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Supplementary materials for

Zhe WANG, Jiayi ZHANG, Wenhui YI, Huahua XIAO, Dusit NIYATO, Bo AI, 2024. Effective degree of freedom for near-field plane-based XL-MIMO with tri-polarization. *Front Inform Technol Electron Eng*, 25(12):1723-1731. https://doi.org/10.1631/FITEE.2400167

Numerical results

In Fig. S1, we compare the EDoF performance between the UPA and 2D CAP plane systems over the dyadic Green channel for various transmitting distances. As observed, with the number of antennas increasing, the EDoF performance of the UPA system initially increases and finally converges to that of the 2D CAP plane system. For the UPA system with a fixed physical size, increasing the number of antennas may not always improve the EDoF performance, where an approximately saturated EDoF performance can be achieved under a particular number of antennas. For instance, for $D = 15\lambda$, only 0.22% EDoF performance improvement can be achieved for $N_\mathrm{t} = 18$ compared with $N_\mathrm{t} = 16$; it is costly to add a total of 68 antennas to achieve a relatively small EDoF performance improvement. Thus, it is crucial to design the UPA system with a proper number of antennas to achieve nearly optimal EDoF performance.

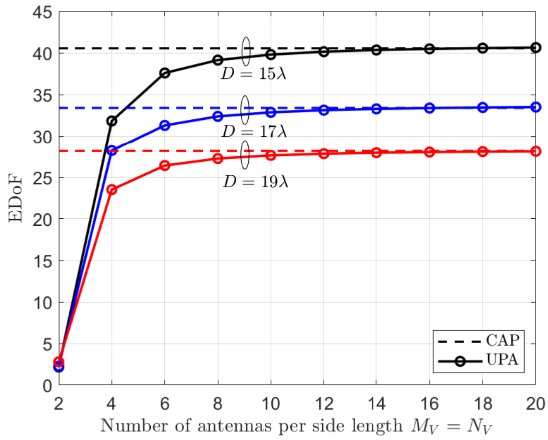

Fig. S1 EDoF performance for the UPA system with $L_\mathrm{t} = L_\mathrm{r} = 8\lambda$ and the 2D CAP plane system over the dyadic Green channel

Fig. S2 considers the EDoF for the 2D CAP plane system as a function of transmitting distance D over different numbers of polarization. Note that the triple-, double-, and single-polarization scenarios represent all three of the polarization directions, considering only the x and y polarization directions, and only the x polarization direction for the transceiver, respectively. As observed, the near field with Green function based channel can significantly enhance the EDoF performance compared to the far field with only 1 EDoF. The consideration of more polarization directions can improve the EDoF performance; for example, 109.8% and 93.85% EDoF improvements can be achieved for the triple-polarization scenario for $D = 4$ m compared with the double-polarization and single-polarization scenarios, respectively, because more EM waves can be impinged from different polarization directions. Additionally, with the increase of D, the performance gap between the triple- and double-polarization scenarios becomes smaller because z polarization vanishes with increasing transmitting distance.

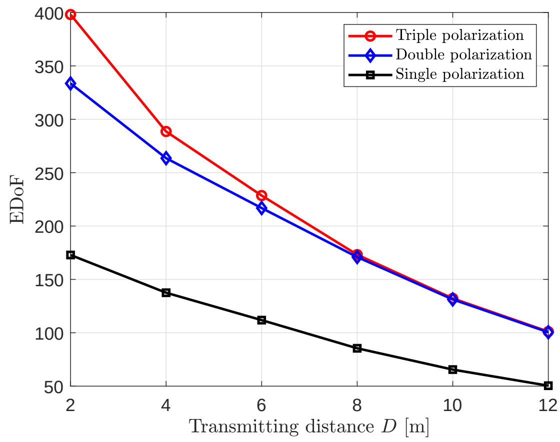

Fig. S2 EDoF performance against the transmitting distance D for the 2D CAP plane system over the dyadic Green channel with single, double, or triple polarization, with $L_\mathrm{t} = L_\mathrm{r} = 30\lambda$

In Fig. S3, we evaluate the effect of the physical size of the 2D CAP plane system on the EDoF performance. It is found that the EDoF benefits from a larger physical size of both the transmitter and the receiver. For instance, for $L_\mathrm{r} = 15\lambda$, 27.6% EDoF improvement can be achieved for the scenario with $L_\mathrm{t} = 20\lambda$ compared with the scenario with $L_\mathrm{t} = 15\lambda$. For the scenario with $L_\mathrm{t} = 15\lambda$, the scenario with $L_\mathrm{r} = 20\lambda$ can achieve 14.69% EDoF improvement compared with the scenario with $L_\mathrm{r} = 15\lambda$. However, for a fixed value of L_t or L_r, the improvement rate of the EDoF performance would decrease with increasing L_r or L_t, because the EDoF performance is constrained by the smaller one between the physical sizes of the transmitter and the receiver. A similar argument is widely established in existing works, such as Tse and Viswanath (2005), stating that for discrete arrays, the DoF is limited by the smaller numbers of transmitting and receiving antennas. However, the similar conclusion for the near-field based CAP system above is motivated by the numerical results without detailed proof steps. Therefore, a comprehensive proof of this conclusion remains a necessary focus and a promising direction for future studies.

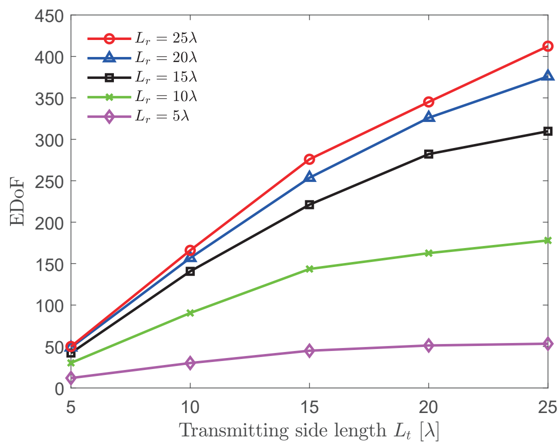

Fig. S3 EDoF performance against the side length of the 2D CAP plane transmitter L_t over the dyadic Green channel with different values of the side length of the 2D CAP plane receiver, with $D = 13\lambda$

Reference

Tse D, Viswanath P, 2005. Fundamentals of Wireless Communication. Cambridge University Press, Cambridge, UK.