OFICIO No. 042/DGA/UNISTMO/2021
Asunto: *Gastos De publicación, Solicitud de Liberación.*
Sto. Domingo Tehuantepec, Oax., 10 de junio de 2021

Dr. Isaías Elizarraraz Alcaraz
Director de Fortalecimiento Institucional
AT´N:
Lic. Sergio Pascual Conde Maldonado
Jefatura de Desarrollo y Operación

Por este conducto le envío un cordial saludo, al tiempo que remito la **Solicitud de Liberación** correspondiente al *apoyo para Gastos de Publicación* autorizado al **PTC RICARDO CARREÑO AGUILERA**, adscrito a la Universidad del Istmo. Cabe señalar que el apoyo fue autorizado mediante oficio No. 511-6/2020-10231, de fecha 16 de diciembre de 2020.

Nombre del PTC	*Revista / ISSN*	*Título del artículo*	*Costo (M.N.)*
Dr. Ricardo Carreño Aguilera	Fractals / 0218-348X	SPARSE CODE MULTIPLE ACCESS CODEBOOK DESING USING SINGULAR VALUE DECOMPOSITION	$25,000.00

Se adjunta solicitud de liberación por parte del PTC en comento, Informe final (impacto académico logrado), copia del artículo publicado; y desglose financiero de recursos que emite la Universidad del Istmo. Los documentos en PDF se enviaron a los correos dfi.degesui@nube.sep.gob.mx, sconde@nube.sep.gob.mx y graciela.hernandez @nube.sep.gob.mx.

Garantizando la transparencia en el ejercicio de los recursos, agradezco la atención prestada al presente, y aprovecho la ocasión para agradecer los apoyos que nos brinda el Programa en mejora de la educación de nuestra región, nuestro estado y nuestro país.

ATENTAMENTE

Voluntas totum potest
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L.C.E. Claudia Hernández Cela
Jefa del Departamento de Gestión Académica

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Dr. Isaías Elizarraraz Alcaraz
Director de Fortalecimiento Institucional

AT´N:
Lic.

Sergio Pascual Conde Maldonado
Jefatura de Desarrollo y Operación

Sirva el presente para enviarle un cordial saludo y mi agradecimiento por el apoyo recibido en el proyecto Gastos de Publicación. Así mismo, aprovecho la ocasión para solicitarle de la manera más respetuosa la **Carta de Liberación** correspondiente al apoyo recibido en mérito del Programa, autorizado en el oficio No. 511-6/2020-10231 de fecha 16 diciembre del 2020. Es importante comentar que el artículo titulado "SPARSE CODE MULTIPLE ACCESS CODEBOOK DESIGN USING SINGULAR VALUE DECOMPOSITION", se publicó en la revista "fractals journal", con ISSN 0218-348X, en el volumen 28 (7) de fecha 23 noviembre del 2020.

Se adjunta al presente, copia del artículo publicado en revista indexada, así como, informe final que contiene el impacto académico logrado con el apoyo recibido.

Sin más por el momento quedo de usted.

A T E N T A M E N T E.

"Voluntas totum potest"
Guirá' zanda ne guendaracala'dxi'

Atentamente

Dr. Ricardo Carreño Aguilera
Profesor-Investigador Titular A
Universidad del Istmo

