

# On Design and Performance Analysis of Asymmetric 2PAM: 5G Network NOMA Perspective

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## 비대칭 2PAM의 설계와 성능 분석: 5G 네트워크의 비직교 다중 접속 관점에서

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**Abstract:** In non-orthogonal multiple access (NOMA), the degraded performance of the weaker channel gain user is a problem. In this paper, we propose the asymmetric binary pulse amplitude modulation (2PAM), to improve the bit-error rate (BER) performance of the weaker channel user in NOMA with the tolerable BER loss of the stronger channel user. First, we design the asymmetric 2PAM, calculate the total allocated power, and derive the closed-form expression for the BER of the proposed scheme. Then it is shown that the BER of the weaker channel user improves, with the small BER loss of the stronger channel user. The superiority of the proposed scheme is also validated by demonstrating that the signal-to-noise ratio (SNR) gain of the weaker channel user is about 10 dB, with the SNR loss of 3 dB of the stronger channel user. In result, the asymmetric 2PAM could be considered in NOMA of 5G systems. As a direction of the future research, it would be meaningful to analyze the achievable data rate for the proposed scheme.

**Key Words :** NOMA, 5G, Superposition coding, Successive interference cancellation, Power allocation

**요약:** 비직교 다중 접속에서 약 채널 사용자의 저하된 성능은 문제로 제기되고 있다. 본 논문에서는, 수용 가능한 정도의 강 채널 사용자의 BER 손실로, 비직교 다중 접속의 약 채널 사용자의 BER 성능을 향상시키기 위해, 비대칭 2PAM을 제안한다. 먼저, 비대칭 2PAM을 설계하고, 총 할당 전력을 계산한 후, 제안된 기법의 BER에 대한 폐쇄형 수식을 구한다. 다음, 강 채널 사용자의 적은 BER 저하로, 약 채널 사용자의 BER이 향상되었음을 보여준다. 또한, 강 채널 사용자의 3 dB의 SNR 저하로 약 채널 사용자의 SNR 이득이 10 dB에 달하는 것을 보여줌으로써 제안된 기법의 우수성을 입증한다. 결과적으로, 5G 시스템의 비직교 다중 접속에서 비대칭 2PAM이 고려될 수도 있다. 향후 연구 주제로서, 제안된 기술에 대한 최대 전송률을 분석하는 것은 의미있는 연구일 수 있다.

**주제어 :** 비직교 다중 접속, 5G, 중첩 코딩, 연속 간섭 제거, 전력 할당

### 1. Introduction

In the fifth-generation (5G) network, non-orthogonal

multiple access (NOMA) is an efficient multiple access (MA) technique, which is considered as a promising candidate, owing to its higher

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spectral efficiency and low latency [1, 2], compared to orthogonal multiple access (OMA). NOMA is based on well-known schemes such as superposition coding (SC) and successive interference cancellation (SIC) [3, 4]. NOMA can improve the spectral efficiency by sharing the transmission resources simultaneously [5]. In addition, the bit-error rate (BER) NOMA performance was analyzed for  $M$ -user in [6]. The effect of local oscillator imperfection was studied for NOMA [7]. In [8], the BER expression was analyzed with randomly generated signals. In [9], the exact BER expression was presented for the two and three-user cases. The exact average symbol error rate (SER) expressions were presented in [10]. Recently, it was reported that SIC is crucial for the performance of NOMA [11]. The performance of a secure NOMA-enabled mobile network is investigated in [12]. In [13], the authors investigated the physical layer security in NOMA. The intelligent reflecting surface (IRS) assisted NOMA was proposed in [14]. In [15], the authors attempted to reduce further the complexity of the near-end users, with a mutual-aid NOMA strategy. The higher order modulation schemes in downlink power domain NOMA-based visible light communication (VLC) systems was studied in [16].

Meanwhile, a problem in NOMA is that the worse performance of the weaker channel gain user. Even though the more power is allocated to the weaker channel gain user, there is still a problem for the performance of the weaker channel gain user.

In this paper, we propose the asymmetric binary pulse amplitude modulation (2PAM), which improves the BER of the weaker channel gain user, with the tolerable loss of the BER performance of the stronger channel user. Specifically, first, we design the asymmetric

PAM, and then the total allocated power of the asymmetric PAM is derived. In addition, the analytical expression of the BER is derived. We show that the BER of the weaker channel user improves, at the cost of the tolerable BER loss of the stronger channel user.

