www.czasopisma.pan.pl PAN www.journals.pan.pl

jet INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2018, VOL. 64, NO. 4, PP. 481-485
Manuscript received February 28, 2018; revised October, 2018. DOI: 10.24425/123549

Uplink NOMA Scheme for Wi-Fi Applications

Hind Salim Ghazi and Krzysztof Wesołowski

***Abstract*—Non-Orthogonal Multiple Access (NOMA) with Successive Interference Cancellation (SIC) is one of the promising techniques proposed for 5G systems. It allows multiple users with different channel coefficients to share the same (time/frequency) resources by allocating several levels of (power/code) to them. In this article, a design of a cooperative scheme for the uplink NOMA Wi-Fi transmission (according to IEEE 802.11 standards) is investigated. Various channel models are exploited to examine the system throughput. Convolutional coding in conformance to IEEE 802.11a/g is applied to evaluate the system performance. The simulation results have been addressed to give a clear picture of the performance of the investigated system.**

***Keywords*—5G, Non-Orthogonal Multiple Access (NOMA), Successive Interference Cancellation (SIC)**

I. Introduction

NOWADAYS, multicarrier techniques are mainly used in broadband wireless communications, because of their adaptability in resource allocation, in addition to advantages resulting from multiuser diversity [1]. Cellular networks widely use Orthogonal Multiple Access (OMA) techniques such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Orthogonal FDMA (OFDMA) for serving multiple users within the network [2]. Due to the growing demand for mobile access to the Internet and the Internet of Things (IoT), the requirements for 5G wireless communications systems established a challenge, such as high spectral efficiency, massive connectivity, and user fairness [3]. Non-orthogonal multiple access (NOMA) has emerged as one of the promising techniques to meet these requirements when compared to conventional orthogonal multiple access (OMA) [4].

The NOMA transmission approach allows multiple users to transmit or receive information upon the same channel resources (e.g., time/frequency) by being allocated either in the code domain (CDM) or in the power domain (PDM). There are two categories of CDM-NOMA, namely, low-density spreading (LDS) and sparse code multiple access (SCMA) [5], [6]. Persistently in PDM-NOMA, more power is assigned to the users that have poor channel conditions [7].

At the transmitting side, the superposition coding (SC) principle is applied to superpose the information signals coming from different users with proper transmission power levels, while the composite multiuser signal is separated at the receiving side by using the concept of Successive Interference Cancellation (SIC) [5], [8].

To achieve user fairness, NOMA nominates a user terminal with good channel conditions and combines it with another one which experiences poor channel conditions [9].

Moreover, the power allocation scheme that is employed for NOMA users has an impact on the system throughput, including the throughput of cell-edge users. Several algorithms have been studied for allocating the power among the users within the same sub-band, for instance, the Full Search Power Allocation algorithm (FSPA), Iterative Water Power Allocation algorithm (IWPA), Fractional Transmit Power Allocation algorithm (FTPA), and finally Fixed Power Allocation algorithm (FPA) [10], [11].

Internet of Things (IoT) has become a very interesting technology especially for the industrial and marketing sectors. It represents the proposed expansion of the Internet in the future by achieving a massive jump in the capability of collecting, analyzing and spreading data which can be converted into information, knowledge, etc. [12].

In order to connect things to each other or to the cloud, there are several standards and proper devices can be used for this purpose, such as Wi-Fi, Bluetooth, ZigBee, Active RFID, etc. Because of the Wi-Fi features (energy consumption and secure network), it is considered the most suitable choice to provide the Internet connection everywhere in the world [13].

This article presents a novel approach in wireless communication systems by employing the principle of Wi-Fi standards with NOMA. The rest of this paper is organized as follows: Section II presents the system design of the Wi-Fi LAN standard based on the NOMA technique using different channel models. Sections III and IV formulate the simulation results and conclusions, respectively.

II. System Model

A. *IEEE 802.11a Wi-Fi Standard*

Currently, wireline digital networks are strongly supported by wireless access due to the enormous increase in using mobile communication devices like smartphones, laptops with wireless communication capabilities, etc., at homes, in offices, and in public areas. Wireless LAN technologies proved their capabilities of providing unlimited access for users who were formerly served by wireline networks [14].

In the early 1990s, the IEEE 802.11 standard was released by the Institute of Electrical and Electronic Engineers (IEEE) for Local and Metropolitan Area Networks as an enhancement for wireless LAN standards. The IEEE 802.11 standard is a set of various standards (e.g., IEEE802.11a, b, g, n, and ac) operating at different frequencies and ranging allotments [15].

