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FLEXIBLE MULTIPLE ACCESS CONTROL ALGORITHM IN 5G MOBILE WIRELESS SYSTEM

Abstract. With the development of mobile communication technology, wireless spectrum resources have become increasingly scarce. Researchers are eagerly looking for a new mobile communication technology which do not only meet user expectations but also improve wireless spectrum efficiency. The key technologies of the next generation wireless network research concentrates on complex multiple access control algorithms in the physical layer. This paper discusses the concept and practical aspects of non-orthogonal multiple access (NOMA) with a successive interference canceller at the receiver side. Using Matlab simulations, we justify, for multiple configurations, that the system-level performance achieved by NOMA is higher by more than 30 % compared to orthogonal multiple access (OMA) in maximum value.

Keywords: non-orthogonal multiple access, multiple access control algorithms, successive interference canceller

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АЛГОРИТМ ГИБКОГО УПРАВЛЕНИЯ МНОЖЕСТВЕННЫМ ДОСТУПОМ В МОБИЛЬНОЙ БЕСПРОВОДНОЙ СИСТЕМЕ 5G

Аннотация. С развитием технологий мобильной связи ресурсов беспроводного спектра становится недостаточно. Исследователи ищут новые технологии мобильной связи, которые будут не только отвечать ожиданиям пользователей, но и улучшат эффективность беспроводного спектра. Ключевые технологии исследования беспроводной сети следующего поколения основаны на сложных алгоритмах управления множественным доступом на физическом уровне. В статье предлагается новый алгоритм гибкого множественного доступа (неортогонального множественного доступа, НОМД), анализируется производительность системы для НОМД восходящей линии связи с усовершенствованным приемником последовательного подавления помех, применяемым на стороне базовой станции. С помощью Matlab показывается, что производительность системы, достигнутая в НОМД, выше на 30 % по сравнению с системой ортогонального множественного доступа.

Ключевые слова: неортогональный множественный доступ, алгоритм управления множественным доступом, фильтр сигналов

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1. Introduction of algorithm of orthogonal multiple access. In the field of wireless terminal application, the design of radio access technology is an important aspect to enhance system capacity in a cost-effective manner. Radio access technologies are typically characterized by multiple access schemes, e.g., orthogonal frequency division multiple access (OFDMA), which provide the means for multiple users to access and share system resources simultaneously. OMA is a reasonable choice for achieving good system level throughput performance in packet-domain services with a simplified receiver design. The receiver does not need to use a filter to distinguish subcarriers in OFDMA algorithm [1–3]. In fig. 1 the binary sequence signal processing is converted to frequency band signal by quadrature amplitude modulation (QAM) combine to fast Fourier transformation (FFT) and imaginary exponential function ($e^{j2\pi ft}$) to get OFDMA symbol.