A comment on the asymmetric 2PAM is that the asymmetric 2PAM is proposed for the first time in this paper, because the performance of the asymmetric 2PAM is inferior to that of the symmetric 2PAM in OMA. However, in NOMA, the multiple signals are superimposed, so that the asymmetric 2PAM affects the performances of the multiple users, differently. Such gain and loss is investigated intensively in this paper.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The design and the performance analysis are presented in Section 3. The results are presented and discussed in Section 4. Finally, the conclusions are presented in Section 5.

## 2. System and Channel Model

We consider a cellular downlink NOMA transmission system, in which two users are paired from a base station within the cell. The Rayleigh fading channel between the  $m$ th user and the base station is denoted by  $h_m \sim \mathcal{CN}(0, \Sigma_m)$ ,  $m = 1, 2$ , where  $\mathcal{CN}(\mu, \Sigma)$  represents the distribution of circularly-symmetric complex Gaussian (CSCG) random variable (RV) with mean  $\mu$  and variance  $\Sigma$ . The channels are sorted as  $\Sigma_1 > \Sigma_2$ . At the base station, the superimposed signal  $x = \sqrt{\alpha P} s_1 + \sqrt{(1-\alpha)P} s_2$  is transmitted, where  $s_m$  is the message for the  $m$ th user with unit power,  $E[|s_1|^2] = E[|s_2|^2] = 1$ ,  $\alpha$  is the power allocation factor, with  $0 \leq \alpha \leq 1$ , and  $P_A$  is the total allocated power. The observation at the  $m$ th user is given by

$$r_m = |h_m| x + n_m, \quad (1)$$

where  $n_m \sim \mathcal{N}(0, N_0/2)$  is additive white Gaussian noise (AWGN). The notation  $\mathcal{N}(\mu, \Sigma)$  represents the distribution of Gaussian RV with mean  $\mu$  and variance  $\Sigma$ , and  $N_0$  is one-sided power spectral density.

### 3. Design and BER Derivation of Asymmetric 2PAM

First, in subsection 3.1, we design the asymmetric 2PAM. Then, in subsection 3.2, the total allocated power is calculated. In subsection 3.3, an analytical expression for the BER is derived. In addition, to ensure the user fairness, we consider the power allocation range,  $\alpha \leq 0.5$ .

#### 3.1 Asymmetric 2PAM Design

In this paper, we assume that the standard 2PAM,  $s_2 \in \{+1, -1\}$ , and the asymmetric 2PAM,  $s_1 \in \{\pm \sqrt{2-v}, \pm \sqrt{v}\}$ , are used, for the weaker and stronger channel users, respectively, where  $v$  is the asymmetric factor,  $0 \leq v \leq 1$ . It is assumed that for the given information bits  $b_1, b_2 \in \{0, 1\}$ , the bit-to-symbol mapping of the standard 2PAM with  $v=1$  is given by

$$\begin{cases} s_1(b_1=0) = +1 \\ s_1(b_1=1) = -1 \end{cases} \quad \begin{cases} s_2(b_2=0) = +1 \\ s_2(b_2=1) = -1 \end{cases}, \quad (2)$$

whereas the bit-to-symbol mapping of the asymmetric 2PAM with  $v \neq 1$  is given by

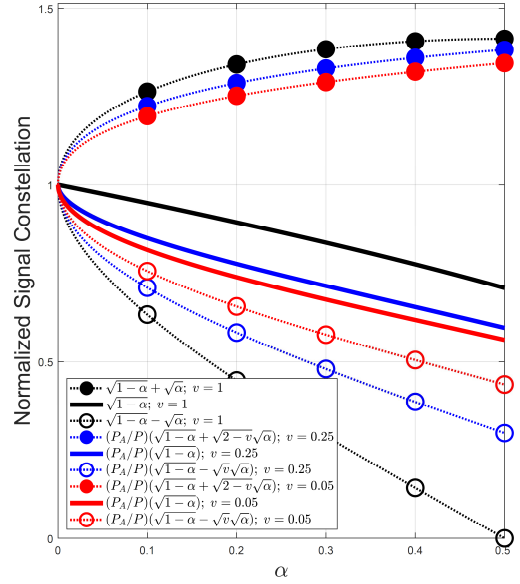


Fig. 1 Normalized Signal Constellation for Asymmetric 2PAM

$$\begin{cases} s_1(b_1=0 \mid b_2=0) = +\sqrt{2-v} \\ s_1(b_1=1 \mid b_2=0) = -\sqrt{v} \end{cases} \quad \begin{cases} s_2(b_2=0) = +1 \\ s_2(b_2=1) = -1 \end{cases}. \quad (3)$$

$$\begin{cases} s_1(b_1=0 \mid b_2=1) = -\sqrt{2-v} \\ s_1(b_1=1 \mid b_2=1) = +\sqrt{v} \end{cases}$$

The normalized signal constellations are depicted in Fig. 1.