Let us concentrate our attention on IEEE 802.11a. Transmission in conformance to this standard is less liable to

This work was supported by the project 08/81/DSMK/8125 at the Faculty of Electronics and Telecommunications, Poznan University of Technology, Poznan, Poland.

Hind Salim Ghazi is a doctoral student in the Chair of Wireless Communications, Poznan University of Technology, Poland (e-mail: hind.ghazi@doctorate.put.poznan.pl).

Krzysztof Wesolowski is a Professor in the Chair of Wireless Communications, Poznan University of Technology, Poland (e-mail: krzysztof.wesolowski@put.poznan.pl).

interference than IEEE 802.11g due to the high operating frequency (5 GHz), and it is more convenient for indoor deployment. This standard uses Orthogonal Frequency Division Multiplexing (OFDM) as a modulation technique and utilizes the single input/single output (SISO) antenna technology [16].

Table I shows the specification of the IEEE 802.11a standard that has been chosen in our experiments.

TABLE I
SPECIFICATION OF THE IEEE 802.11A STANDARD

Parameter	Value
Bandwidth	20 MHz
Cyclic prefix duration	0.8 µsec
Data duration	3.2 µsec
FFT size	64
No.of subcarriers	52
Operating frequency	5 GHz
Sampling rate	40 MHz
Subcarrier spacing	312.5 KHz
Throughput	6 up 54 Mbps
Total symbol duration	4.0 µsec

B. Uplink NOMA Principle

In this part, an uplink scenario with indoor environment is assumed. The signal s_j ($j = 1, 2$) is transmitted by the user equipment UE_j to the access point with the allocated transmit power p_j. Its value depends on the channel conditions and the distance between the user and the access point. Without loss of generality we assume that $p_1 > p_2$ according to Fractional Transmit Power Allocation algorithm ($FTPA$) [10].

Suppose that two NOMA users simultaneously send their signals s_1 and s_2 to the access point with allocated powers equal to p_1, and p_2, respectively. These two signals share the same frequency and interfere with each other as shown in Fig. 1.

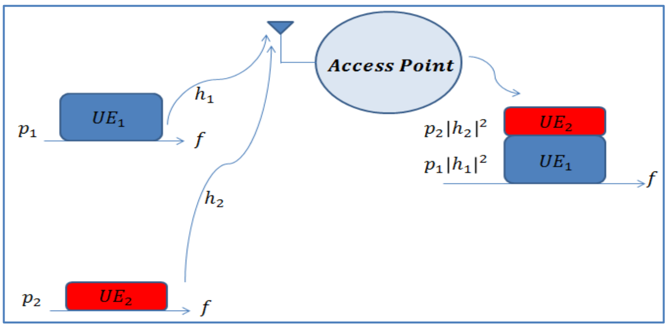

Fig. 1 Uplink NOMA scheme

The received signal at the access point can be represented by the following formula:

$$x = \sqrt{p_1}h_1 s_1 + \sqrt{p_2}h_2 s_2 + noise \qquad (1)$$

where h_j represents the complex channel gain coefficient vector between UE_j and the access point, while the term *noise* is referred to as an Additive White Gaussian Noise (AWGN) that is generated at the receiving side.

Successive Interference Cancellation (SIC) is implemented at the receiving side, in which the access point is trying to recover both signals s_1 and s_2, respectively, in two steps.

In general, the SIC receiver decodes s_1 and treats s_2 as noise. After s_1 being recovered, it is subtracted from the whole received signal x to decode the component s_2. A more precise description of this rule applied in the analysed system will be presented below.

C. Proposed System

In this article, an OFDM-based uplink NOMA system is considered. It consists of two users co-operating with one access point. User selection depends on the Channel State Sorting-Pairing Algorithm (CSS-PA). One of them is a strong user (closer to the access point) and has good channel conditions, while the other one is considered a weak user with poor channel conditions. We assume that the multi-symbol stream (that is transmitted by both users) is synchronous and mutually independent. Synchronization has to be achieved with the accuracy of a fraction of the OFDM cyclic prefix, so that the receiver can find the orthogonality period common for both users.

At the transmitting side, the data of each user before being transmitted are first encoded using the convolutional code with coding rate (R = 1/2). The standard (133,171) code is applied.

