International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 7 (2020) pp. 648-653

Design of Polar Code for High Altitude Platform Station based Communication Systems

Hien Thi Thu Nguyen, Tra Thanh Nguyen

Faculty of Telecommunications 1, Posts and Telecommunications Institute of Technology, Km10, Nguyen Trai Street, Ha Dong District, Hanoi, Vietnam.

Abstract

The polar codes have attracted the attention of academia and industry in recent years. Polar code was selected as the channel coding scheme in the standardization of the 5th generation (5G) wireless system of a 3rd generation cooperation project (3GPP). Polar codes are near-capacity codes having low encoding and decoding complexity. The code uses polarization for achieving Shannon limits. In this paper, we present the research results on design and performance evaluation of polar code that is proposed to be used as channel code for High Altitude Platform Station (HAPS) based communication systems over a Rician fading channel.

Keywords: High Altitude Platform Station, Rician Fading Channel, Polar Code, Frame Error Rate.

INTRODUCTION

As emerging economies around the world focus on digital transformation as a path toward socioeconomic empowerment, bringing connectivity to all is increasingly critical. Nearly half of the world's population is still not connected to the Internet. Connecting these people requires not just bringing network infrastructure to more people, but establishing a regulatory environment that fosters innovation and encourages investment. So many organizations has been investing in research and development for a range of technologies, including mobile, satellite, and aerial, like high altitude platform stations (HAPS) [1].

HAPS are stratospheric stations, each composed of an aerial vehicle and a payload that operate at around 20 km above ground. HAPS systems have the potential to become an important tool for bringing broadband Internet to hard-to-reach and unserved areas, supplementing existing networks to meet ever-increasing demand, and serving as "instant infrastructure" in emergency communications and disaster relief.

HAPS has many more outstanding features than traditional wireless systems such as (1) rapid deployment to cover large service areas - a radius of about 50 km - on any type of geography, including difficult terrain; (2) reliability thanks to advances in aviation, as well as battery and solar technology, allowing HAPS to operate continuously over long periods without the risk; (3) broadband capabilities, thanks to unprecedented advances in communications technologies. These features make HAPS economically viable as a transmission line for broadband and 5G [1], as part of both terrestrial and satellite networks in areas where other technologies may be difficult to deploy because difficult terrain or distance from a residential center [2]. In addition, HAPS can provide immediate, immediate infrastructure to expand rapid connectivity in natural disasters.

During propagation from HAPS to user terminal on the ground, the wireless signal is normally influenced by path loss, shadows, and multipath fading. Multipath fading is generated on communication scenario between HAPS and ground users in urban areas where there is a high density of human structures such as houses, commercial buildings, roads, bridges, and railways. In this scenario, the propagation channel is generally believed that the Rician fading characteristic is appropriate, which includes the line of sight (LOS) and non-LOS (NLOS) components [3]. The NLOS components with different attenuation and delays add or subtract to the LOS component. This causes the amplitude of the receiver signal to increase or decrease and affects the quality of HAPS based communication systems.

To ensure reliable HAPS communication, one of the common and effective techniques is to use channel coding. Channel coding is a way of encoding data in a communication channel that adds redundant patterns to the link to reduce error rates. Following the research results of channel coding schemes for HAPS in [3], [4], we recognize that, in order to achieve near-capacity performance, these coding schemes require the decoder to perform multiple iterative loops and a large information frame's length. This makes the channel coding schemes not quite effective, especially for small size transmission frames. We therefore propose the use of polar code [5] due to its simple efficiency.

Polar code was invented by Erdal Arıkan at Bilkent University [5]. It has been discussed for over a decade, with many research articles on various aspects. Polar code is said to achieve channel capacity in a given binary discrete memoryless channel. This can be achieved only when the block size is large enough. The complexity of encoding and decoding is less and these codes can be successfully decoded [5].

A major challenge in design of polar codes is how to choose the positions of information and frozen bits. The frozen set selection of polar codes, known as bit selection, determines the error-correcting performance of polar code. The original bit selection was derived for successive cancellation decoding for symmetric binary-input memoryless channels [6]. Density evolution has been used to evaluate the bit error probability in binary memoryless channel [7], but the computational complexity is still high and the simplified versions rely on different degrees of approximations. Therefore, we apply Monte Carlo simulation-based frozen bits selection method and belief propagation (BP) decoding [8]. The simulation based method does not rely on channel models and it can be applied to any practical channels in the field.