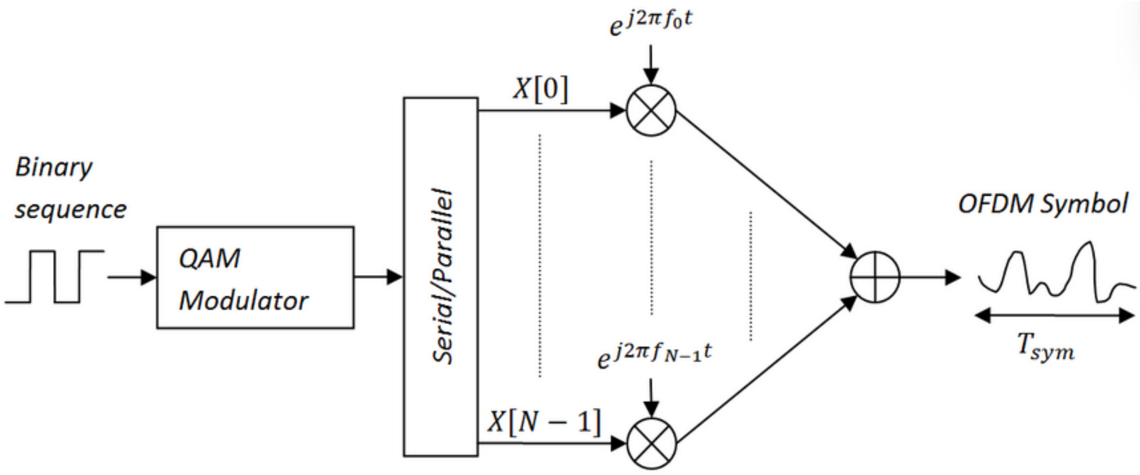


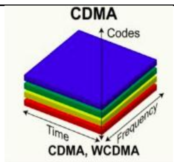
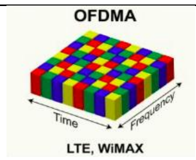
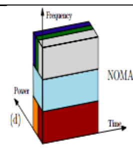
Fig. 1. The model of modulation in OFDMA

However, in order to boost further the spectrum efficiency in the future, more advanced multiple access algorithms are required in order to mitigate intra-cell and/or inter-cell interference. As a candidate multiple access scheme for frequency radio access, we propose an uplink NOMA scheme where multiple users are multiplexed in the power-domain on the transmitter side, and multi-user signal separation on the receiver side is conducted based on successive interference cancellation.

2. Concept of NOMA algorithm. In this section, we focus on the principle of NOMA and OFDMA technology as air interface technology for current and future mobile wireless broadband access systems. The next section provides the concept considerations of NOMA with a successive interference canceller at the receiver side. In the remaining part of the article, we present performance analysis of NOMA algorithm model system, successive interference canceller capacity analysis for uplink and we propose multiuser scheduling scheme to defuse these challenges.

NOMA is the result of an evolution of digital transmission techniques and advances in the digital signal processing methods and technologies. The basic idea of NOMA is to actively introduce interference technology in transmission at the transmitter. A receiver with successive interference canceller can achieve the correct demodulation. The complexity of the system has been improved by using the successive interference canceller algorithm, however, it can also improve the spectral efficiency. The essence of NOMA algorithm is in increasing the spectral efficiency by increasing the complexity of the receiver [4].

The comparison of multiple access algorithms

Terminal multiple access algorithm	Non-orthogonal code division multiple access	Orthogonal OFDMA	Non-orthogonal successive interference canceller
The waveform of signals	Single-carrier	OFDM (DFT-s-OFDM)	OFDM (DFT-s-OFDM)
Link adaptability	High-speed transfer protocol control	Adaptive modulation coding	Adaptive modulation coding + power allocation
Graphical			

OFDMA algorithm is still used in the sub-channel transmission of NOMA algorithm (table). The sub-channels are orthogonalities which do not interfere with each other [5]. The resources which according to discrete Fourier transform orthogonal multiplexing on a sub-channel can be shared by multiple users. The transmission is non-orthogonally on the same sub-channel between different devices. At this point, the signal of devices will have interference between each other [6]. The receiver has to use successive interference canceller technology for multi-user detection purposes due to this reason. At the transmitter, different devices on the same sub-channel use power multiplexing algorithm in transmission. The power resource of a signal is allocated according to NOMA algorithm for different devices [7]. Therefore, the signal power of each device is different at the receiver. The successive interference canceller receiver performs interference elimination based on signal power algorithm (power size in a certain order) to achieve the purpose of different devices [8].