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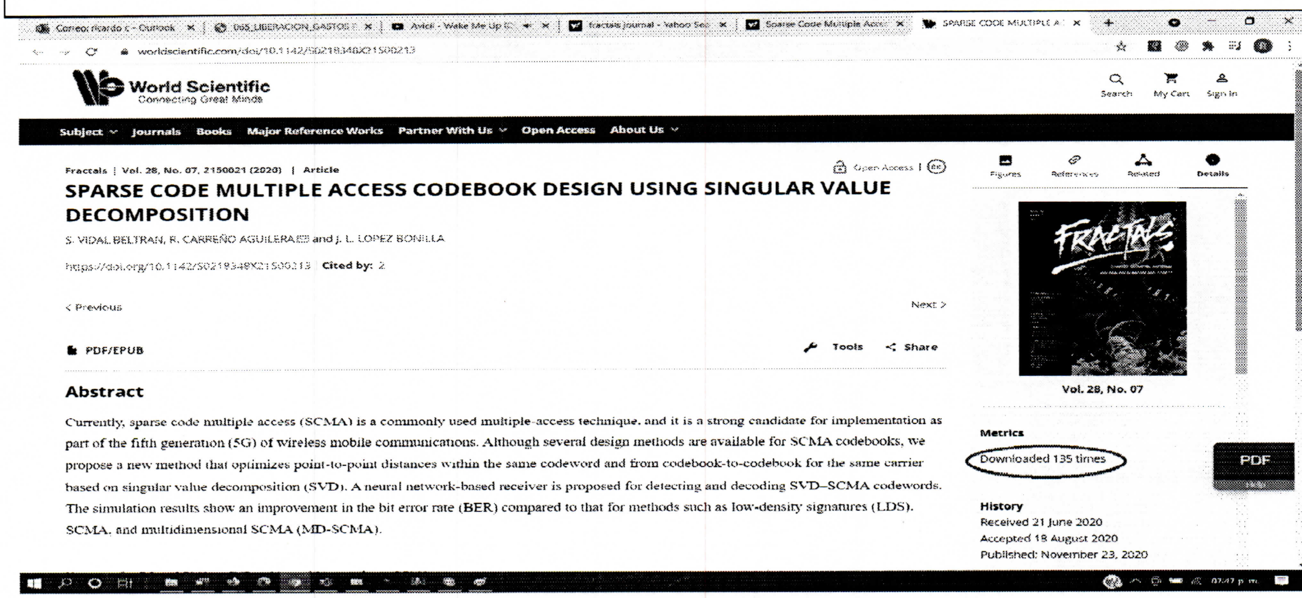

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SPARSE CODE MULTIPLE ACCESS CODEBOOK DESIGN USING SINGULAR VALUE DECOMPOSITION

S. VIDAL BELTRAN, R. CARREÑO AGUILERA and J. L. LOPEZ BONILLA

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Abstract

Currently, sparse code multiple access (SCMA) is a commonly used multiple-access technique, and it is a strong candidate for implementation as part of the fifth generation (5G) of wireless mobile communications. Although several design methods are available for SCMA codebooks, we propose a new method that optimizes point-to-point distances within the same codeword and from codebook-to-codebook for the same carrier based on singular value decomposition (SVD). A neural network-based receiver is proposed for detecting and decoding SVD–SCMA codewords. The simulation results show an improvement in the bit error rate (BER) compared to that for methods such as low-density signatures (LDS), SCMA, and multidimensional SCMA (MD-SCMA).

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SPARSE CODE MULTIPLE ACCESS CODEBOOK DESIGN USING SINGULAR VALUE DECOMPOSITION

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Abstract

Currently, sparse code multiple access (SCMA) is a commonly used multiple-access technique, and it is a strong candidate for implementation as part of the fifth generation (5G) of wireless mobile communications. Although several design methods are available for SCMA codebooks, we propose a new method that optimizes point-to-point distances within the same codeword and from codebook-to-codebook for the same carrier based on singular value decomposition (SVD). A neural network-based receiver is proposed for detecting and decoding SVD–SCMA codewords. The simulation results show an improvement in the bit error rate (BER) compared to that for methods such as low-density signatures (LDS), SCMA, and multidimensional SCMA (MD-SCMA).

Keywords: 5G; SCMA; SVD; Neural Networks; SCMA.

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resulting matrices U and V^* are orthonormal, which indicates that they exhibit an optimal point-to-point Euclidean distance. Moreover, the peak-to-average power ratio (PAPR) and the interleaving effect from SVD protect the signals from channel fading.

To design codebooks using SVD, the following information must be considered:

- Number of users: 6 ($J = 6$)
- Radio carriers: 4 ($K = 4$)
- Codewords: 4 ($M = 4.00, 01, 11, 10$)
- Code dimensions: 2 ($N = 2$)
- Users for each carrier: 3 ($d_f = 3$)
- Overloading factor: 1.5 ($\lambda = 1.5$)
- User data, which are transported via two radio subcarriers. Therefore, each pair of bits (a codeword) can be represented using four combinations, which means that the four codewords are represented by up to 16 possible combinations.