Against this background, the novel contribution of this paper is that we present the design & performance results of polar code using for HAPS based systems. The rest of the paper is organized as follows. In Section 2, a system model is considered. In Section 3, a review of polar code, the belief propagation (BP) decoding and design algorithm is covered. The research results of polar codes design and frame error rate (FER) performance of HAPS systems is represented in Section 4. Finally, conclusion is offered in Section 5.

SYSTEM MODEL

Let's consider a HAPS based wireless communication scenario as shown in Fig.1. In this scenario, the transmitter is HAPS and the receiver is user terminal on the ground. The binary data stream is first coded by polar code encoder, then it is modulated and mapped to a sequence of complex modulation symbols. The modulated sequence s is transmitted via the wireless channel influenced by Rician fading and Additive white Gaussian noise (AWGN). The received signal sequence y in the receiver can be represented as

$$y = h.s + n \tag{1}$$

where h is the Rician fading coefficient that fluctuates on a symbol-by-symbol basis, and n is the AWGN process having a variance of $N_0/2$ per dimension.

The amplitude process h(t) possesses the Rician distribution:

$$f(h) = \frac{2(K_R+1)h}{\Omega}\exp\left\{-K_R - \frac{(K_R+1)h^2}{\Omega}\right\} I_0\left(2\sqrt{\frac{K_R(K_R+1)}{\Omega}}h\right) \qquad h \geq 0, \tag{2}$$

where $I_0(.)$ is the modified Bessel function of the first kind of order zero; K_R the Rice factor and Ω is the total power from both line of sight (LOS) and non-LOS paths.

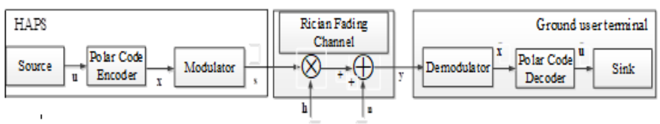

Figure 1: Channel coding scheme in HAPS based system.

At the receiver side pictured in Fig. 1, the signals received during a single frame duration are demodulated by demodulator and then decoded by the decoder of Polar code. The decoder uses belief propagation (BP) decoding algorithm. BP decoding works by passing the frozen set information from left to right and and passing the channel output y from right to left following the factor graph.

DESIGN OF POLAR CODE FOR HAPS SYSTEM

Polar Code

As shown in Fig. 1, let $\mathrm{u} = (u_0, u_1, ..., u_{N-1}) \in \mathrm{F}_2^N$ denote a binary input sequence of length *N*. Let $\mathrm{G}_N \in \mathrm{F}_2^{N\times N}$ denote a generator matrix formulated as

$$\mathrm{G}_N = \mathrm{G}_2^{\otimes n},\ \mathrm{G}_2 = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix} \tag{3}$$

where $n = \log_2 N$ and $\mathrm{A}^{\otimes n} = \mathrm{A} \otimes \mathrm{A}^{\otimes(n-1)}$ is the nth Kronecker power of matrix **A** with $\mathrm{A}^{\otimes 0} = (1)$ [5]. The corresponding output $\mathrm{x} = (x_0, x_1, ..., x_{N-1}) \in \mathrm{F}_2^N$ is expressed as

$$\mathrm{x} = \mathrm{u}\mathrm{B}_N\mathrm{G}_N, \tag{4}$$

where $\mathrm{B}_N \in \mathrm{F}_2^{N\times N}$ is the $N \times N$ bit reversal permutation matrix [5] which guarantees that decoding is performed in the bit reversal order of the binary channel index.

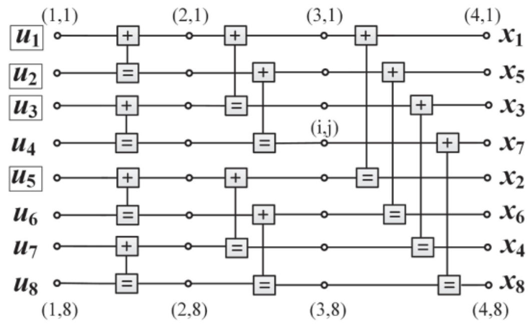

Fig. 2. Factor graph of the polar code with *N*=8 and code rate *R*=0.5 [8].