2.1. NOMA algorithm based serial interference cancellation system. The serial interference cancellation (SIC) receiver has a great improvement in performance compared with the conventional detectors. The modified structure of SIC system is easy to achieve. The basic principle of serial interference cancellation is to gradually subtract the maximum signal power from the user interference in the receiving terminal. The received signal will be uniquely recovered from SIC detector. The multiple access interference caused by the user signal is subtracted when a user signal is determined. This keeps circulating until all the multiple access interference is eliminated as shown in fig. 2. The out of band noise is eliminated maximally when a mixed signal $y(t)$ passing through the band pass filter. Then this mixed signal enter into the verdict. The order of single judgment operation according to its power value (high power signal sequence first, because of the highest power is easiest to capture). The output value of each time cycle is the signal decision of the maximum power user and subtract the multiple access interference caused by this user. In this way, multiple access interference can be reduced to a minimum (the weaker the signal is, the greater the benefit will be) and the reliability of detection will be greatly increased. The multi time cycle structure takes the output signal of the previous cycle as the input signal of the next cycle to repeat the operation in detection, amplitude estimation, detection. T_b is a timer which strictly controls the system clock synchronization of each cycle detection signal.

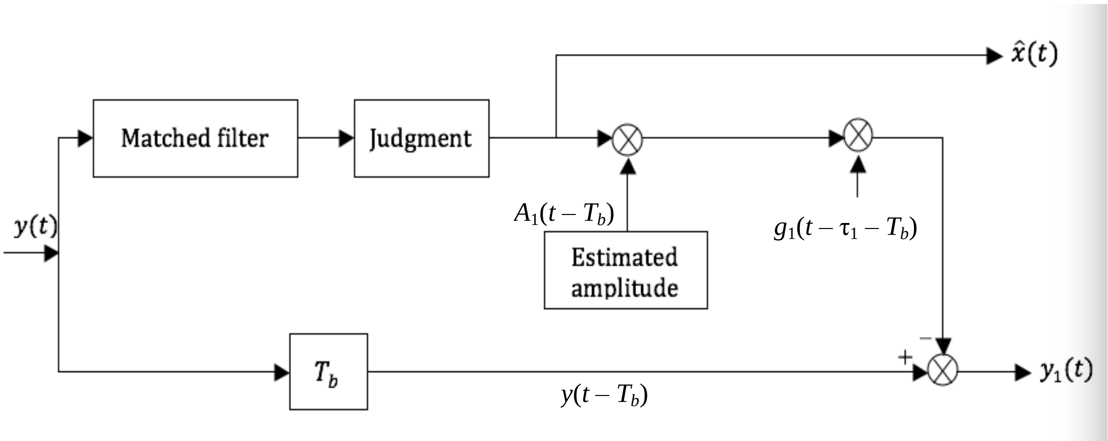


Fig. 2. The structure of SIC detector

NOMA is a multiplexing scheme that utilizes an additional new domain, i.e., the power domain, which is not sufficiently utilized in previous systems. The NOMA in power domain is different from power control in 4G wireless system [8]. Different transmit power is allocated to different transmitter device according to the base station NOMA algorithm on one side; on the other side the SIC receiver could distinguish signals from devices in different power [8].

2.2. Performance analysis of NOMA algorithm model system. In order to analyze the performance of the NOMA system, we take a downlink as an example. There has a simplified model for the NOMA downlink as fig. 3. The transmitter and the receiver adopt a mode which in single illuminator – multiple receiver [9, 10].

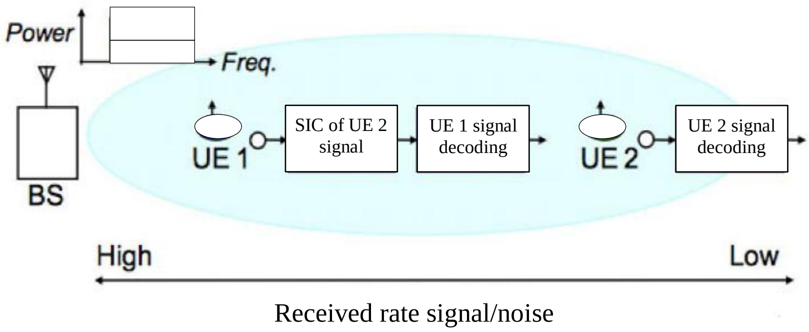


Fig. 3. Simplified model for the NOMA downlink

The signal is UE I (I = 1, 2), the channel bandwidth is 1 Hz, and the device signal is $E[|X_i|^2]$=1in this model. The signal after encoding in superposition is: $X = \sqrt{P_1}X_1 + \sqrt{P_2}X_2$. Among them, P_i is the power of the UE I (I = 1, 2), the total power of signal from devices as in (1)