Different modulation schemes are supported depending on the channel propagation path in the channel of each user. Hence, 16-QAM or QPSK is suggested to be used for the strong user, while the weak one uses QPSK due to poor channel conditions. Other modulation arrangements are also possible.

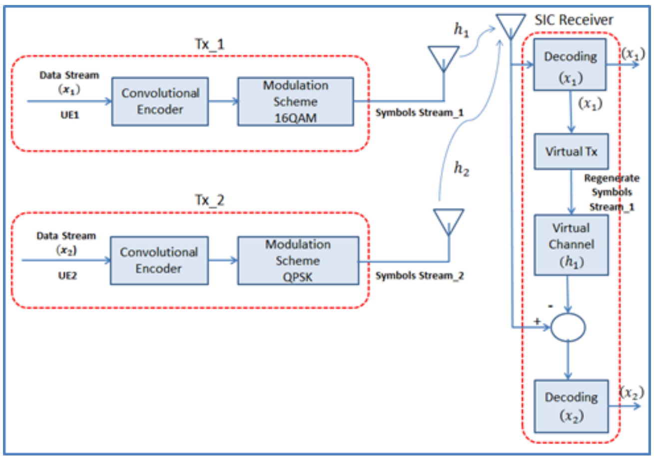

Fig. 2 Design of the proposed system

Rayleigh fading channels whose complex channel gain coefficient vectors are indicated as $\mathbf{h}_1, \mathbf{h}_2$ represent the channel models between UE1 and the access point and UE2 and the access point, respectively. Thereafter, the access point receives a combined version of the signals that have been transmitted by both users.

SIC is implemented at the receiving side with two stages; at first, the data of the strong user (x_1) are decoded, whereas the weak user's data (x_2) are treated as noise. These data constitute the input stream to the local virtual transmitter which, knowing the channel gain coefficient of the strong user, resynthesizes his signal approaching the receiver. Such sample stream is subsequently subtracted from the samples of the received joint signal in order to decode the data symbols of the weak user (x_2). The investigated system is demonstrated in Fig. 2.

Let us note that, in contrast to cellular systems, in IEEE 802.11 WiFi the users have access to the transmission medium based on contention according to the CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) rule. Thus, only a single user is able to transmit his data in a given time and frequency channel, otherwise, collision between different users occurs. In order to enable NOMA in WiFi and potentially increase its spectral efficiency considerably, the radio resource management rule has to be substantially changed. An access point managing uplink and downlink transmissions should arrange appropriate users in pairs after learning from them their wish to transmit data in packets of similar lengths and knowing their propagation path losses. Thus, the NOMA transmission in a WiFi cell shown in this paper can be treated as a proposal that checks the potential of a possible increase in WiFi network capacity due to this technology. A new MAC procedure enabling NOMA has to be worked out.

III. Simulation Results

In this section, some simulation results are presented to show the performance of the analysed system. BER vs. SNR measurements are considered for that purpose. Certainly, the propagation path loss of the strong user is assumed to be greater than the propagation path loss of the weak user ($g_1 > g_2$).

$$g_j = \sqrt{\frac{p_x}{p_j}} \qquad for\ j = 1,2 \tag{2}$$

where p_x represents the received power at access point.

The simulation results are shown for two scenarios determined by the channel models which have been employed, i.e., AWGN and Rayleigh channels.

A. AWGN Channel

We assume the channel models between the users and the receiving side are AWGN channels. The propagation path losses are assumed to be $g_1 = 1.0, g_2 = 0.3$, respectively.

In our experiments we assumed the number of packets that are transmitted from each user to be $K = 100$, while the number of OFDM symbols that are sent in every packet is $L = 300$. Figs. 3 and 4 respectively illustrate BER vs. SNR for the strong and weak user after the decoding process.

We modelled our system in two versions with respect to convolutional code decoding: one which employs the hard decision (HD) Viterbi decoder and a second one in which soft decision (SD) 8-level decoder input is applied. For that purpose we evaluated log-likelihood ratios for each transmitted bit in a signal constellation and then we quantized them into 8 levels. As we can expect, soft decision decoding (SD) achieved better performance than hard decision decoding (HD). The difference in coding gain is about 2 dB at BER level of 10^{-2}. Therefore, soft decision decoding is adopted in all other investigations.

