

Appendix I

Proofs of Chapter 4

IV.1 Proofs of upper bound of ABEP (4.65)

The SNR of NU is expressed as

$$\begin{aligned}\gamma_{\max}^{\text{NU}} &= \frac{\left| \left(\sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^N \xi_i \mu_{ij} \lambda_{jk} \zeta_k^{\text{NU}} \right) \right|^2 \alpha_1 P_t}{P_1 N_0} \\ &= \frac{Z_{\text{NU}} \alpha_1 P_t}{P_1 N_0},\end{aligned}\tag{IV.1}$$

where

$$Z_{\text{NU}} = \left| \left(\sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^N \xi_i \mu_{ij} \lambda_{jk} \zeta_k^{\text{NU}} \right) \right|^2.\tag{IV.2}$$

Further, Z_{NU} follows the Gaussian distribution [76] with mean and variance as

$$E\{Z_{\text{NU}}\} = N^3 \sqrt{\frac{\pi^4}{64 P_1 (K+1)^4}} L_{\frac{1}{2}}^4(-K^2/K+1),$$

and

$$\text{VAR}\{Z_{\text{NU}}\} = \frac{N^3}{P_1} \left(1 - \frac{\pi^4}{64 (K+1)^4} L_{\frac{1}{2}}^8(-K^2/K+1) \right),\tag{IV.3}$$

where $L_{\frac{1}{2}}(\cdot)$ denotes the Laguerre polynomial of degree $1/2$. The maximized SNR of NU ($\gamma_{\max}^{\text{NU}}$) is non-central chi-square distribution with a degree of freedom is one. Therefore, its moment generating function (MGF) is expressed as

$$M_{\gamma_{\max}^{\text{NU}}}(s) = \frac{\exp\left(\frac{\frac{sN^6\pi^4 L_{1/2}^8(-K^2/K+1)\alpha_I P_t}{64(K+1)^4(P_1 N_0)}}{1 - \frac{sN^3[64(K+1)^4 - \pi^4 L_{1/2}^8(-K^2/K+1)]\alpha_I P_t}{32(K+1)^4(P_1 N_0)}}\right)}{\sqrt{1 - \frac{sN^3[64(K+1)^4 - \pi^4 L_{1/2}^8(-K^2/K+1)]\alpha_I P_t}{32(K+1)^4(P_1 N_0)}}}. \quad (\text{IV.4})$$

Furthermore, in general, BEP for BPSK can be expressed as

$$P_e = \frac{1}{\pi} \int_0^{\pi/2} M_{\gamma_{\max}}\left(-\frac{1}{\sin^2 \eta}\right) d\eta. \quad (\text{IV.5})$$

Therefore, the average BEP (ABEP) of NU for BPSK modulation is expressed as

$$P_e^{\text{NU}} = \frac{1}{\pi} \int_0^{\pi/2} \frac{1}{\sqrt{1 + \frac{N^3[64(K+1)^4 - \pi^4 L_{1/2}^8(-K^2/K+1)]\alpha_I P_t}{32(K+1)^4(P_1 N_0) \sin^2 \eta}}} \times \exp\left(-\frac{\frac{N^6\pi^4 L_{1/2}^8(-K^2/K+1)\alpha_I P_t}{64(K+1)^4(P_1 N_0) \sin^2 \eta}}{1 + \frac{N^3[64(K+1)^4 - \pi^4 L_{1/2}^8(-K^2/K+1)]\alpha_I P_t}{32(K+1)^4(P_1 N_0) \sin^2 \eta}}\right) d\eta. \quad (\text{IV.6})$$

The upper bound of ABEP of NU by considering $\eta = \pi/2$ is expressed as

$$P_e^{\text{NU}} \leq \frac{0.5 \exp\left(\frac{-\frac{N^6\pi^4 L_{1/2}^8(-K^2/K+1)\alpha_I P_t}{64(K+1)^4 P_1 N_0}}{1 + \frac{N^3[64(K+1)^4 - \pi^4 L_{1/2}^8(-K^2/K+1)]\alpha_I P_t}{32(K+1)^4 P_1 N_0}}\right)}{\sqrt{1 + \frac{N^3[64(K+1)^4 - \pi^4 L_{1/2}^8(-K^2/K+1)]\alpha_I P_t}{32(K+1)^4 P_1 N_0}}}. \quad (\text{IV.7})$$

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Author's Publications

Journals

1. **M. Hemanta Kumar**, Sanjeev Sharma, M. Thottappan, and Kuntal Deka. "Precoded spatial modulation-aided cooperative NOMA", *IEEE Communications Letters* 25, no. 6 (2021): 2053-2057.
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