The factor graph of a polar code with *N*=8 and code rate *R*=0.5 is shown in Fig. 2. In this example, 1, 2, 3 and 5 are set to zero and frozen bits. Besides, each circle in the graph represents a node that stores and passes the belief message. To perform polar encoding, an *N*-bit input message **u** is passed from the left hand side of the factor graph, and an *N*-bit codeword x is obtained from the right hand side.

BP decoding algorithm

We denote the received signal sequence of length $N = 2^n$ as $\mathrm{y}_n = (y_0, y_1, ..., y_{2^n-1})$, from (1). BP decoding is performed based on the factor graph in Fig. 2. The message crosses node (i, j) from right to left (left to right) is denoted as $L_{i,j}(R_{i,j})$. Firstly, the left-most source vector nodes are initialized according to the information set A (A^C is complement set of A):

$$R_{1,j} = \begin{cases} 0 & if \quad j \in A \\ \infty & if \quad j \in A^C \end{cases} \tag{5}$$

and the right-most codeword nodes are initiated with the channel output log likelihood ratios (LLRs):

$$L_{n+1,j} = \log \frac{\Pr\left(y_j \left| x_j = 0, h\right.\right)}{\Pr\left(y_j \left| x_j = 1, h\right.\right)} \tag{6}$$

The rest nodes are initiated as zero LLR.

Then, the node-LLRs will update from left to right and return back through the factor graph as one time iteration. Following the direction of belief calculation on general factor graphs [7, 8, 9], the whole iterative BP decoding expressions can be expressed as:

$$L_{i,j} = f\left(L_{i+1,2j-1}, L_{i+1,2j} + R_{i,j+N/2}\right) \tag{7}$$

$$L_{i,j+N/2} = f\left(R_{i,j}, L_{i+1,2j-1}\right) + L_{i+1,2j} \tag{8}$$

$$R_{i+1,2j-1} = f\left(R_{i,j}, L_{i+1,2j} + R_{i,j+N/2}\right) \tag{9}$$

$$R_{i+1,2j} = f\left(R_{i,j}, L_{i+1,2j-1}\right) + R_{i,j+N/2} \tag{10}$$

where $f(x,y) = ln\left(cosh\left((x+y)/2\right)\right) - ln\left(cosh\left((x-y)/2\right)\right)$

Eventually, after reaching the specified number of iterations, the hard decision can be made for each information bit according to Eq. (11) and $\hat{u}_n$, the estimate of u_n can be obtained.

$$\hat{u}_j = \begin{cases} 0 & if \quad R_{1,j} \geq 0 \\ 1 & else \end{cases} \tag{11}$$

Simulation-based method to select the information bits under BP decoding

For polar codes with rate $R = K/N$, K channels out of N total channels are selected for information transmission. Let $A \subset \{0,1,...,N-1\}$ denote the set of the channel indices selected to be information bits, i.e., the *information set* [5], with its cardinality given by $|A| = K$. The bits that are not in this set are called *frozen bits* in A^C and fixed to known values (usually set as 0). Therefore, design of polar code is equivalent to the selection of a set A that leads to a near-DCMC capacity and a good block error rate (BLER) performance.

In designing polar codes for HAPS based system, we mostly focus on design of polar codes based on the information bits selection algorithm in [8]. The algorithm selects the information bits in an incremental manner. It guarantees the optimal selection of information bit for K=1. To speed up the selection process, multiple bits can be selected instead of one bit each time.

RESULTS AND DISCUSSION

We used information bits selection algorithm in [8] to design polar codes HAPS systems with $N_{\max} = 1024$ and various modulation schemes over a Rician fading channel (K_R=10 dB), the maximum iteration number is set to 50.