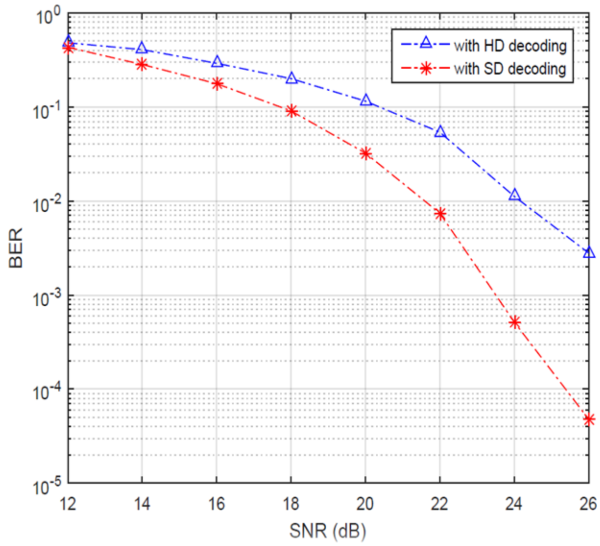

Fig. 3 BER vs. SNR Curve for the strong user ($g_1 = 1.0, g_2 = 0.3$)

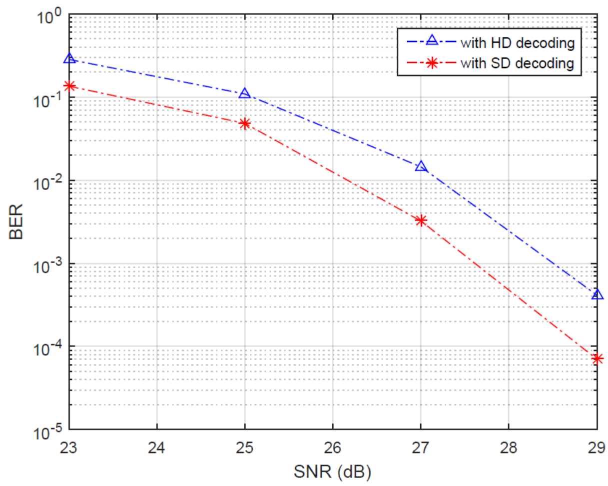

Fig. 4 BER vs. SNR Curve for the weak user ($g_1 = 1.0, g_2 = 0.3$)

B. Rayleigh Multipath Fading Channel.

We also used a multipath Rayleigh fading channel as a channel model between users and the receiving side, with different channel gain coefficient vectors which can be represented by $\boldsymbol{h}_1, \boldsymbol{h}_2$ respectively. Elements of the channel gain vectors represent subsequent channel path gains in conformance to a typical multipath channel used in WiFi investigations [17]. The channel model applied in our simulations had an exponentially decreasing power delay profile with an appropriately selected rms delay spread. For each transmitted packet block, new multipath channel gain coefficient vectors were drawn.

In the simulation experiments K=100 packets were transmitted by each user, whereas each packet consisted of L=100 OFDM symbols.

Fig. 5 shows BER vs. SNR measurement for the strong user by setting the propagation path loss $g_1 = 1.0$ versus different values of g_2, the rms delay spread used in this simulation was ($T_{rms} = 50\, nsec$).

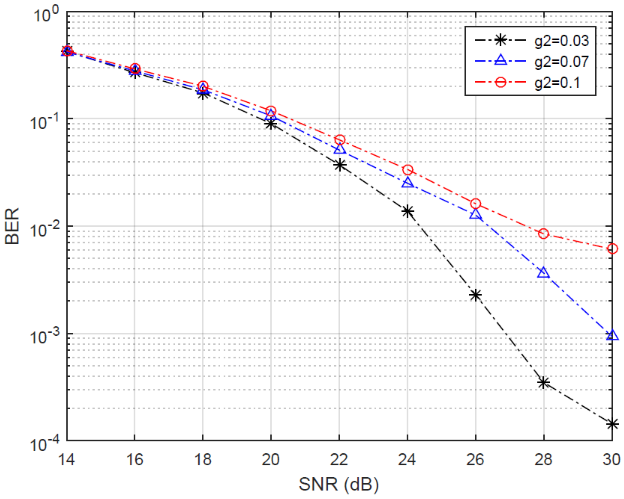

Fig. 5 BER vs. SNR curve for the strong user ($g_1 = 1.0$) with several values of the weak channel gain g_2

It can be easily observed that there is an enhancement in the performance (nearly 2 dB gain at BER level of 10^{-2}) with a lower value of propagation path loss (g_2) as the signal of the weak user looks more like noise in the strong user's receiver.