$$\sum_{i=1}^{2} P_i = P. \quad (1)$$

In this fig. 4 the UE with high channel gain (UE 1) is allocated less power and the UE with low channel gain (UE 2) is allocated more power ($P_1 < P_2$). Such large power difference facilitates the successful decoding (with high probability) and thus the successful cancellation of the signal designated to UE 2 (being allocated high power) at UE 1 receiver.

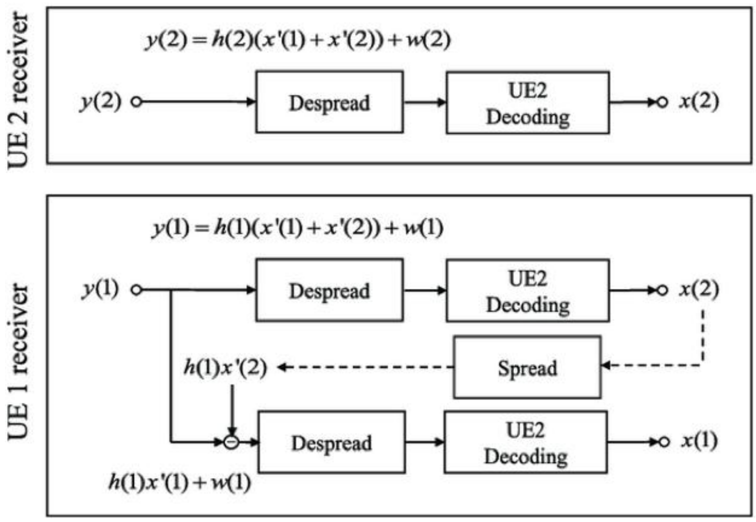


Fig. 4. The process of signal detection by user UE I

The example on a sub-channel shared by 2 users which as mentioned above, the superimposed signal is could be expressed as

$$x = x(1) + x(2). \quad (2)$$

Among the formula (2), $x(i)$, i =1, 2 represents the signals which from 2 users respectively. In addition, at UE 2 receiver, the signal designated to UE 2 is decoded directly by treating the interference from the signal designated to UE 1 (being allocated low power) as noise. As formula (3)

$$y_i = h_i X + w_i \quad (3)$$

$y(i)$ is the input mixed signal, where $h(i)$ is the complex channel coefficient between user terminal (UE-i) and the base station (BS). Term $w(i)$ denotes additive white Gaussian noise (AWGN) including inter-cell interference. The power spectral density of $w(i)$ is $N_{0,\,i}$. In downlink NOMA, the SIC process is implemented at the UE receiver. The optimal order for decoding is in the order of decreasing channel gain normalized by noise and inter-cell interference power, $|h_i|2/N_{0,\,i}$ (called simply channel gain in the remaining). Based on this order, we assume that any user can correctly decode the signals of other users whose decoding order comes before the corresponding user. Thus, *UE-i* can remove the inter-user interference from the j-th user whose $|h_j|2/N_{0,\,j}$ is lower than $|h_i|2/N_{0,\,i}$. In this 2-UE case, assuming that $|h_1|2/N_{0,\,1} > |h_2|2/N_{0,\,2}$, UE 2 does not perform interference cancellation since it comes first in the decoding order. UE 1 first decodes x_2 and subtracts its component from received signal y_1, and then next, it decodes x_1 without interference from x_1. Assuming successful decoding and no error propagation, the throughput of UE-i, R_i, is represented as formula (4)

$$R_1 = log_2^{(1+\frac{P_1|h_i|^2}{N_{0,1}})},\ R_2 = log_2^{(1+\frac{P_2|h_2|^2}{N_{0,2}+P_1|h_i|^2})}. \tag{4}$$

It can be seen that by adjusting the power allocation ratio, P_1/P_2, the base station can flexibly control the throughput of each UE. Clearly, the overall cell throughput, cell-edge throughput, and user fairness are closely related to the power allocation scheme adopted.

