM (A-QAM) modulation schemes is required, which automatically switches the modulation scheme according to the channel state. As the signal-to-noise ratio (SNR) improves, the modulation scheme adapts to a higher order, which allows maximum use of the available channel resource and higher transmission rates. If SNR decreases, a lower QAM scheme is applied, the transmission rate becomes slower, but there is no data loss. At the same time, it is important to set the SNR thresholds for modulation switching so that, on the one hand, the transition between QAM schemes is not too frequent and, on the other hand, it is not too slow, which may entail either idle free channel resources, or data loss. There are modern software tools e.g. ONEPLAN RPLS-DB Link, which allows to solve such tasks of calculations for microwave link in praxis. However, it is necessary to formalize the channel model for adaptive QAM switching under specific fading conditions from the theoretical point of view, in order to obtain its common characteristics.

Thus, the material in this paper is organized in the following order. The base aspects of the channel model with adaptive modulation is described in Section 2. The calculation results based on the proposed model is given in Section 3, considering the fading conditions of microwave link and adaptive switch of quadrature amplitude modulation (QAM). Finally, conclusions are drawn in the in Section 4.

2 Base aspects of channel model

2.1. Common structure of channel model

The channel model consists of mathematical expressions for calculation of the bit error probability (BEP) and throughput. The common structure of the channel model can be represented in the following steps.

First step. Find the dependency of BEP $P_{b-AWGN}(\gamma_s)$ on signal-to-noise ratio (SNR) in a basic Gaussian channel for each M-QAM scheme used in the adaptive modulation system [5, 6]:

$$P_{b-AWGN}(\gamma_s) = \sum_i A_i Q(\sqrt{a_i \gamma_s}) \quad (1)$$

where γ_s is SNR in form of symbol to noise power ratio, a_i and A_i are specific QAM coefficients, Q-function represents tail distribution function of the standard normal distribution.

* Corresponding author: stepanets.irina@gmail.com

Second step. Find the dependency of the bit error probability BEP_{Fading} on SNR in the investigated fading channel according to the formula:

$$BEP_{Fading} = \int_0^{\infty} P_{b-AWGN}(\gamma_s) f_{\gamma_{Fading}}(\gamma_s) d\gamma_s \quad (2)$$

where $f_{\gamma_{Fading}}(\gamma_s)$ is probability density function of a random variable, which characterizes the investigated channel.

Third step. Define the SNR thresholds for each of M-QAM switching level by required BEP_{req}. This step is discussed more detailed in the section 2.2.

Fourth step. Estimate the channel throughput B_{adapt} in bits per symbol (BPS) for the system with adaptive M-QAM according to the formula:

$$B_{adapt} = \sum_{i=1}^{N} B_{i-adapt} = \sum_{i=1}^{N} L_i \int_{SNR_i}^{SNR_{i+1}} f_{\gamma_{Fading}}(\gamma_s) d\gamma_s \quad (3)$$

where i is an iteration number through the switching levels of adaptive M-QAM; $L_i = log_2 M_i$ is a number of bits per symbol on modulation level M_i-QAM; SNR_i is a switching SNR threshold for M_i-QAM level; $B_{i-adapt} = \int_{SNR_i}^{SNR_{i+1}} f_{\gamma_{Fading}}(\gamma_s) d\gamma_s$ is throughput provided by each used in a system modulation scheme, whereby the integration limits represent SNR switching thresholds, which were found in the Third step.

Fifth step. Estimate the bit error probability BEP_{adapt} of a channel with adaptive modulation. Using the estimated parameter from the previous steps, calculate the BEP_{adapt} by formula:

$$BEP_{adapt} = B_{adapt}^{-1} \left(\sum_{i=1}^{N} L_i \cdot \int_{SNR_i}^{SNR_{i+1}} P_{b-AWGN_i}(\gamma_s) \cdot f_{\gamma_{Fading}}(\gamma_s) d\gamma_s \right) \quad (4)$$

2.2 SNR switching threshold for channel with adaptive modulation

To define the state-of-the-art of the paper topic, different research works were analyzed by us and the overview of this analysis is summarized in the Table 1 with references to the corresponding literature.