In Fig. 6, another comparison of BER vs. SNR for the strong user is studied by defining the propagation path losses of the users as $g_1 = 1.0, g_2 = 0.03$ and simulating the system with different values of the rms delay spread. The rms delay spread is considered an important parameter in calculating the channel gain coefficient vector per each user.

Fig. 7 presents a similar comparison as in Fig. 6. Here, the measurement of BER vs. SNR is assessed for the weak user by adjusting the propagation path losses as $g_1 = 1.0, g_2 = 0.1$ and simulating the system by using various rms delay spread values.

From Figs. 6 and 7 we can conclude that the relationship between the system performance and rms delay spread value is more or less inversely proportional. We can get a better performance when a low rms delay spread value is chosen due to its influence on the channel gain coefficient vector which in turn decreases the effect of multipath fading.

Our MATLAB simulation model contained many procedures performed in real WiFi transmitters and receivers typically operating in a single link between a user and an access point. Most of them were described and illustrated in [17]. One of them is the detection of the start of a packet in a receiver. Typically, a certain minimum change in the signal level has to appear at the receiver input to be interpreted as a start of a signal different from

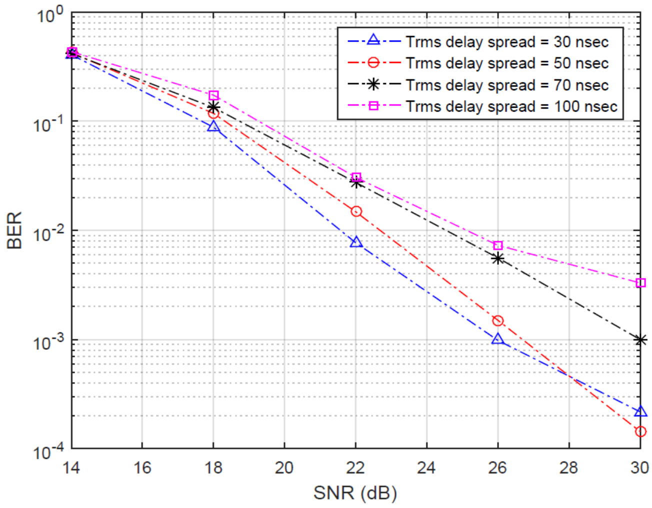

Fig. 6 BER vs. SNR curve for the strong user ($g_1 = 1.0, g_2 = 0.03$) with different values of rms delay spread

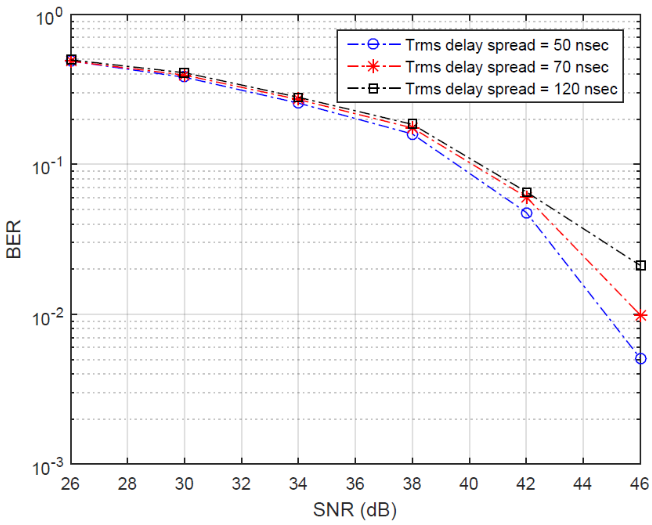

Fig. 7 BER vs. SNR Curve for the weak user ($g_1 = 1.0, g_2 = 0.1$) with several values of rms delay spread

noise. In fact, the increase in SNR is detected. In the case of two such signals being the mixture of a strong and a weak one, if their levels differ too much, the receiver of the weak signal working individually can have a problem with recognizing the packet start if SNR is low for it. During investigations of our NOMA system we have found that the receiver parameter, often called a comparison ratio, which plays the role of the detection threshold, substantially influences the system performance. When the value of this parameter is low, we can detect the received packet with a low power level (low SNR value), however, when the threshold is set sufficiently high, the receiver of a weak signal has a problem with detecting the beginning of the start of a packet. Fortunately, as both receivers for strong and weak signals are physically located at the same place, it is sufficient to use the sufficiently high threshold of the strong signal to start the reasonable operation of both receivers. Certainly, the synchronization of both signals has to be ensured first.