2.3. Serial interference cancellation channel capacity analysis for uplink. An additive white Gaussian noise channel model as an example to analyze in this section. The uplink access model of two users is represented as formula (5):

$$y = x_1 + x_2 + n, \tag{5}$$

where n is Gaussian white noise, user power is p_i. According to the AWGN channel capacity theory which propose by Shannon could infer that the information transmission rate R_1, R_2 (two different terminal devices) satisfying the following conditions as:

$$\begin{cases} R_1 < \ log^{\left(1+\frac{P_1}{N_0}\right)}; \\ R_2 < \ log^{\left(1+\frac{P_2}{N_0}\right)}; \\ R_1 + R_2 < \ log^{\left(1+\frac{P_1+P_2}{N_0}\right)}, \end{cases} \tag{6}$$

$R_1 < \ log^{(1+\frac{P_1}{N_0})}$ and $R_2 < \ log^{(1+\frac{P_2}{N_0})}$ in formula (6) indicate that the signal transmission rate of 2 users can not exceed point to point channel capacity by power p_i respectively. $R_1 + R_2 < \ log^{(1+\frac{P_1+P_2}{N_0})}$ in formula indicate that the total channel capacity of the system can not exceed the capacity of the point to point transmitted by power $P_1 + P_2$. When user 1 reaches the maximum channel transmission rate, the user 2 can be expressed as:

$$R_2 = (R_1 + R_2) - R_1 = log^{(1+\frac{P_1+P_2}{N_0})} - log^{(1+\frac{P_1}{N_0})} = log^{\left(1+\frac{P_2}{P_1+N_0}\right)}. \tag{7}$$

The formula (7) can be expressed in a mathematical coordinate axis as follow.

The signal from user 2 is first detected at the receiving terminal in practical applications (one of them includes the multiple access interference and noise from the user 1). The channel capacity of user 2 is $log^{(1+\frac{P_2}{P_1+N_0})}$ as shown in fig. 5. In this moment, the value of user 2 is need to subtract from the received signal after the successful decoding.

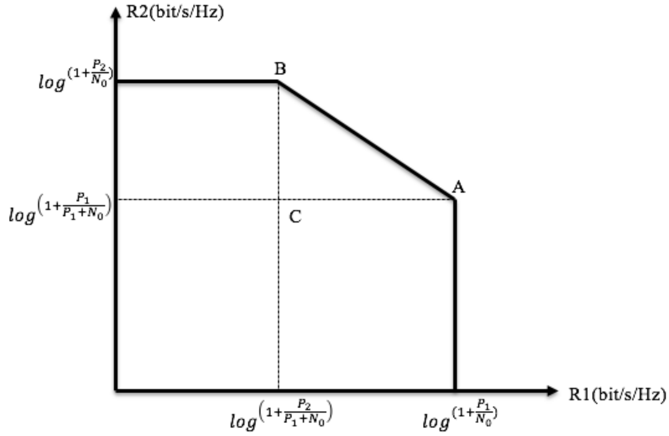


Fig. 5. Analysis of the capacity in a AWGN uplink channel from two users

Then the user 1 is detected at the receiving terminal. At this time, in virtue of the detected only contain signal (user 1) and noise, thus the maximum reachable rate of user 1 is $log^{(1+\frac{P_1}{N_0})}$ (the channel capacity characteristics at A points). It is equally proved that at any point on line segment AB satisfies the maximum wireless channel capacity. At this time, the fairness of the user channel must be considered when the value of power is much difference between user 1 and user 2 at present (we suppose that the signal power of the user 2 is much greater than the power of user 1). The point A is more likely to be fair in fig. 6. Therefore, the A point is the best serial interference cancellation channel capacity for uplink [11].