First, we select a set of grey mapping vectors that represents each point in the constellation, which will be known as the mother constellation (M_c). Therefore, an S_1 subset of Gaussian integers is then defined with the following structural equation:

$$S_1 = \{A_m(1+i) \mid A_m = 2m - 1 - M, \quad m = 1, \dots, M\}. \tag{3}$$

Then values are assigned to each S_{1m} point of S_1. Because $M = 4$ (M being the number of codewords), grey mapping is based on the following equation set:

$$\begin{aligned} S_{11} &= -3(1+i), \\ S_{12} &= -1(1+i), \\ S_{13} &= +1(1+i), \\ S_{14} &= +3(1+i), \end{aligned} \tag{4}$$

where S_1 is the first dimension. In this work, codebooks are constructed with two dimensions ($N = 2$). The following dimensions are obtained considering that $S_l = S_1 U_l$, where $U_l = I_{M\times M} e^{i\theta_{l-1}}$, $\theta_{l-1} = \frac{(l-1)\pi}{MN}$, and $l = 1, \dots, N$, so M_C is given as follows:

$$M_c = (S_1, S_2)^T = \begin{bmatrix} S_{11} & S_{12} S_{13} & S_{14} \\ S_{21} & S_{22} S_{23} & S_{24} \end{bmatrix}. \tag{5}$$

One of the primary SCMA properties is that books and codewords are sparse, thus achieving massive user connectivity. In SCMA, the length of codewords is determined based on the number of available K subcarriers (i.e. the spreading factor). Codewords are considered sparse because the number of nonzero terms in each codeword N is less than K. When the values of K and N are determined, it is possible to determine the number of codebooks (J). The number of codebooks is given by the binomial coefficient in the following equation:

$$J = \binom{K}{N} = \frac{K}{N}\binom{K-1}{N-1}. \tag{6}$$

Because $K = 4$ & $N = 2$, $J = 6$. In OFDMA systems, each subcarrier transmits to only one user, which avoids overload issues. SCMA includes transmissions for more than one user per subcarrier. Since $K = 4$ and $N = 2$, $J = 6$ codebooks are generated.

The number of users connected to a subcarrier (d_f) is given as follows:

$$d_f = \binom{K-1}{N-1} = \frac{JN}{K}. \tag{7}$$

However, the overload factor is given by $\lambda = \frac{J}{K} = \frac{d_f}{N}$. For example, considering six users ($J = 6$), and since each user uses a different codebook, the overload factor (λ) is 1.5, and d_f is equal to 3. Hence, an SCMA subcarrier provides transmissions for more users than does an OFDMA carrier.

Once M_c is defined, the factorization of SVD to M_c is performed, which yields a 2×4 matrix, as follows:

$$M_c = U_{n\times p} \Sigma_{p\times p} V^*_{m\times p}. \tag{8}$$

As previously stated, V^* represents a 2×4 set of orthonormal eigenvectors; thus, V^* is now the new M_c, from which codebooks will be generated for all users.

Figure 1a shows the original mother constellation, and the SVD mother constellation is given in Fig. 1b.

As shown in Fig. 1b, V^* maintains the rotation of the original matrix, with the advantage that the matrix columns are orthonormal.

Now, V^* may generate codebooks for each user. The different user rotation angles are obtained from d_f and e_u, which represent the number of users transported by a radio resource (in this case, 3); therefore, the rotation angle φ_u for the different