IV. Conclusions

In this paper, uplink NOMA transmission scheme has been suggested for WiFi aiming to examine NOMA performance in such systems in order to achieve better QoS and hence throughput increase. User selection has to be made, e.g., by using the Channel State Sorting-Pairing Algorithm (CSS-PA), whereas the allocation of transmission power to the users can be based on the Fractional Transmit Power Allocation algorithm (FTPA). Nevertheless, another multiple access method different from the current one has to be applied which allows joint operation of two appropriately selected users at the same time on the same frequency channel. In our simulations, different channel models were employed to give a clear perception of the system performance.

References

[1] S. Yan, D. W. Kwan Ng, Z. Ding, and R. Schober. "Optimal joint power and subcarrier allocation for MC-NOMA systems." In Global Communications Conference (GLOBECOM), 2016 IEEE, pp. 1-6. IEEE, 2016.

[2] P. Parida, and S. S. Das. "Power allocation in OFDM based NOMA systems: A DC programming approach." In Globecom Workshops (GC Workshops), 2014, pp. 1026-1031. IEEE, 2014.

[3] L. Dai, B. Wang, Y. Yuan, S. Han, I. C.-Lin, and Z. Wang. "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends." IEEE Communications Magazine, Vol. 53, No. 9, 2015.

[4] Z. Wei, D.W. Kwan Ng, and J. Yuan. "Power-efficient resource allocation for MC-NOMA with statistical channel state information." In Global Communications Conference (GLOBECOM), 2016 IEEE, pp. 1-7. IEEE, 2016.

[5] C.-L. Wang, J.-Y. Chen and Y.-J. Chen. "Power Allocation for a Downlink Non-Orthogonal Multiple Access System." IEEE Wireless Communications Letters 5, No. 5, 2016, pp. 532-535.

[6] Z. Wei, J. Yuan, D. W. Kwan Ng, M. Elkashlan, and Z. Ding. "A survey of downlink non-orthogonal multiple access for 5G wireless communication networks." arXiv preprint arXiv, pp. 1609-01856, 2016.

[7] P. Xu, Y. Yuan, Z. Ding, X. Dai, and R. Schober. "On the outage performance of non-orthogonal multiple access with 1-bit feedback." IEEE Transactions on Wireless Communications 15, No. 10, 2016: 6716-6730.

[8] R. Sun, Y. Wang, X. Wang, and Y. Zhang. "Transceiver design for cooperative non-orthogonal multiple access systems with wireless energy transfer." IET Communications 10, No. 15, 2016: 1947-1955.

[9] Z. Ding, Y. Liu, J. Choi, Q. Sun, M. Elkashlan, I. C.-Lin, and H. V. Poor. "Application of non-orthogonal multiple access in LTE and 5G networks." IEEE Communications Magazine 55, No. 2, 2017: 185-191.

[10] H. Zhang, D.-K. Zhang, W.-X. Meng, and C. Li. "User pairing algorithm with SIC in non-orthogonal multiple access system." In: 2016 IEEE International Conference on Communications (ICC), 1-6. IEEE, 2016.

[11] L. Yao, J. Mei, H. Long, L. Zhao, and K. Zheng. "A novel multi-user grouping scheme for downlink non-orthogonal multiple access systems", In: 2016 IEEE Wireless Communications and Networking Conference (WCNC), 1-6. IEEE, 2016.

[12] T. Kramp, R van Kranenburg, and S. Lange." Introduction to the Internet of Things". In: A. Bassi et al. (eds) Enabling Things to Talk. Springer, Berlin, Heidelberg, 2013.

[13] https://www.networkworld.com/article/2917793/internet-of-things/is-wi-fi-going-to-be-the-technology-of-choice-for-iot.html

[14] S. Banerji, and R. S. Chowdhury. "On IEEE 802.11: Wireless LAN Technology." arXiv preprint , 2013:1307-2661.

[15] J. Berg. "The IEEE 802.11 standardization its history, specifications, implementations, and future". Technical Report GMU-TCOM-TR-8, George Mason University, Fairfax, VA, USA, 2011.

[16] R. B. M. Addelrahman, A. B. A. Mustafa, and A. A. Osman. "A Comparison between IEEE 802.11 a, b, g, n and ac Standards", IOSR Journal of Computer Engineering (IOSR-JEC) 17, No. 5, 2015, 26-29.

[17] A. Schwarzinger, Digital Signal Processing in Modern Communication Systems, Mary Lake, FL, 2013