#### 3.2 Total Allocated Power Calculation

We assume that the base station can transmit only the power of  $P$ . Thus, the constant total transmitted power  $P$  is represented as the power of the superimposed signal,

$$\begin{aligned} P &= E[|x|^2] \\ &= E[|\sqrt{\alpha P_A} s_1 + \sqrt{(1-\alpha)P_A} s_2|^2]. \end{aligned} \quad (4)$$

First, for the standard 2PAM of both users, the total allocated power  $P_A$  is calculate by

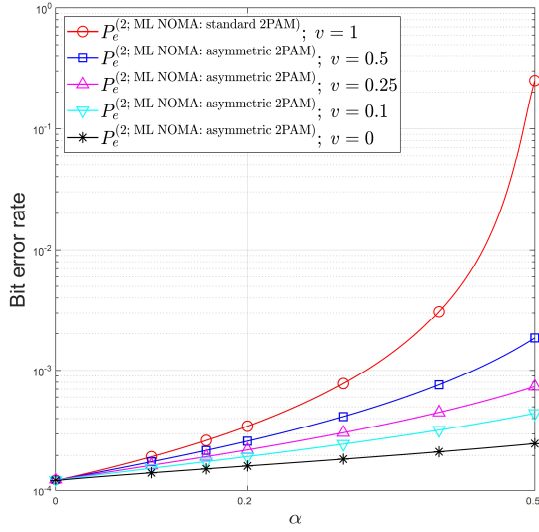


Fig. 2 Comparison of BER for standard/asymmetric 2PAM for second user.

$$\begin{aligned}
 P_A &= E[|\sqrt{\alpha P_A} s_1|^2] + E[|\sqrt{(1-\alpha) P_A} s_2|^2] \\
 &= E[|\sqrt{\alpha P_A} s_1 + \sqrt{(1-\alpha) P_A} s_2|^2] \\
 &= P.
 \end{aligned} \tag{5}$$

However, for the asymmetric 2PAM of the first user, the total allocated power  $P_A$  is calculate by

$$\begin{aligned}
 P_A &= P_A \\
 &\times \frac{E[|\sqrt{\alpha} s_1|^2] + E[|\sqrt{(1-\alpha)} s_2|^2] + 2\text{Re}\{E[\sqrt{\alpha} s_1 \sqrt{(1-\alpha)} s_2^*]\}}{E[|\sqrt{\alpha} s_1|^2] + E[|\sqrt{(1-\alpha)} s_2|^2] + 2\text{Re}\{E[\sqrt{\alpha} s_1 \sqrt{(1-\alpha)} s_2^*]\}} \\
 &= \frac{E[|\sqrt{\alpha P_A} s_1 + \sqrt{(1-\alpha) P_A} s_2|^2]}{E[|\sqrt{\alpha} s_1|^2] + E[|\sqrt{(1-\alpha)} s_2|^2] + 2\text{Re}\{E[\sqrt{\alpha} s_1 \sqrt{(1-\alpha)} s_2^*]\}} \\
 &= \frac{P}{1 + 2\text{Re}\{E[\sqrt{\alpha} s_1 \sqrt{(1-\alpha)} s_2^*]\}} \\
 &= \frac{P}{1 + 2\sqrt{\alpha} \sqrt{(1-\alpha)} \text{Re}\{E[s_1 s_2^*]\}} \\
 &= \frac{P}{1 + 2\sqrt{\alpha} \sqrt{v}}
 \end{aligned} \tag{6}$$

where  $\text{Re}\{z\}$  is the real part of a complex number  $z$ . It should be noted that for  $v=1$ ,  $P_A=P$ .