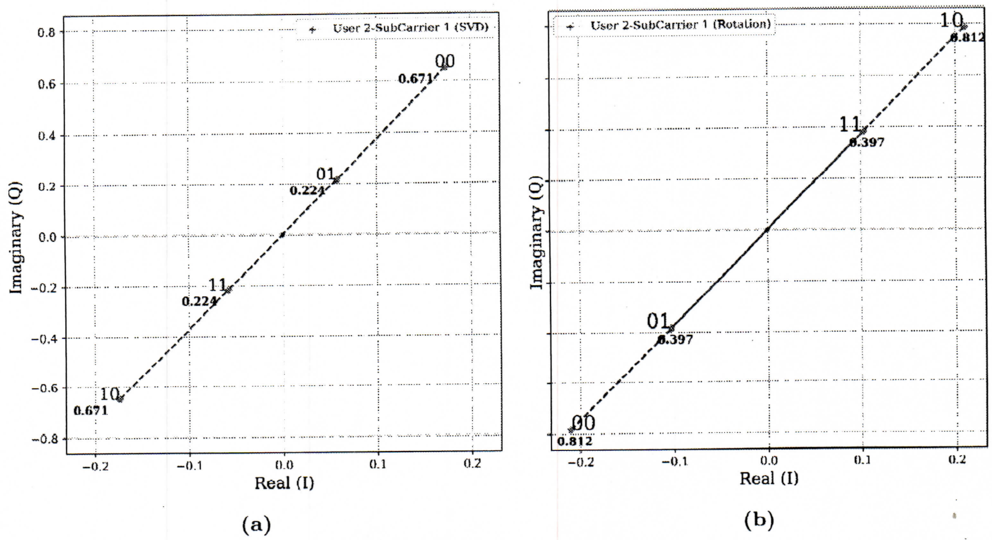

Fig. 2 **(a)** Minimum distance between SVD points and **(b)** Minimum distance between original rotation points.

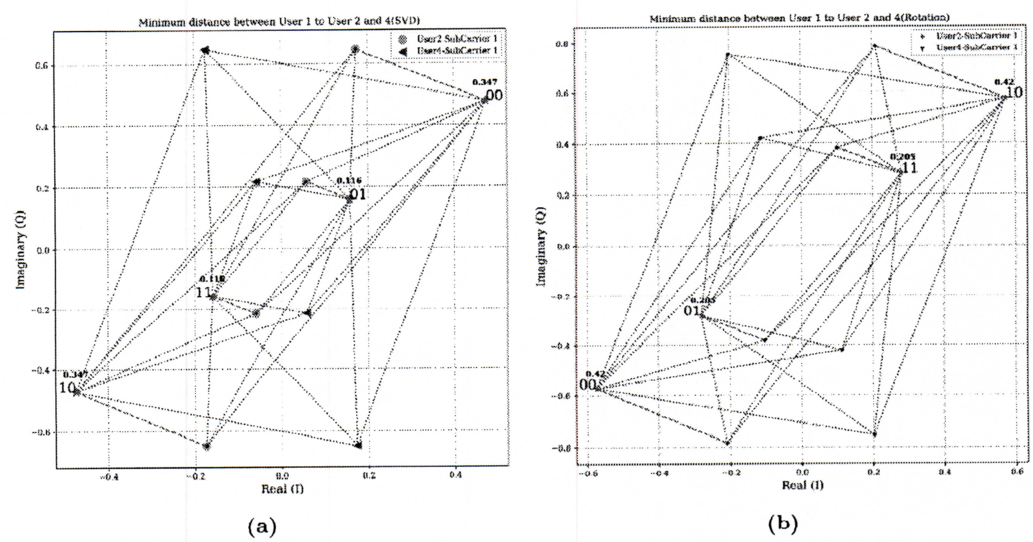

Fig. 3 **(a)** Minimum distance between User 1 and Users 2 and 4 (SVD) and **(b)** Minimum distance between User 1 and Users 2 and 4 (rotation).

and the closest point from the constellations of users 1 and 4.

In Fig. 3a, the relationship between the minimum separation distances is given by $\frac{0.347}{0.116} = 2.99$, whereas in Fig. 3b, the relationship is $\frac{0.413}{0.205} = 2.00$. Both the separations — that between adjacent points within the same codeword and the codeword point-to-point distance for users with the same carrier — are equal to 2.99, which is the singular value obtained by applying SVD to the mother constellation M_c. The same relationship is found for all other users. SVD optimizes the distance between the constellation points; the greater the distance between the points is, the greater the immunity to the effects of noise and interference.