The comparison of the mentioned works above and our research is given in this paragraph. The analysis of existing techniques for finding the SNR switching thresholds in a system with adaptive modulation shows, that either these approaches do not reflect the desired accuracy [14,15], or are based on averaging of the current BEP values [7-13]. Such averaging can be acceptable for mobile communication systems, however, it is unacceptable for transport wireless data transmission, such microwave link to backhaul of 5G networks. Since in the case of microwave link communication it is important to maintain a required BEP_{req} at every moment, it was decided to use numerical method by assumption of AWGN channel in order to define SNR switching threshold

As formula (1) gives accurate coefficient only till 256-QAM and the existing approximation do not give enough accuracy, authors of this work developed own higher accuracy approximation method of BEP calculation for the higher modulation schemes such 1024-QAM and 4096-QAM. These higher QAM schemes are necessary to be used in modern microwave link systems to fulfill the requirements on 5G capacity.

The examples of corresponding SNR switching threshold values for different re-quired BEP_{req} are presented in Table 2

Having known the SNR threshold for switching of adaptive modulation in com-mon, as a next step it is possible to apply these values for the BEP and throughput estimation of a specific fading channel.

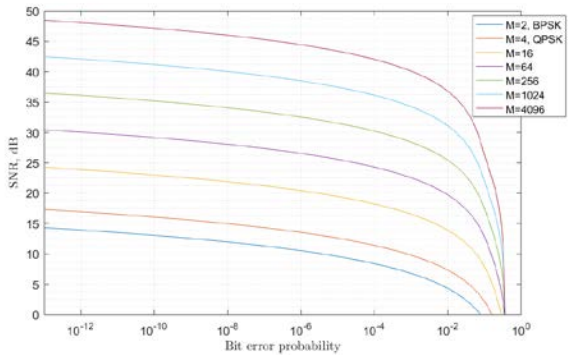

Fig. 1. SNR switching thresholds for required BEP by numerical method.

2.3 Consideration of fading for microwave link

The existing works devoted to research of adaptive modulation transmission consider only the assumption of Raleigh channel model [5-8]. This can be applicable for the mobile communication with multipath transmission. But as microwave link is characterized by one dominant signal component transmitted in line-of-sight (LOS) channel, the channel model should be described by another law, e.g. Rice distribution [16-19]. That is why the applied in Second, Fourth and Fifth steps described in section 2.1 probability density function $f_{\gamma_{Fading}}(\gamma_s)$ takes the form:

$$f_{\gamma_{Fading-Rice}}(\gamma_s) = \frac{1+k}{\overline{\gamma_s}} e^{-\left(k + \frac{(1+k)\gamma_s}{\overline{\gamma_s}}\right)} \cdot I_0\left(2\sqrt{\frac{k(1+k)\gamma_s}{\overline{\gamma_s}}}\right) \quad (5)$$

Where factor k is ratio of LOS to non-LOS signal power; $\overline{\gamma_s}$ is average symbol SNR; γ_s is current symbol SNR; I_0 is modified Bessel function of zero order.

Whereby as the SNR distribution is represented in terms of power, which is a squared value, it is necessary to modify the distribution law in terms of squared random value. This condition was considered by authors of current paper in (4).

Table 1. Analysis of existing approaches on finding of switching thresholds for systems with adaptive modulation A-QAM.

Authors	Shorten name of work with reference	Used technique to find SNR threshold depending on the required BEP
L. Hanzo, W. Webb, T. Keller	Book "Single-and Multi-carrier Quadrature Amplitude Modulation" [7**Fehler! Verweisquelle konnte nicht gefunden werden.**]	A solution with use of Powell optimization method based on [13] is proposed.
J.Torrance, L. Hanzo	Paper "Optimization of switching levels for adapt. mod., Rayleigh fading" [8]	A solution with use of Powell optimization method based on [13] is proposed.
B. J. Choi, L. Hanzo	Paper "Optimum mode-switching for adaptive modulation systems" [9]	A solution with use of Lagrange multiplier method is proposed.
B. J. Choi, L. Hanzo	Paper "Optimum mode-switching assisted adaptive modulation" [10]	Proposed solution gives average error probability by the method of Lagrange multipliers.
B. J. Choi, L. Hanzo	Paper "Optimum mode-switching-assisted adaptive modulation" [11]	Proposed solution gives average error probability by the modified method of Lagrange multipliers.
B. J. Choi, L. Hanzo и др.	Paper "Performance of adaptive modulation over Rayleigh fading channel" [12]	Proposed solution gives average error probability by the method of Powell optimization based on [13].
T. Liew, L. Hanzo	Paper "Switching threshold for turbo coded adaptive modulation" [13]	Proposed solution gives average error probability for systems with turbo-coding
M. Alouini, A. Goldsmith	Paper "Adaptive modulation over Nakagami fading channels" [14,15]	Description of the approximate calculation technique. Gives rough results.