In case the system uses QPSK modulation scheme, the Polar sequence $Q_i^{N_{\max}}$ denoting a bit index before Polar encoding for $i = 0,1,...,N_{\max}$, $N_{\max} = 1024$ and its corresponding reliability $W\left(Q_i^{N_{\max}}\right)$ is shown below. The Polar sequence $Q_i^{N_{\max}}$ is in ascending order of reliability $W\left(Q_0^{N_{\max}}\right) < W\left(Q_1^{N_{\max}}\right) < ... < W\left(Q_{N_{\max}-1}^{N_{\max}}\right)$:

$W\left(Q_i^{N_{\max}}\right)_{\text{QPSK}}$ = [31 307 279 538 339 87 331 55 583 72 47 106 326 563 157 143 647 520 179 771 283 59 205 155 6 211 354 341 644 32 772 555 168 309 327 88 210 528 84 417 115 107 272 142 56 100 535 550 395 140 288 151 79 27 313 78 773 551 94 26 166 391 390 408 554 295 80 606 217 156 108 337 76 185 22 557 174 149 23 541 54 62 294 28 131 282 312 43 167 386 299 109 402 203 561 581 259 241 146 227 548 39 568 589 527 226 319 275 103 86 323 643 158 15 525 24 178 216 609 194 229 271 582 110 531 514 276 553 387 57 269 770 102 705 98 585 213 85 277 199 61 118 176 16 338 48 150 580 526 389 139 90 594 262 530 58 258 238 95 801 8 595 593 587 17 122 449 284 71 114 552 691 393 651 116 200 333 336 533 119 534 833 569 645 181 136 195 250 646 562 401 650 264 516 529 367 301 117 604 268 260 198 38 93 357 600 290 292 204 2 52 519 164 147 89 233 565 83 197 658 544 29 274 397 280 159 524 660 165 584 353 403 104 291 537 45 547 306 30 172 536 111 430 153 330 162 415 196 522 4 540 74 121 610 396 96 532 105 202 340 344 578 163 19 244 405 657 419 579 60 325 5 298 777 132 667 152 278 769 138 348 169 296 316 774 257 517 642 42 225 91 180 523 437 473 414 546 137 222 236 220 44 63 261 285 324 321 328 577 329 246 171 586 434 173 265 483 113 515 641 400 40 124 188 655 25 141 785 133 289 394 412 193 521 77 64 65 545 154 539 286 345 177 807 201 10 392 318 135 592 810 424 598 362 281 33 235 232 92 518 3 14 212 385 99 20 101 148 37 46 69 73 234 350 270 53 208 267 441 209 239 573 206 112 778 34 68 469 673 783 305 899 711 251 273 351 223 81 120 310 795 13 182 308 683 616 649 633 263 355 191 97 50 678 7 418 574 421 556 572 129 409 560 36 806 452 413 253 11 334 144 426 130 450 70 372 791 597 549 901 690 366 459 134 435 605 82 542 619 461 297 12 175 126 652 361 218 66 41 215 67 304 575 364 603 656 590 322 513 456 788 406 714 664 602 365 207 287 35 676 247 161 184 674 398 429 18 775 601 715 611 214 427 245 697 170 266 374 626 21 621 160 482 662 410 905 710 466 629 428 599 787 300 51 228 467 790 666 685 243 836 811 127 804 145 378 49 627 231 422 782 9 454 431 682 186 75 388 818 794 679 293 663 786 558 404 564 360 797 566 722 620 190 455 779 356 780 302 230 618 659 648 358 377 613 359 567 849 332 596 346 187 349 451 123 317 776 841 708 615 835 1 898 249 897 453 128 693 570 457 375 607 183 654 559 838 717 433 371 543 411 588 721 373 436 614 839 670 370 669 407 335 219 221 311 347 723 485 458 817 591 680 913 622 369 713 834 363 628 438 342 420 837 625 571 802 809 617 803 612 125 303 343 668 681 237 653 242 805 707 677 315 865 314 425 789 709 224 189 481 192 661 379 399 737 675 423 706 465 793 725 460 623 781 819 665 842 689 738 320 489 671 813 684 843 784 462 468 630 900 439 739 686 240 442