3. METHODS/EXPERIMENTS

This section provides the simulation scenario and parameters used, including the SVD–SCMA codewords with the method proposed in the above section. Then, a neural network model is designed, the neural network is trained, predictions regarding

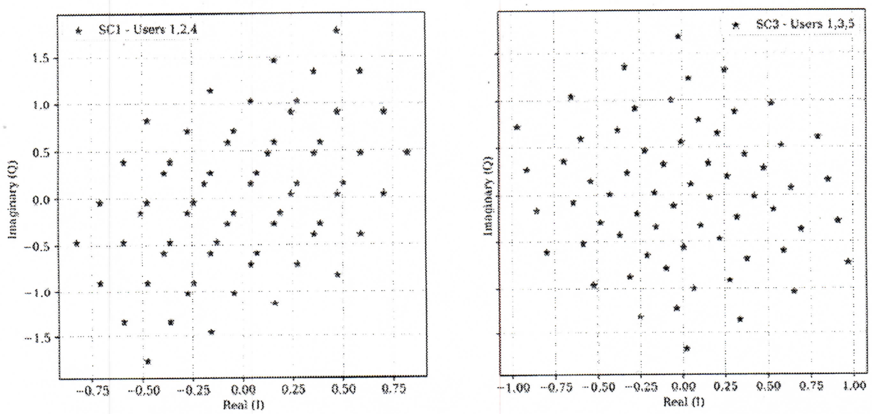

Fig. 6 Reference constellation in the IQ plane for SC1 and SC3.

The detection and decoding of SCMA codewords is affected by the code design, channel performance, and noise. The message-passing algorithm (MPA) and minimum Euclidean distance method are two techniques primarily used by the receiver, and they are briefly described below. The proposed receiver is also described.

3.3.1. *Message-passing algorithm (MPA)*

MPA uses the sum-product algorithm to calculate the marginal probability of different codewords. Bayesian probability methods are used to calculate the codeword probability based on an initial probability within the codebook.[26] For example, for six users and four codewords in each codebook, and assuming that all users transmit within the same data frame because there is no prior knowledge of the data to be transmitted, it is assumed that each selected codeword has the same probability. In this scenario, it is possible to establish the initial probability of a user by selecting a codeword equal to 1 divided by the cardinality M of the codeword set in each user's codebook.[26] Therefore, all codewords have an initial probability of 1/4. Because MPA is an algorithm that works with joint probabilities, it is complex to implement and requires considerable machine time to perform calculations.

3.3.2. *Minimum Euclidean distance*

The transmitter and receiver agree on the same reference constellation to modulate and demodulate user information[14] in consistent detection. The first step in IQ detection is to calculate the Euclidean distance between two given vectors (the reference array and the symbols received with noise). Each symbol in the received vector must be compared with each symbol of the reference array before calculating the minimum Euclidean distance. Because $x = (x_1, x_2, \ldots, x_p)$ and $y = (y_1, y_2, \ldots, y_p)$ are two vectors in the p-plane. The Euclidean distance is shown by the following equation:

$$d(x, y) = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2 + (x_p - y_p)^2}. \quad (15)$$

Figure 7 shows the reference constellation (red dots) and random data (blue dots affected by an SNR = −3 dB).

For each datum received (blue dots), the minimum distance to each constellation reference point (red dots) is calculated to decode the data. This process, although easier to implement than the MPA, results in intensive machine use because each datum received is compared to 64 possible reference constellation values.

3.3.3. *Neural network-based receiver*

Figure 8 shows the detector used for SVD–SCMA, which is based on supervised learning through a neural network. For the proposed receiver based on the neural network, the following configuration parameters were used: four inputs (one for each subcarrier); three dense hidden layers; and 64, 32, and 16 neurons for the first, second, and third hidden layers, respectively. Moreover, 100 iterations (epochs) were used to train the neural network, and the batch size used was 10. The activation function for the hidden layers was a ReLU function, and SOFTMAX was used for the final layer.

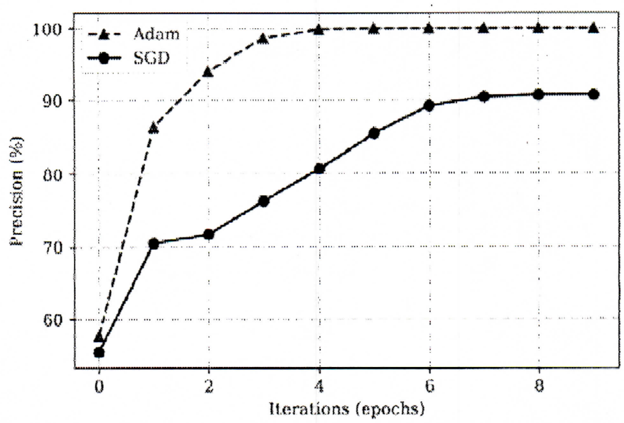

Fig. 9 Optimization algorithm precision.