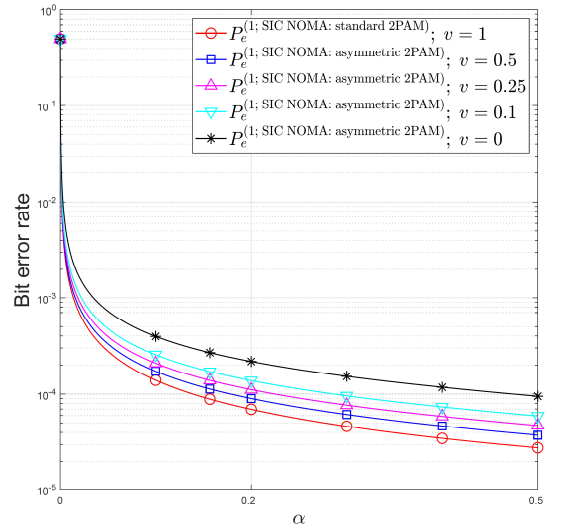


Fig. 3 Comparison of BER for standard/asymmetric 2PAM for first user.

### 3.3 BER Derivation

For the first user, if the perfect SIC is assumed, i.e.,  $b_2$  is given, the interference is subtracted,

$$\begin{aligned}
 y_1 &= r_1 - |h_1| \left( \sqrt{(1-\alpha) P_A} + \frac{\sqrt{2-v} - \sqrt{v}}{2} \right) (-1)^{b_2} \\
 &= |h_1| \sqrt{\alpha P_A} \left( s_1(b_1 | b_2) - \frac{\sqrt{2-v} - \sqrt{v}}{2} (-1)^{b_2} \right) + n_1.
 \end{aligned} \tag{7}$$

The likelihood for the first user is expressed as

$$\begin{aligned}
 P_{R_1 | B_1}(y_1 | b_1, b_2) &= \\
 &= \frac{1}{\sqrt{2\pi N_0/2}} e^{-\frac{\left( y_1 - |h_1| \sqrt{\alpha P_A} \left( s_1(b_1 | b_2) - \frac{\sqrt{2-v} - \sqrt{v}}{2} (-1)^{b_2} \right) \right)^2}{2 N_0/2}}.
 \end{aligned} \tag{8}$$

Based on the maximum likelihood (ML), the optimum detection is expressed as

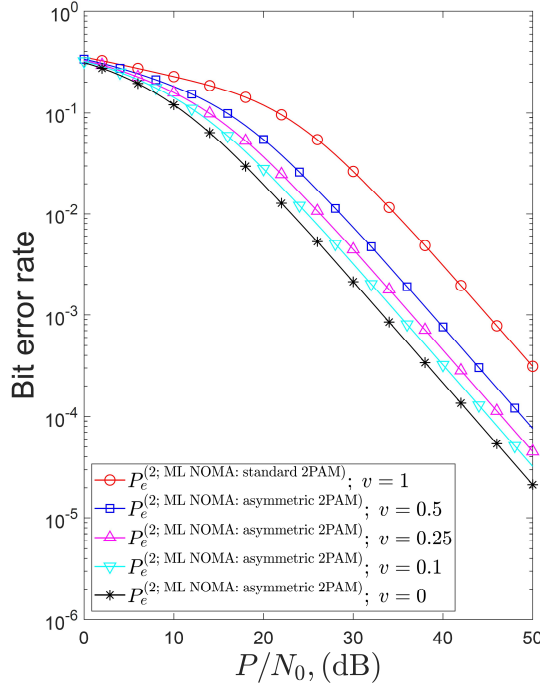


Fig. 4. Comparison of BER for standard/asymmetric 2PAM for second user.

$$\hat{b}_1 = \arg \max_{b_1 \in \{0,1\}} P_{R_1 | B_1}(y_1 | b_1, b_2). \quad (9)$$

Then we solve the equal likelihood equation

$$P_{R_1 | B_1}(y_1 | b_1 = 0, b_2) = P_{R_1 | B_1}(y_1 | b_1 = 1, b_2), \quad (10)$$

which is given by

$$\begin{aligned} & \frac{1}{\sqrt{2\pi N_0/2}} e^{-\frac{\left(y_1 - |h_1| \sqrt{P_A \alpha} \left(s_1(b_1 = 0 | b_2) - \frac{\sqrt{2-v} - \sqrt{v}}{2} (-1)^{b_1}\right)\right)^2}{2N_0/2}} \\ &= \frac{1}{\sqrt{2\pi N_0/2}} e^{-\frac{\left(y_1 - |h_1| \sqrt{P_A \alpha} \left(s_1(b_1 = 1 | b_2) - \frac{\sqrt{2-v} - \sqrt{v}}{2} (-1)^{b_1}\right)\right)^2}{2N_0/2}}. \end{aligned} \quad (11)$$