Table 2. Calculation results of SNR thresholds by numeric method

BEP_{req}	SNR_{BPSK}, dB	SNR_{QPSK}, dB	SNR_{16}, dB	SNR_{64}, dB	SNR_{256}, dB	SNR_{1024}, dB	SNR_{4096}, dB
10^{-3}	6,7	9,8	16,5	22,5	28,4	34,2	40
10^{-6}	10,5	13,5	20,4	26,5	32,5	38,5	44,4
10^{-9}	12,5	15,5	22,5	28,6	34,6	40,6	46,6

3 Calculation results

In this section the simulation results of the microwave link channel are presented according to the proposed channel model with LOS under the fading conditions.

The simulation results are provided for required BEP_{req} values 10^{-3} and 10^{-6} and presented on the figures 2-5. The simulations were done for different LOS intensity, i.e. different values of k-factor: 5; 10; 20; 50. The higher the k-factor is, the more prevailing the LOS signal power is. The simulated system with adaptive modulation contents switching modes with square constellations: QPSK, BPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM, 4096-QAM (thin lines on figures show its individual BEP without adaptation). The holistic BEP of the system with adaptive modulation is presented as red bold line. BEP values are plotted along the vertical left axis depended on SNR values (horizontal axes). The right vertical axis depicts the values of throughput in bits per second.

* Corresponding author: stepanets.irina@gmail.com

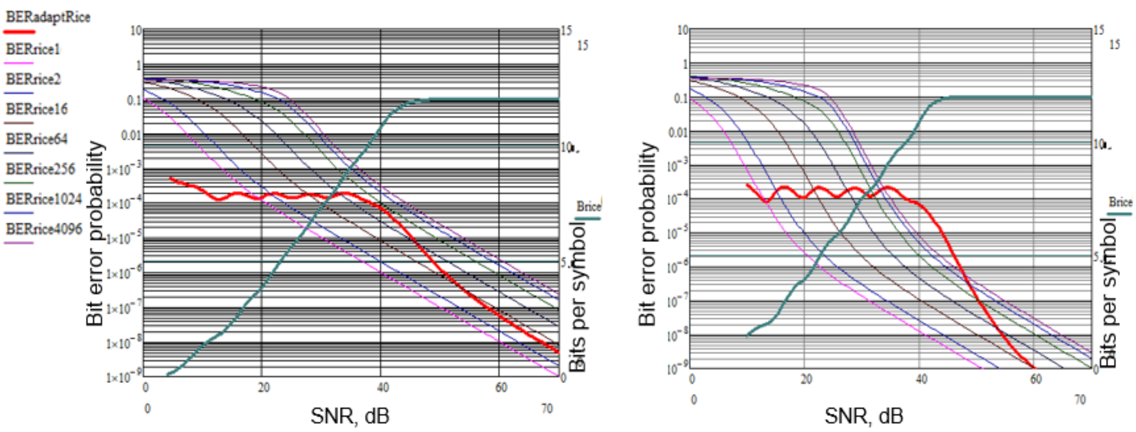

Fig. 2. Simulation results for BEPreq=10-3 and k=5 (on the left), k=10 (on the right).

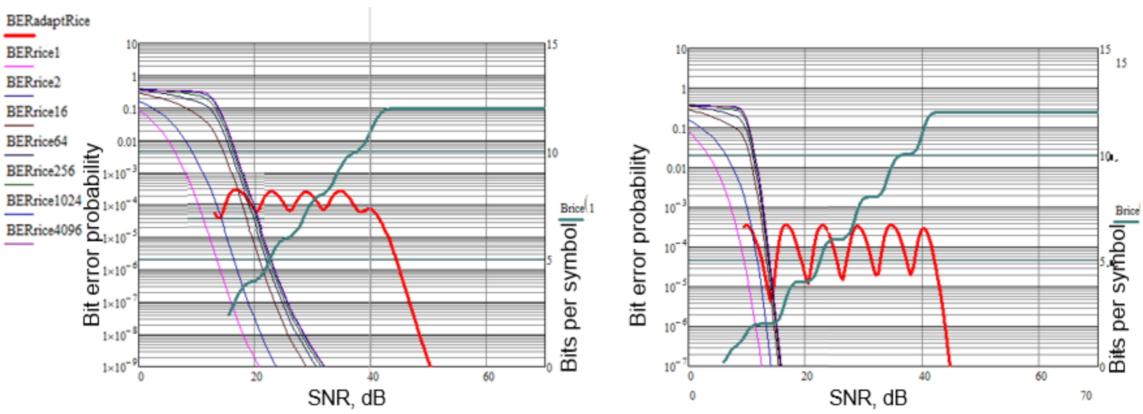

Fig. 3. Simulation results for BEPreq=10-3 and k=20 (on the left), k=50 (on the right).