381 821 792 631 463 352 845 929 634 443 692 902 712 850 248 796 729 470 497 687 741 716 903 851 635 825 576 808 798 471 252 368 694 484 906 445 474 416 812 376 254 907 718 745 853 799 637 486 866 695 608 724 961 475 698 432 255 719 914 814 380 867 840 487 909 490 820 624 699 726 857 477 440 672 753 915 815 844 382 869 491 740 727 822 464 632 701 730 930 383 444 498 846 917 823 688 493 742 873 904 852 636 826 472 731 931 499 446 847 743 921 696 746 827 800 908 638 733 933 854 962 881 476 447 501 720 256 488 868 747 639 855 910 829 963 700 858 937 478 816 505 754 916 870 749 911 492 965 859 479 728 702 755 945 384 918 871 824 494 874 703 969 861 732 932 757 919 500 848 922 495 744 875 828 977 761 934 448 882 734 502 923 877 748 935 830 856 640 735 993 964 925 883 503 938 506 831 750 966 885 939 507 756 480 912 860 946 889 967 751 872 941 704 509 758 970 862 947 920 863 759 876 978 762 949 971 496 973 763 936 979 924 953 878 504 736 884 926 994 995 985 765 879 832 981 940 508 972 886 942 766 512 928 950 951 952 927 954 955 956 957 958 959 960 764 511 760 510 767 896 895 968 894 893 892 944 891 974 975 976 890 888 887 980 768 982 983 984 943 986 987 988 989 990 991 992 880 864 752 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 948].

Similarly, when the system uses BPSK and QAM modulation schemes, we also determine the reliability of the polar sequence $W\left(Q_i^{N_{\max}}\right)$ as follow:

$W\left(Q_i^{N_{\max}}\right)_{\text{BPSK}}$ = [79 78 537 519 55 547 91 59 32 6 71 99 72 523 553 138 549 149 263 579 84 228 48 31 267 389 276 521 39 293 201 43 546 147 75 197 76 53 134 51 516 7 148 54 86 578 74 323 290 45 154 68 15 533 112 196 113 517 387 305 29 166 52 135 30 143 340 515 266 531 643 58 77 100 275 325 10 268 37 269 46 96 69 581 131 141 150 322 163 47 337 564 83 102 520 396 329 8 328 358 194 343 36 40 21 61 18 151 219 23 26 297 153 56 4 103 262 260 155 160 291 404 11 271 136 281 536 87 2 104 67 19 101 90 144 272 235 126 44 386 518 33 385 152 274 342 265 540 522 356 25 193 106 42 139 334 140 278 34 529 165 41 24 132 530 594 183 209 561 145 38 242 14 353 142 64 214 176 332 264 314 93 20 393 177 207 231 98 289 27 116 234 130 89 525 114 212 13 66 294 3 642 105 514 641 187 156 277 182 133 279 164 542 296 259 769 786 9 175 270 82 169 80 550 543 174 617 324 650 94 674 513 16 586 57 111 292 545 419 146 552 258 225 300 315 195 120 335 528 65 304 35 117 115 307 675 110 398 12 118 170 1 651 162 524 28 22 172 399 286 97 273 50 17 257 588 282 198 159 200 73 158 237 558 70 204 658 585 613 206 218 556 161 186 583 215 108 85 310 303 95 317 81 243 425 137 565 202 180 625 577 562 567 406 409 124 284 346 584 60 287 392 570 648 566 189 646 347 597 451 590 779 129 92 770 526 261 596 774 221 288 551 677 339 311 63 321 527 230 362 233 405 421 775 88 661 123 49 122 309 283 188 302 647 571 407 402 778 107 401 659 457 453 326 357 450 109 285 532 5 171 210 394 331 653 298 245 190 359 168 593 306 610 772 308 569 433 167 354 185 391 127 563 665 559 157 62 611 534 587 119 645 535 213 341 644 181 781 589 363 787 548 539 355 395 418 349 208 280 410 226 598 591 184 295 125 833 580 199 369 361 333 601 420 609 390 338 555 179 229 241 173 327 217 557 785 203 205 411 216 706 313 397 388 417 554 771 673 582 178 299 345 403 789 538 649 595 777 191 801 227 211 657 707 422 602 121 465 330 301 249 599 773 541 652 681 232 220 312 612 705 573 449 423 897 370 365 654 802 614 660 316 336 371 426 413 222 544 603 709 236 452 655 615 344 803 776 427 662 793 223 373 481 454 318 560 689 805 618 348 605 319 238 434 663 400 713 676 455 244 666 834 780 429 619 360 458 350 568 377 239 435 835 678 592 782 128 626 809 408 572 246 667 788 364 351 621 459 721 679 783 247 600 627 437 412 790 682 466 192 574 366 250 708 837 669 424 461 898 372 817 575 604 367 414 656 251 791 467 629 710 441 683 841 804 737 616 224 899 794 428 690 374 415 711 253 685 482 806 606 633 469 320 664 795 901 714 375 456 691 620 430 849 607 240 378 483 807 436 715 836 473 810 797 431 668 693 905 622 352 460 379 485 722 248 784 680 438 865 628 811 717 838 623 670 462 381 697 723 818 913 439 576 489 839 630 684 368 792 813 468 252 442 671 842 738 463 819 900 725 416 631 929 712 497 254 443 686 470 843 739 634 821 902 796 376 692 729 808 850 608 484 687 471 255 741 445 635 961 845 903 716 474 825 432 694 798 906 851 380 637 799 486 475 745 866 718 695 812 853 907 624 698 914 724 382 487 477 440 719 753 909 867 490 840 814 915 672 383 857 699 820 726 869 464 491 815 701 917 930 498 740 632 727 444 873 493 844 822 921 931 730 636 499 881 688 823 962 256 472 846 446 826 904 742 933 731 501 852 963 447 746 743 733 854 965 476 847 800 937 827 638 908 829 696 505 868 720 855 945 747 639 749 969 384 700 911 479 916 728 910 754 918 875 478 448 832 848 831 830 828 816 768 767 856 766 858 859 860 861 862 863 864 765 764 763 762 761 870 871 872 760 874 759 876 877 878 879 880 758 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 757 756 755 752 751 750 748 744 736 735 734 732 704 703 702 912 640 512 511 510 509 508 919 920 507 922 923 924 925 926 927 928 506 504 503 932 502 934 935 936 500 938 939 940 941 942 943 944 496 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 495 494 492 964 488 966 967 968 480 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 824].