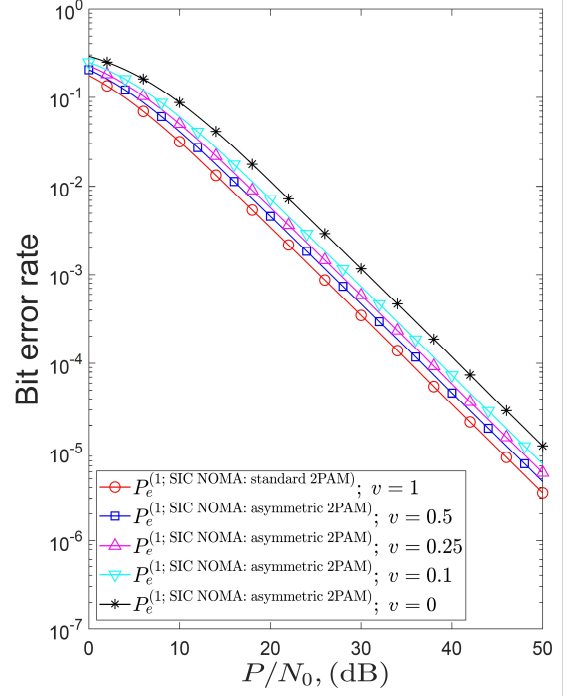


Fig. 5 Comparison of BER for standard/asymmetric 2PAM for first user.

Thus, the one exact decision boundary is given by

$$y_1 = 0. \quad (12)$$

Then, the decision regions are given by

$$\begin{cases} b_1 = 0 : 0 < y_1 \\ b_1 = 1 : y_1 < 0 \end{cases}, \text{ for } b_2 = 0, \quad (13)$$

$$\begin{cases} b_1 = 0 : y_1 < 0 \\ b_1 = 1 : 0 < y_1 \end{cases}, \text{ for } b_2 = 1.$$

Here, the perfect SIC BER performance of the first user, conditioned on the channel gain, is given by

Table 1. SNR gain of asymmetric PAM over standard PAM

$v = 0.5$	+7 dB
$v = 0.25$	+9 dB
$v = 0.1$	+10 dB
$v = 0$	+11 dB

$$P_{e1}^{(1; SIC\ NOMA; asymmetric\ 2PAM)} = Q\left(\sqrt{\frac{|h_1|^2 P_A \left(\frac{\sqrt{2-v} + \sqrt{v}}{2}\right)^2 \alpha}{N_0/2}}\right), \quad (14)$$

where

$$Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz. \quad (15)$$

Then we can use the well-known Rayleigh fading integration formula

$$\int_0^\infty Q(\sqrt{2\gamma}) \frac{1}{\gamma_b} e^{-\frac{\gamma}{\gamma_b}} d\gamma = \frac{1}{2} \left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right), \quad (16)$$

where  $\gamma$  is exponentially distributed with mean  $\gamma_b$ . Thus, the BER expression can be expressed by

$$P_e^{(1; SIC\ NOMA; asymmetric\ 2PAM)} = F\left(\frac{\Sigma_1 P_A \left(\frac{\sqrt{2-v} + \sqrt{v}}{2}\right)^2 \alpha}{N_0}\right), \quad (17)$$

where

$$F(\gamma_b) = \frac{1}{2} \left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \quad (18)$$