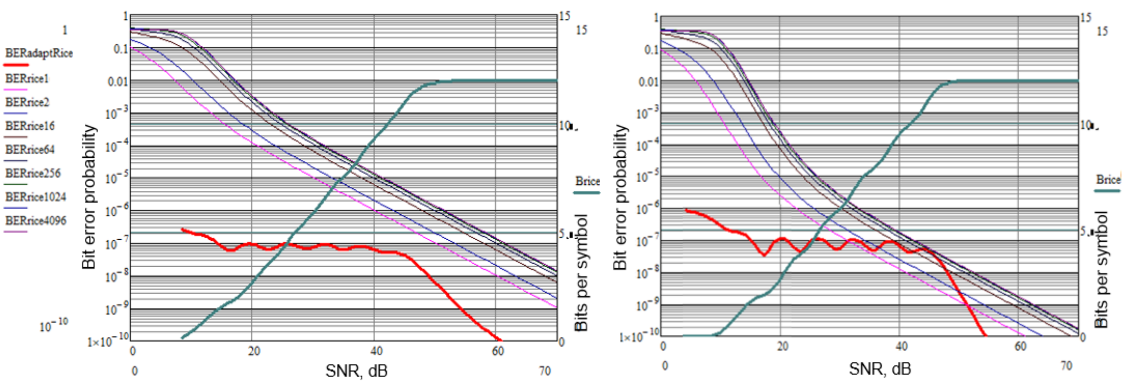

Fig. 4. Simulation results for BEPreq=10-6 and k=5 (on the left), k=10 (on the right).

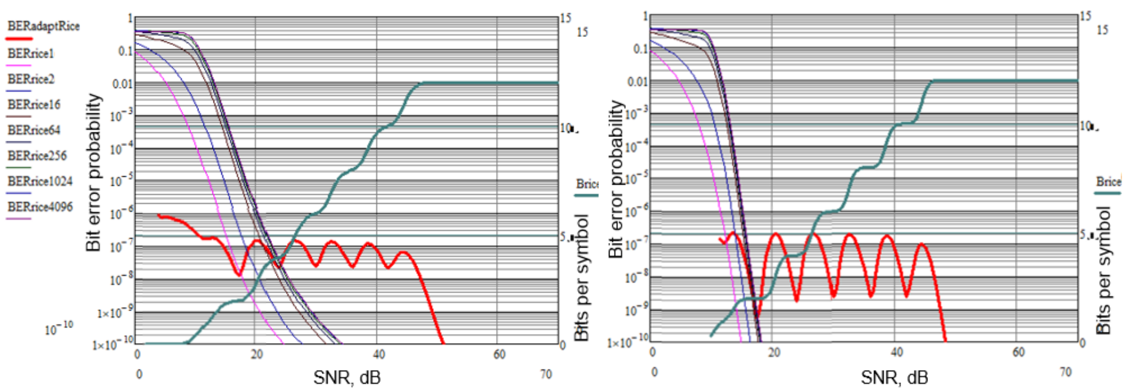

Fig. 5. Simulation results for BEPreq=10-6 and k=20 (on the left), k=50 (on the right).

The obtained results of the Rice channel estimation by criteria of throughput and BEP allow to draw out the following conclusions. The graphs depict the operation of the system with adaptive modulation: by increase of SNR, the signal energy becomes stronger, which allows the system to switch to a higher QAM modulation level. This change is represented by the hills of the bit error rate $BEP_{adapt_{Rice}}$ (red bold curve) and the steps of the throughput B_(adapt_Rice) (bold turquoise curve). At the same time, with an increase of the k-factor of Rice distribution, the hills of the bit error rate $B_{adapt_{Rice}}$ curve of adaptive modulation switching are observed more obviously. Also, as the k-factor increases, the throughput $B_{adapt_{Rice}}$ curve exhibits more evident stepwise jumps. The behavior of the hills of $BEP_{adapt_{Rice}}$ shows a dependence on the steps of the throughput curve $B_{adapt_{Rice}}$: each time the throughput (data rate in an interval of one step) increases, the bit error probability increases $BEP_{adapt_{Rice}}$; when a stable state of $B_{adapt_{Rice}}$ occurs (when the BPS step takes a horizontal line), a decrease of the bit error rate $BEP_{adapt_{Rice}}$ is observed, i.e. in a stable state, when there is no change from one modulation scheme to the next and the SNR increases, the system becomes more noise-resistant; then, with a sufficient increase in SNR, the change to the next modulation scheme occurs again and the throughput $B_{adapt_{Rice}}$ increases, the noise resistance $BEP_{adapt_{Rice}}$ decreases; and so on, the cycle repeats, which is valid also for the opposite direction