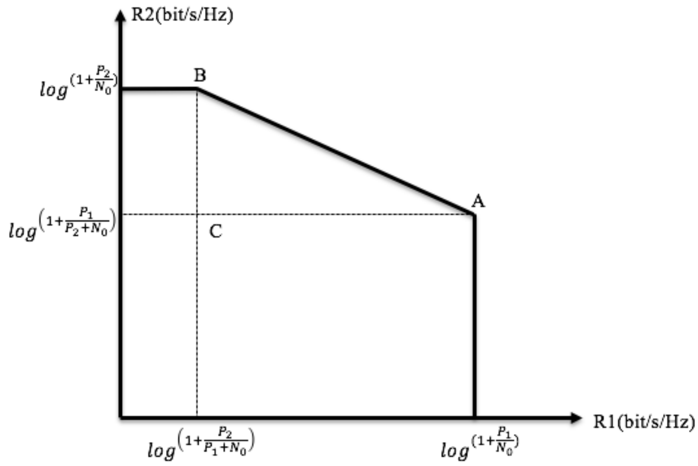


Fig. 6. Analysis of channel capacity in difference power from two users

2.4. Proposed multiuser scheduling scheme. In this section, the proportional fairness (PF) based multiuser scheduling scheme proposed for NOMA uplink is described. First, we present the PF scheduling metric of a set of NOMA multiplexed users [12]. Then, we introduce the sub-band assignment method for NOMA users with the constraint of contiguous resource allocation. In NOMA with a SIC [13], more than one user can be simultaneously scheduled using the same sub-band. The scheduling candidates' S should contain all the sets of users in a cell. In order to reduce the computation of scheduling, all the possible combinations of users in a cell are firstly exhaustively searched at the beginning of scheduling [13]. In this procedure, users within a cell are multiplexed as user set S, $1-|S|-N_{max}$. Each set S includes one or more users but no more than N_{max} users. Therefore, in a cell with K users in total, the number of scheduling user candidate sets, N_{us} as in formula (8). All the users are uniformly distributed in the cells and the number of user per cell is assumed to K

$$N_{us} = \binom{K}{1} + \binom{K}{2} + \cdots + \binom{K}{N_{max}}. \quad (8)$$

The system performance, such as average user throughput and cell edge user throughput, is greatly associated with the scheduling policy [12]. The PF scheduler has been proved as an effective method to achieve good tradeoff between capacity and fairness by maximizing the PF metric as scheduling objective function [14]. The average user throughput at time instance t +1 of user i is expressed as in formula (9)

$$T_i(t+1) = \left(1 - \frac{1}{t_c}\right) \times T_i(t) + \frac{1}{t_c} \sum_b R_b(i,t), \quad (9)$$

where t_c is the time index representing a sub-frame index, t_c is the length of time window for throughput averaging, $R_b(i_b(l)|s_b)$ is the throughput of user $i_b(l)$, s_b is a neighbor sub-band, t is at time when data comes in a sub-band user, $i_b(l)$ is the channel gain user, i_b could be defined as $g_b(i_b(l))$, including the large scale channel gain, distance-dependent loss and shadowing loss [14]. According to the Shannon first law known W is the bandwidth, $R_b(i_b(l)|s_b)$ is the wireless channel capacity in NOMA, $h_b(i_b(l))$ is the N_r-dimensional channel coefficient vector of the link between user $i_b(l)$ and the serving base station at sub-band b, which consists of path-loss, shadow fading, and small scale fading coefficients, $p_b(i_b(j))$ denotes the transmission power of user $i_b(l)$ at sub-band b, $n_b(i_b(l))$ is the noisy at sub-band b. In a scheduled user set S_b at sub-band b is expressed as in formula (10)

$$R_b(i_b(l)|s_b) = W log_2\left(1 + \frac{\| h_b(i_b(l))\|^2 p_b(i_b(l))}{\sum_{j\in S_b, g_b(j_b(l) > g_b(j))} |h_b^H(i_b(l)) * h_b(i_b(l))|^2 p_b(i_b(j)) + n_b(i_b(l))}\right). \quad (10)$$

