# Index Modulation Multiple Access for Multichannel ALOHA

Muhammad Sajid Sarwar *Soo Young Shin
Department of IT Convergence Engineering,
Kumoh National Institute of Technology (KIT), Gumi, South Korea
Email: {sajid.sarwar, *wdragon}@kumoh.ac.kr

## Abstract

This article suggests multi-channel (MC) index modulation (IM) multiple access for ALOHA systems. In this uplink random access, users choose a frequency slot of classical orthogonal frequency division multiplexing (OFDM) based on a portion of their input bits. The remaining bits of a user will be transmitted using conventional M-ary constellation. The proposed system is built on the top of classical MC-ALOHA which can achieve similar throughput. However, it will improve the spectral efficiency (SE) and energy efficiency (EE) of the users by virtually transmitting a part of the information using index selection of the subcarriers. The improvement in SE and EE is shown by comparing it with conventional systems without IM.

## Ⅰ. Introduction

Uncoordinated communication does not require a scheduling algorithm which makes the system energy efficient and flexible at the expense of increase inter-user interference. ALOHA is a classical example of random access (RA) in which users transmit their packet immediately, without considering the channel activity. Slotted ALOHA (SA) was a more prevalent extension of ALOHA which transmits packets only at the beginning of a time slot to reduce the inter user collisions. Although SA provides better throughput than conventional ALOHA but suitable for sufficiently sporadic transmissions [1].

Machine-type communications (MTC) is crucial for future wireless systems. According to recent literature, random or uncoordinated access is suitable for MTC due to low signal overhead [2]. Multi-channel (MC) ALOHA employs orthogonal frequency division multiple access (OFDMA) where each subcarrier of OFDMA acts as an orthogonal subchannel [3]. If there are $B$ subchannels in MC-ALOHA, it can increase the throughput of single channel ALOHA by $B$ times.

Index modulation multiple access (IMMA) was recently proposed scheme where uplink users choose a time or frequency slot based on a portion of their incoming data and the rest of the information bits are transmitted using classical M-ary constellation symbols [4]. This technique does not require any pre-scheduling or coordination between the users. Users can transmit immediately whenever they have generated their packet. However, collision may occur on time or frequency resource if the multiple users have same index bits [5]. On the other hand, this technique provides energy efficiency (EE) and low signaling overhead which could be regarded as suitable for MTC [6].

Against this background, authors of this article propose IMMA for MC-ALOHA (IMC-SA) where users will select a subchannel based on their information. As the partial information is being transmitted virtually using index information and the remaining information through M-ary modulation symbols, therefore, it improves the SE of the system. To observe the system performance, SE and throughput of IMC-SA is calculated and compared with the counterparts such as ALOHA, SA, MC-ALOHA.

TABLE I. Index mapping table

| $b_1$ bits | Subchannel index |
|---|---|
| 00 | $B_1$ |
| 01 | $B_2$ |
| 10 | $B_3$ |
| 11 | $B_4$ |

## Ⅱ. Proposed Methodology

The transmitter block diagram of IMC-SA is shown in Figure 1. Consider $B$ subchannels of OFDM which are being accessed by $U$ users. Each user has $b$ Bits to transmit which are divided into $b_1$ and $b_2$ representing index and constellation bits, respectively. Each user utilizes $b_1$ to choose a subchannel out $B$ subchannels and then transmit over that frequency resource using M-ary modulation. The process of subchannel selection is shown in TABLE I. The SE for a user is calculated as below.

$$b = \lfloor log_2(B) \rfloor + log_2(M) \tag{1}$$

Where $M$ denotes the size of quadrature amplitude modulation (QAM)/phase shift keying (PSK). The transmission vector of $u^{th}$ user is denoted by $x_u$ which contains a single non-zero element and $B-1$ zeros. Over $b^{th}$ subchannel, the received signal can be expressed as follows.

$$y_b = \sum_{u=1}^{U} h_{ub} s_{ub} + w_b \tag{2}$$

Where $s_{ub}$ represents the transmitted symbol over $b^{th}$ resource by $u^{th}$ user and $w_b$ denotes the additive white Gaussian noise with zero mean and $\sigma^2$ variance. In addition, $y_b$ is the signal received signal of $b^{th}$ subcarrier through an independent and identical channel $h_{ub}$. If more than one user chooses same subchannel due to the random incoming bits $b_1$, collision will occur which leads to throughput deterioration. The throughput of IMC-SA can be calculated using a collision probability model based on

Poisson distribution. Assuming $u$ as the number of active users, the probability mass function of this Poisson random variable is given as,

$$p_{\lambda}(u) \sim \frac{e^{-\lambda}\lambda^{u}}{u!} \tag{3}$$

Where $\lambda$ is a parameter representing the arrival rate of the users. It is given as $\lambda = \frac{Up}{B}$ where $p$ indicates the access probability of a user. As the throughput is the number users who successfully transmit without collision. In the given scenario, $u = 1$ which means at a given time only a single user accesses a subchannel. It is possible for the case IMC-SA if the index information of each active user is different. In this way, for $B$ subchannels, the throughput $T$ of IMC-SA is expressed as follows,

$$T = B\lambda e^{-\lambda} \tag{4}$$

Note that the throughput is same as the MC-ALOHA which is $B$ times higher than SA. However, the SE per user is increased due to the selection of subchannel through index bits.