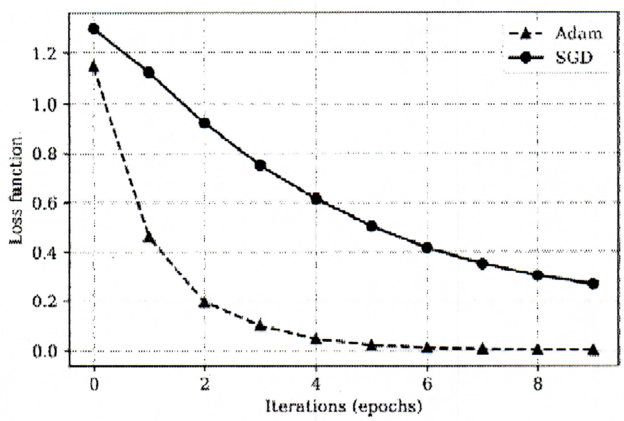

Fig. 10 Optimization algorithm loss function.

function. Figure 9 shows the precision of the optimization algorithms. Herein, Adam reaches an accuracy of 100%, and in the best case, SGD reaches 92.5%. Furthermore, the loss function is an objective function, as shown in Fig. 10. Adam reaches a value of zero for the loss function, and SGD has a loss value close to 0.2.

As mentioned previously, for the uplink, the effects of a channel influenced by Rayleigh fading were simulated, and the SVD–SCMA results were compared with those of the LDS, SCMA and MD–SCMA methods presented in Refs. 4–7 and 9.

Table 1 lists the main codebook characteristics.

The BER was used to evaluate the performance of the four algorithms; the MPA[26] was used in the SCMA, LDS, and MD-SCMA methods; the detector described in the previous section was applied in SVD–SCMA based on supervised learning through neural networks. Figure 11 depicts the performance of the five codebook building methods, wherein

Table 1 Codebook Characteristics.

	$d_{\min}$	E_{avg}	PAPR (dB)	Receiver
SCMA	2.44	1	0	MPA
LDS	$\sqrt{2}$	1	0	MPA
MD–SCMA	2	1	0	MPA
SVD–SCMA	2.99	1	0	Neural network

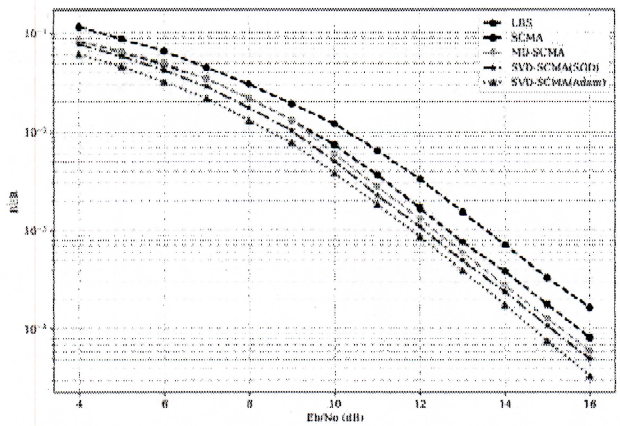

Fig. 11 BER for the five different algorithms.

SVD–SCMA exhibits an improvement over its predecessors.

As shown in Fig. 11, SVD–SCMA using SGD and Adam as neural network optimization algorithms displays better BER performance than the algorithms proposed in Refs. 4–7 and 9. Furthermore, as shown in Fig. 9, Adam exhibits better performance than SGD, which is reflected in a better BER, thus enhancing data transmission and reducing errors.

SVD–SCMA is an easy algorithm to implement as a V^* matrix that is orthonormal, maintains average signal energy and can be obtained in a single step.

5. CONCLUSIONS

This work proposes a new approach for the design and construction of SCMA codebooks using SVD. The results show that the singular value reflects the separation between adjacent points within the same codeword; thus, it can be used to optimize point-to-point distances within the same codeword and from codebook-to-codebook for the same subcarrier. The SVD method of generating SCMA codewords in conjunction with neural network-based detection displayed better performance (BER) than its predecessors (LDS, SCMA, and MD–SCMA). The results show that SVD–SCMA is a better alternative than

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