At a sub-band b, the scheduler calculates the scheduling metric of each user set to be scheduled as in formula (11)

$$f_b(S_b) = \prod_{i\in S_b}\left(1 + \frac{R_b(i|S_b)}{(t_c - 1)(T_i(t))}\right), \quad (11)$$

where $f_b(S_b)$ is the product of the average user throughput among users in a user set S_b. The scheduler selects the user set maximizing the scheduling metric of each sub band [15].

According to these formulas could illustrate the cumulative distribution function probability curves [16] of the user throughput with maximum number of multiplexed user ranging from 1 to 3 as shown in fig. 7, SIC as N_{max} > 1 in the NOMA.

Using the proposed PF-based scheduling scheme can achieve better throughput compared to OFDMA for the most region of the cumulative distribution function curve. Because of the user throughput in OFDMA is limited by the orthogonal bandwidth allocation, which results in reduction of the bandwidth for the respective users. On the contrary, NOMA with a SIC can allow all users to utilize the overall bandwidth, irrespective of the channel conditions. However, in the cell-edge throughput region, NOMA achieves worst performance, due to the increased inter-cell interference. Furthermore, the degradation of the cell-edge performance becomes severe as the maximum number of multiplexed users N_{max} = 3. The result is the total transmission power per-cell in the NOMA with a SIC is larger than that of OFDMA.

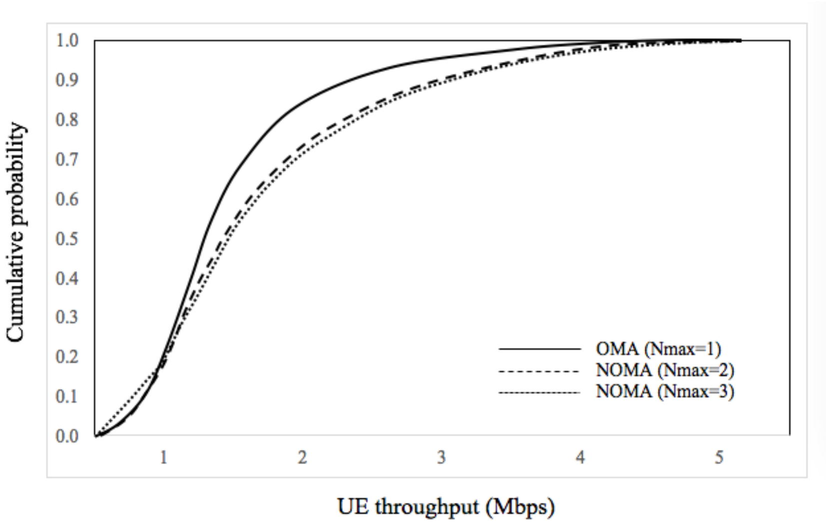


Fig. 7. Cumulative distribution function of user throughput of non-orthogonal access with different maximum number of non-orthogonal multiplexed users

Conclusion. The specific technical standard of 5G has not been formulated yet at present, spectrum efficiency is a key developing direction for wireless communication system from the research results which released by major international organizations. Further advantages of NOMA are the very efficient spectrum usage and, with digital signal processing being cost-effective and flexible, also low-complexity application of the Massive MIMO principle [17]. From this point of view, the NOMA algorithm can satisfy both the demand rate and the spectral efficiency of mobile services.