$W\left(Q_i^{N_{\max}}\right)_{\text{16QAM}}$ = [371 119 95 125 399 591 587 79 63 605 598 175 328 899 183 775 662 651 311 231 603 660 158 647 192 120 96 235 373 207 215 335 111 571 359 123 94 779 219 599 427 242 303 28 542 710 364 390 420 190 208 804 152 316 600 708 646 423 276 615 264 84 782 666 245 667 156 287 406 709 279 606 27 538 272 363 176 543 184 841 563 678 278 89 238 789 365 410 560 527 413 787 315 774 391 198 567 518 790 159 48 422 46 783 34 459 663 835 585 595 407 88 554 126 166 588 458 187 310 66 594 151 805 523 619 347 345 93 216 392 555 541 21 91 20 803 834 132 537 465 92 370 386 160 23 802 898 221 532 369 573 237 897 54 679 236 338 262 455 533 586 106 174 689 648 404 56 424 55 584 737 62 394 528 7 457 229 45 611 837 8 277 358 141 38 781 243 580 103 566 292 234 109 612 793 31 556 179 64 481 298 665 144 654 550 602 32 150 614 435 143 675 833 655 596 57 136 301 713 582 76 309 259 263 333 170 589 644 682 182 429 355 188 60 362 41 426 30 610 350 344 300 327 656 314 189 39 535 673 590 16 204 196 597 124 433 569 122 117 75 308 346 40 265 530 98 312 643 707 230 334 12 163 297 232 296 360 332 258 514 695 260 37 434 331 167 540 349 652 400 282 24 90 393 217 36 544 411 539 336 806 326 570 627 776 18 302 47 294 155 577 557 389 579 552 25 565