Similarly, for second user, the optimal ML BER performance is given by

$$P_e^{(2; ML\ NOMA; asymmetric\ 2PAM)} = \begin{aligned} & + \frac{1}{2} F\left(\frac{\Sigma_1 P_A (\sqrt{(1-\alpha)} + \sqrt{2-v} \sqrt{\alpha})^2}{N_0}\right) \\ & + \frac{1}{2} F\left(\frac{\Sigma_1 P_A (\sqrt{(1-\alpha)} - \sqrt{v} \sqrt{\alpha})^2}{N_0}\right) \\ & + \frac{1}{4} F\left(\frac{\Sigma_1 P_A (\sqrt{(1-\alpha)} + \sqrt{2-v} \sqrt{\alpha})^2}{N_0}\right) \\ & + \frac{1}{4} F\left(\frac{\Sigma_1 P_A (\sqrt{(1-\alpha)} - \sqrt{v} \sqrt{\alpha})^2}{N_0}\right) \\ & + \frac{1}{4} F\left(\frac{\Sigma_1 P_A (\sqrt{(1-\alpha)} - \sqrt{2-v} \sqrt{\alpha})^2}{N_0}\right) \\ & + \frac{1}{4} F(\Sigma_1 P_A (\sqrt{(1-\alpha)} + \sqrt{v} \sqrt{\alpha})^2) \end{aligned} \quad (19)$$

#### 4. Numerical Results and Discussions

It is assumed that  $\Sigma_1 = 1.5$  and  $\Sigma_2 = 0.5$ . It should be noted that we compare the BER of the asymmetric 2PAM ( $v \neq 1$ ) to that of the standard symmetric 2PAM ( $v = 1$ ), in NOMA. We also mention that the BER of the asymmetric 2PAM ( $v \neq 1$ ) is generally inferior to the standard symmetric 2PAM ( $v = 1$ ), in OMA.

##### 4.1 BER of Second Uer for Fixed SNR

First, we consider the constant total transmitted signal power to noise power ratio (SNR)  $P/N_0 = 40$  dB. In Fig. 2, for the second user, we depict the BER of the asymmetric 2PAM, compared to that of the standard PAM, for the various asymmetric factor,  $v = 1, 0.5, 0.25, 0.1, 0$ . As the asymmetric factor  $v$  increases, i.e., the asymmetry of the 2PAM increases, the BER performance improvement increases.

##### 4.2 BER of First Uer for Fixed SNR

Second, for the first user, the BER performances of the asymmetric 2PAM and the standard PAM are shown in Fig. 3, for the various asymmetric factor,  $v = 1, 0.5, 0.25, 0.1, 0$ . It is observed that for the first user, the BER performance is degraded.

It should be noted that based on the results in Fig. 1 and 2, we should allocate the more power to the first user, because the BER of the first user degrades, whereas the BER of the second user improves. Thus, the power allocation  $\alpha=0.4>0.2$  is chosen for the results of the varying SNR,  $0 \leq P/N_0 \leq 50$  (dB).

#### 4.3 BER of Second User for Varying SNR

Third, in Fig. 4, for the second user, we depict the BER of the asymmetric 2PAM, compared to that of the standard PAM, for varying SNR. As shown in Fig. 4, we observe the SNR gain of 10 dB for the asymmetric 2PAM of  $v=0.1$ , compared to that of the standard 2PAM. We also show the SNR gain for the various asymmetric factor,  $v=1, 0.5, 0.25, 0.1, 0$ , in Table 1.

#### 4.4 BER of First User for Varying SNR

Fourth, in Fig. 5, for the first user, we plot the BER of the asymmetric 2PAM, compared to that of the standard PAM, for varying SNR. As shown in Fig. 5, it is observed that the SNR loss of 3 dB for the asymmetric 2PAM of  $v=0.1$ , compared to that of the standard 2PAM. Note that the 3 dB loss of the first user might be tolerable, owing to the 10 dB gain of the second user. For comparison, we also show the SNR loss for the various asymmetric factor,  $v=1, 0.5, 0.25, 0.1, 0$ , in Table 2.

### 5. Conclusion

In this paper, we proposed the asymmetric 2PAM, in order for the BER of the weaker

tolerable BER loss of the stronger channel user. First, we derived the analytical expressions for the BERs of both users. Then it was shown that the BER of the weaker channel user improves, with the small BER loss of the stronger channel user. We also validated that the SNR gain of the weaker channel user is about 10 dB, with the SNR loss of 3 dB of the stronger channel user, for the fixed power allocation,  $\alpha=0.4$ . As a consequence, the asymmetric 2PAM could be a promising scheme in NOMA of 5G systems.

In addition, the proposed NOMA could promote the convergence of artificial intelligence (AI) and internet of things (IoT) by the improved 5G networks.

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**Table 2. SNR loss of asymmetric PAM over standard PAM**

$v = 0.5$	-1 dB
$v = 0.25$	-2 dB
$v = 0.1$	-3 dB
$v = 0$	-5 dB

channel user in NOMA to be improved, with the

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