References

1. 3GPP TS36.300. *Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN)*. Avaliable at: https://www.etsi.org/deliver/etsi_ts/136300_136399/136300/09.04.00_60/ts_136300v090400p.pdf (accessed 13.05.2018).

2. 3GPP TR36.913. *3GPP; TSG RAN; Requirements for further advancements for E-UTRA (LTE-Advanced)*. Avaliable at: https://www.etsi.org/deliver/etsi_tr/136900_136999/136913/09.00.00_60/tr_136913v090000p.pdf (accessed 14.05.2018).

3. 3GPP TR36.814. *Further advancements for E-UTRA physical layer aspects*. Avaliable at: http://www.qtc.jp/3GPP/Specs/36814-900.pdf (accessed 03.06.2018).

4. Eisuke F., Akishige N., Mamoru H. OFDM Wireless Transmission Technique for System Beyond IMT2000. Avaliable at: https://www.fujitsu.com/downloads/MAG/vol38-2/paper15.pdf (accessed 05.06.2018).

5. Yuan Q. LTE easily to progress. *Publishing House of Electronics Industry*. Beijing, China, 2014, vol. 1, pp. 21–71.

6. Tong X. J., Luo T. Principles and applications of OFDM mobile communication. *Post and Telecommunication Press.* Beijing, 2009, vol. 1, pp. 56–81.

7. Beena R. B., Ankit C., Neha S. Orthogonal frequency division multiplexing and its applications. *International Journal of Science and Research*, 2013, vol. 2, pp. 325–328.

8. Takeda T., Higuchi K. Enhanced user fairness using nonorthogonal access with SIC in cellular uplink. *Vehicular Technology Conference (VTC fall)*. San Francisco, 2011, vol. 20, pp. 1–5.

9. Benjebbour A., Anxin Li, Saito Y. Y., Kishiyama Y., Harada A., Nakamura T. System-level performance of downlink NOMA for future LTE enhancements. *Globecom 2013 Workshop-Emerging Technologies for LTE-Advanced and Beyond-4G*. Atlanta, 2014, vol. 1, pp. 136–195.

10. Saito Y., Kishiyama Y., Benjebbour A., Nakamura T., Li A., Higuchi K. Non-orthogonal multiple access (NOMA) for future radio access. *IEEE 77th Vehicular Technology Conference.* Dresden, 2013, pp. 205–221.

11. Otao N., Kishiyama Y., Higuchi K. Performance of non-orthogonal access with SIC in cellular downlink using proportional fair-based resource allocation. *International Symposium on Wireless Communication Systems (ISWCS 2012)*. Paris, 2012, pp. 476–480.

12. Higuchi K., Kishiyama Y. Non-orthogonal access with successive interference cancellation for future radio access. *The IEEE VTS Asia Pacific Wireless Communications Symposium*. Kyoto, 2012, pp. 211–246.

13. Umehara J., Kishiyama Y., Higuchi K. Enhancing user fairness in non-orthogonal access with successive interference cancellation for cellular downlink. *International Conference on Computational Science*. New Orleans, 2012, pp. 343–367.

14. Takeda T., Higuchi K. Enhanced user fairness using non-orthogonal access with SIC in cellular uplink. *IEEE 74th Vehicular Technology Conference.* San Francisco, 2011, vol. 5, pp. 68–82.

15. Endo Y., Kishiyama Y., Higuchi K. Uplink non-orthogonal access with MMSE-SIC in the presence of inter-cell interference. *11th International Semantic Web Conference.* Boston, 2012, pp. 261–265.

16. Jason L., Szymon R., Ravi R., Princeton U. Adaptive numerical cumulative distribution funcations for efficient importance sampling. *Eurographics Symposium on Rendering*. Konstanz, Germany, 2005, pp. 11–20.

17. Ping P., Petrenko Y. N. The physical layer technologies in 5g mobile communication system. *International Conference on Physics, Computing and Mathematical Modeling (PCMM).* Shanghai, China, 2018, pp. 111–117.

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