317 283 361 68 169 78 307 222 86 568 581 641 205 281 59 576 318 683 107 102 4 409 437 180 388 202 299 1 658 553 220 178 226 526 52 53 451 348 313 342 105 266 519 121 203 270 108 454 209 330 212 601 319 664 712 642 206 128 228 516 868 61 181 452 320 74 809 901 377 403 343 786 110 118 280 773 791 441 583 817 304 701 233 172 271 354 148 727 812 201 146 559 721 632 694 574 836 15 417 681 551 618 777 42 129 10 58 154 520 626 653 578 210 69 291 2 450 770 405 418 26 134 340 865 339 796 645 904 321 225 397 73 116 142 562 295 357 157 77 171 799 780 87 286 661 185 227 592 669 173 115 657 135 337 199 43 387 534 428 33 810 529 85 186 19 261 239 613 6 453 547 112 677 401 649 97 395 623 140 80 67 100 197 913 177 425 788 558 536 531 244 72 145 617 621 306 772 191 398 684 844 575 223 269 3 743 249 852 769 608 214 724 747 164 692 726 366 561 195 275 356 742 564 676 268 29 905 466 218 730 778 99 194 467 572 461 168 525 629 13 826 130 408 733 81 522 161 51 9 521 545 372 14 792 699 718 798 731 114 274 323 101 456 795 631 127 705 716 22 289 257 740 421 849 200 82 396 153 517 963 842 288 246 687 147 691 224 794 193 620 634 322 524 719 771 213 838 104 137 513 341 593 680 686 624 933 801 290 70 659 822 273 921 284 329 241 637 625 515 672 267 674 285 847 820 139 436 462 746 65 714 671 622 375 402 668 549 785 17 133 604 305 698 211 846 670 706 609 412 83 165 909 690 628 35 325 5 44 324 71 247 797 131 548 442 546 616 930 293 113 138 635 650 827 49 162 784 430 149 50 815 469 929 808 240 367 741 379 823 754 374 908 911 807 419 914 439 814 353 438 250 873 722 607 840 715 858 907 915 738 857 855 962 688 725 753 818 11 859 811 910 378 843 431 351 630 723 633 839 965 869 825 381 483 711 414 415 819 443 854 636 449 717 937 385 900 917 697 352 489 482 850 931 497 866 460 851 881 685 813 845 821 867 468 745 470 251 463 829 902 906 903 693 696 739 729 870 253 248 853 749 484 916 485 961 471 871 473 638 945 368 445 918 700 474 755 800 720 475 252 969 874 757 861 486 639 416 816 376 728 919 702 932 487 875 922 432 732 254 934 477 490 380 824 923 848 255 703 882 744 977 491 761 877 935 440 883 734 828 964 382 938 925 498 464 856 383 748 444 735 830 493 939 885 499 966 993 912 860 750 472 831 446 946 756 872 967 941 501 970 751 640 476 862 920 889 947 447 488 758 876 863 971 478 759 924 505 256 949 704 978 878 762 492 936 479 884 973 926 979 763 879 953 384 736 494 940 886 500 927 994 832 765 981 495 968 887 752 942 995 502 890 948 448 985 943 972 864 891 503 997 950 760 506 480 893 1001 974 951 507 980 954 880 764 975 1009 928 509 955 766 982 496 996 888 983 957 767 986 944 987 504 892 998 989 999 894 952 1002 508 895 1003 976 956 510 1010 1005 958 511 1013 1011 959 768 984 1017 988 1004 512 1006 1007 1008 1000 960 992 1012 991 1014 1015 1016 990 1018 1019 1020 1021 1022 1023 1024 896].

From the design results achieved, we run simulations to evaluate the FER performance of polar codes at different coding rates, parameter sets (N, K). For example, in case using QPSK modulation scheme, information set of polar code (1024, 512) is selected as follow:

A=[1,9,49,51,75,123,125,127,128,145,183,186,187,189,19
0,192,219,221,224,228,230,231,237,240,242,243,248,249,252,254,2
55,256,293,300,302,303,311,314,315,317,320,332,335,342,343,346,
347,349,352,356,358,359,360,363,368,369,370,371,373,375,376,377
,378,379,380,381,382,383,384,388,399,404,407,411,416,420,422,42
3,425,431,432,433,436,438,439,440,442,443,444,445,446,447,448,4
51,453,454,455,457,458,460,462,463,464,465,467,468,470,471,472,
474,475,476,477,478,479,480,481,484,485,486,487,488,489,490,491
,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,50
7,508,509,510,511,512,543,558,559,564,566,567,570,571,576,588,5
91,596,607,608,612,613,614,615,617,618,620,622,623,624,625,627,
628,630,631,632,634,635,636,637,638,639,640,648,653,654,659,661
,663,665,666,668,669,670,671,672,675,677,679,680,681,682,684,68
5,686,687,688,689,692,693,694,695,696,698,699,700,701,702,703,7
04,706,707,708,709,712,713,716,717,718,719,720,721,722,723,724,
725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740
,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,75
6,757,758,759,760,761,762,763,764,765,766,767,768,776,779,780,7
81,782,784,786,789,790,792,793,794,796,797,798,799,800,802,803,
804,805,808,809,811,812,813,814,815,816,817,818,819,820,821,822
,823,824,825,826,827,828,829,830,831,832,834,835,836,837,838,83
9,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,8
55,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,
871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886
,887,888,889,890,891,892,893,894,895,896,897,898,900,902,903,90
4,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,9
21,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,
937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952
,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,96
8,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,9
84,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,
1000,1001,1002,1003,1004,1005,1006,1007,1008,1009,1010,1011,1
012,1013,1014,1015,1016,1017,1018,1019,1020,1021,1022,1023,10
24].