4 Conclusions

The model of microwave link channel with adaptive modulation under the fading conditions is proposed in this paper. The base aspects of channel model are de-scribed, in particular the common structure of channel model, which includes the mathematical expressions for calculation of the bit error probability and throughput. Special attention is devoted to definition of SNR switching threshold for channel with adaptive modulation and to consideration of fading for microwave link based on Rice distribution. Calculation results based on the proposed channel model are presented for the modulation levels from BPSK to 4096-QAM. This model can be used to solve the problem of channel estimation for wireless backhaul segment of 5G. In this work we assumed the ideal adaptation model. For the future work it is planned to consider inaccuracies of the adaptive control system caused by random radio conditions.

References

1. ETSI GR mWT 012 V1.1.1: 5G Wireless Backhaul/X-Haul (2018).
2. Stepanets, I., Odoevskii S.: *Features of the application and planning of the microwave link transmission in the 5G networks*. Informaciia i sviaz, no. **3** (2019).
3. Stepanets, I., Fokin, G., Odoevskii, S.: *Model of Integrated Radio Access and Wireless Backhaul for 5th Generation Network*. In: International Youth Conference on Electronics, Telecommunications and Information Technologies, pp. 637-645. Springer, Cham (2021).
4. Hilt, A.: *Availability and Fade Margin Calculations for 5G Microwave and Millimeter-Wave Anyhaul Links*. Applied Sciences, **9**(23), pp. 5240 (2019).
5. Hanzo, L., Webb, W.T. and Keller, T.: *Single-and multi-carrier quadrature amplitude modulation*. IEEE Press-John Wiley. New York, USA (2000).
6. Torrance, J.M., Hanzo, L.: *Upper bound performance of adaptive modulation in a slow Rayleigh fading channel.* Electronics Letters **32**(8), pp. 718-719 (1996).
7. Hanzo L., Webb W.T.: *Single-and Multi-carrier Quadrature Amplitude Modulation*. **2**nd edn. IEEE Press-John Wiley (2000).
8. Torrance, J. M., Hanzo, L.: *Optimisation of switching levels for adaptive modulation in slow Rayleigh fading*. Electronics Letters **32**(13), pp. 1167-1169 (1996).
9. Choi B.J., Hanzo L.: *Optimum mode-switching levels for adaptive modulation systems*. IEEE GLOBECOM (2001).
10. Choi B.J., Hanzo L.: *Optimum mode-switching assisted adaptive modulation. In: GLOBECOM'01.* IEEE Global Telecommunications Conference, vol. **6**, pp. 3316-3320 (2001).
11. Choi B., Hanzo L.: *Optimum mode-switching-assisted constant-power single-and multicarrier adaptive modulation*. IEEE Transactions on Vehicular Technology **52**(3), pp. 536-60 (2003).
12. Choi B.J., Hanzo L., et.al.: *Performance of Rake receiver assisted adaptive-modulation based CDMA over frequency selective slow Rayleigh fading channels*. Electronics Letters **37**(4) (2001).
13. Liew T.H., Hanzo L.: *Switching threshold and coding-rate optimisation for turbo convolutional and turbo BCH coded adaptive modulation*. In: **57**th IEEE Semiannual Vehicular Technology Conference, Spring. vol. 4, pp. 2167-2171 (2003).
14. Alouini M.S., Goldsmith A.J.: *Adaptive modulation over Nakagami fading channels*. Wireless Personal Communications. (2000).
15. Alouini M.S., Goldsmith A.: *Adaptive M-QAM modulation over Nakagami fading channels*. In: IEEE Global Communications Conference (1997).

* Corresponding author: stepanets.irina@gmail.com

16. Proakis, John G., Masoud Salehi*: Digital Communication*. **5th** edn. McGraw-Hill. (2007).
17. Zhou, T., Tao, C., et.al.: *Ricean K-factor measurements and analysis for wideband high-speed railway channels at 2.35 GHz*. Radioengineering 23(2), pp. 578-585 (2014).
18. ITU-R P.1057 Probability distributions relevant to radiowave propagation modelling (08/2019).
19. ITU-R P.1411-10 Propagation data and prediction methods for the planning of short-range outdoor radio communication systems and radio local area networks in the frequency range 300 MHz to 100GHz (08/2019).