## III. Result Analysis

The proposed scheme achieves high SE and EE by providing throughput like MC-ALOHA. The throughput result is illustrated in Figure 2 which is drawn for $B = 4$ and the IMC-SA case outperforms all other scenarios. The SE of IMC-SA is portrayed in Figure 3 as a function of active subchannels or subcarriers. The SE of MC-ALOHA is independent of $log_2(B)$ and follows only $\log_2(M)$ bps/Hz, therefore, remains constant. On the other hand, SE of IMC-SA depends on both $b_1$ and $b_2$ and increase initially and then starts decreasing after a certain activation. More bits can be transmitted in IMC-SA by using the bandwidth like MC-ALOHA and using less energy. The EE of IMC-SA can be calculated as

$$\eta = \frac{\zeta_{\text{IMC-SA}} - \zeta_{MC-SA}}{\zeta_{MC-SA}} = \frac{\log_2(M) - \log_2(M')}{\log_2(M')}. \tag{5}$$

To transmit 5 bits, MC-SA requires $M' = 32$ while IMC-SA can transmit the same number of bits using $M = 2$. In this way $\eta = -80\%$ which indicates the 80% energy can be saved using the proposed method as compared MC-ALOHA.

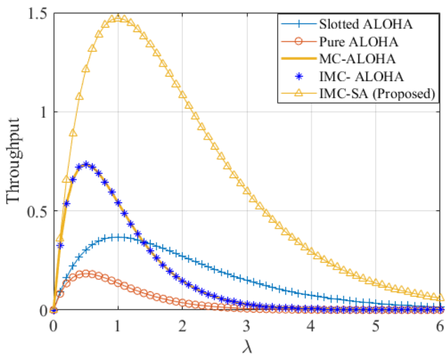

Figure 2. Throughput comparison

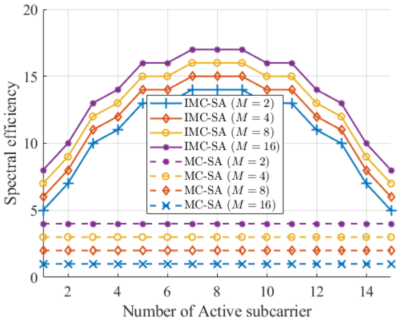

Figure 3. Spectral Efficiency

## IV. Conclusion and Future Work

This article has suggested IMC-SA for uplink RA which employs IM to select a subchannel for the incoming users. The virtual transmission of a portion of user's data results in an increase in SE and EE. IMC-SA can achieve a throughput equal to MC-SA. The proposed technique is suitable for mMTC systems because it does not require any prescheduling algorithm. In future, the scheme could be generalized to activate more than one subchannel for each user to enhance SE further.

## ACKNOWLEDGMENT

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2023-RS-2023-00259061) supervised by the IITP (Institute for Information & Communications Technology Planning & Evaluation). This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government. (MSIT) (No. 2022R1A2B5B01001994).

## Reference

[1] Clazzer, Federico, and Marcel Grec. "Analytical Model of ALOHA and Time-and Frequency-Asynchronous ALOHA with Forward Error Correction for IoT Systems." *Sensors* 22.10 (2022): 3741.

[2] H. S. Dhillon, H. Huang, H. Viswanathan, and R. A. Valenzuela, "Fundamentals of throughput maximization with random arrivals for M2M communications," IEEE Trans. Commun., vol. 62, no. 11, pp. 4094–4109, Nov. 2014.

[3] Y. -J. Choi, Suho Park and Saewoong Bahk, "Multichannel random access in OFDMA wireless networks," in *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 3, pp. 603-613, March 2006.

[4] S. Althunibat, R. Mesleh and K. A. Qaraqe, "IM-OFDMA: A Novel Spectral Efficient Uplink Multiple Access Based on Index Modulation," in *IEEE Transactions on Vehicular Technology*, vol. 68, no. 10, pp. 10315-10319, Oct. 2019.

[5] S. Althunibat, R. Mesleh and T. F. Rahman, "A Novel Uplink Multiple Access Technique Based on Index-Modulation Concept," in *IEEE Transactions on Communications*, vol. 67, no. 7, pp. 4848-4855, July 2019.

[6] J. Li *et al.*, "Index Modulation Multiple Access for 6G Communications: Principles, Applications, and Challenges," in *IEEE Network*, vol. 37, no. 1, pp. 52-60, January/February 2023.