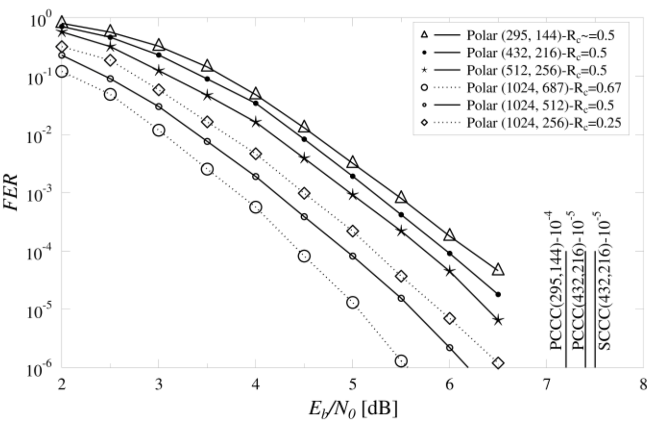

Figure 3: FER performance of Polar code in HAPS based communication system over a Rician fading channel (Rician fator K_R=10 dB).

The results of performance evaluation for HAPS systems using polar code and QPSK modulation are shown in Fig. 3. The achieved results show that the coding gain of HAPS systems using polar codes is improved by about 0.9 dB compared to the coding mechanisms used in [3]. Moreover, the decoder does not have to perform as many decoding iterations as in [3, 4].

CONCLUSIONS

In this paper, we have presented the research results of Polar code used as channel code in HAPS based communication systems including design results and FER performance evaluation. In particular, the typical channel considered for a HAPS-based communication system is a Rician fading channel with a rice factor of 10 dB. In the case of systems using QPSK modulation, the results have shown an improvement in the coding gain of about 0.9 dB compared to the other coding schemes proposed in [3] without having to performn the decoding iterations. We hope the results achieved will be benchmarking for design and deployment of HAP systems in practice.

REFERENCES

[1]. Michael Tseytlin, ITU - High Altitude Platform Stations (HAPS) - bringing connectivity to all. [online] Available at: https://news.itu.int/high-altitude-platform-stations-haps-bringing-connectivity-to-all/ [Accessed 16 June 2020].

[2]. D. Grace and M. Mohorcic, Broadband Communications via High Altitude Platforms. John Wiley & Sons, 2011.

[3]. A. Boch, M. Laddomada, M. Mondin, and F. Daneshgaran, “Advanced channel coding for hap-based broadBand services [internetworking and resource management in satellite systems series],” IEEE Aerospace and Electronic Systems Magazine, vol. 22, no. 9, pp. C–7, 2007.

[4]. Nguyen Thu Hien, Vu Van San, Nguyen Viet Hung, Le Nhat Thang, Design of a near-capacity channel code for High Altitude Platform systems, Journal of Military Science and Technology, pp.52-59, Number 52, December 2017.

[5]. E. Arikan: “Channel polarization: a method for constructing capacity-achieving codes for symmetric binary-input memoryless channels,” IEEE Trans. Inf. Theory 55 (2009) 3051 (DOI: 10.1109/TIT.2009.2021379).

[6]. E. Arikan, “Channel polarization: A method for constructing capacity achieving codes for symmetric binary-input memoryless channels,” IEEE Trans. Inf. Theory, vol. 55, no. 7, pp. 3051–3073, Jul. 2009.

[7]. R.Mori and T. Tanaka, “Performance of polar codes with the construction using density evolution,” IEEE Commun. Lett., vol. 13, no. 7, pp. 519–521, Jul. 2009.

[8]. Liu, Jingbo, and Jin Sha. "Frozen bits selection for polar codes based on simulation and BP decoding." *IEICE Electronics Express* (2017): 14-20170026.