Implications of Polarization Impurity on Diversity for 5G Networks

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Abstract—Millimeter-waves offer the possibility of high data rate for wireless communications. With fifth generation (5G) system designers looking to combine satellite and terrestrial signals at the mobile handset, we consider the beneficial impact, using realistic system parameters, of a third orthogonal polarization at the receiver as a method of improving signal reception.

I. INTRODUCTION

Mobile wireless communications are primarily driven by data transfer rates. Studies concentrating on fifth generation (5G) devices have recently reported rates of between 1.2 Gbs^{-1} [1], up to 1 Tbs^{-1} over a fixed link [2]. The lower bound of these ranges was obtained at 28 GHz, in a mobile scenario. An objective of 5G mobile systems is that wireless and satellite communications may stand together [3]. With a mobile receiver, misalignment issues may prevail. In order to increase data rate in any direction without compromising link reliability, a tri-orthogonal arrangement at the receiver would allow for active beamsteering in three directions [4].

This abstract highlights the possibilities for tri-orthogonal polarization at the receiver and suggests that the inclusion of a third orthogonal polarization would provide enhanced capacity performance, provided mutual coupling is kept low. Figure 1 provides the channel arrangement.

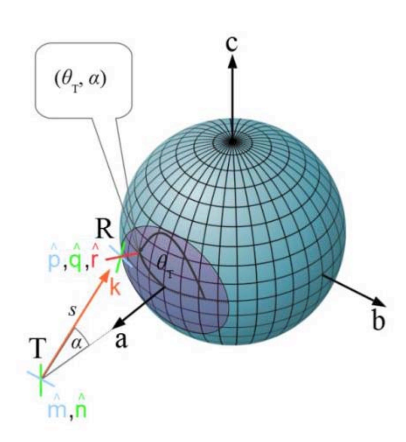

Fig.1. A circularly polarized signal is transmitted from the transmitter T while a tri-orthogonal arrangement at the receiver R allows for enhanced signal reception using MIMO techniques. All antenna orientations are considered.

II. RESULTS

We present simulated performance of a circularly polarized (CP) transmitter at T operating at 28 GHz, with a bandwidth of 250 MHz, a gain profile of 24 dB, transmit power of 29 dBm [5], and an antenna noise temperature of 290 K. At the receiver R, we consider a tri-orthogonal arrangement with dipole-like radiation patterns on each polarization. We consider all antenna orientations at the receiver, and compare capacity performance with that of a CP receiver. We consider the channel [6] to be 20 m in length.

Figure 2(a) shows the percentage capacity enhancement as a result of implementing a third orthogonal polarization at R over a line-of-sight (LoS) channel, and assuming low mutual coupling of -20 dB, while 2(b) shows the capacity enhancement assuming no decoupling at R.

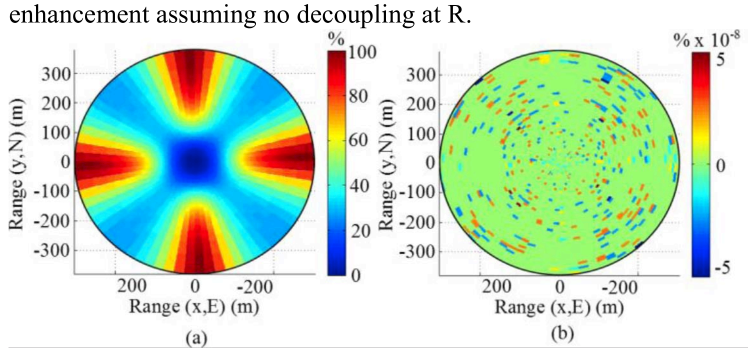

Fig.2. Percentage capacity enhancement over that of a CP antenna at R as a result of implementing a third polarization at R: (a) polarization purity maintained, (b) no mutual decoupling of orthogonal polarizations.

To provide high data transfer rates, or capacity, engineers look to higher operating frequencies. In the case of 5G, millimeter-wave frequencies ranging from 28–80 GHz are cited as potential candidates [7]. Operating at frequencies in this range provides a fundamental challenge. Nonlinear and intermodulation effects reduce the ability to radiate high power, and this reduces range, requiring smaller network cells and higher operating costs.

To mitigate these issues, we may consider pattern diversity at the antenna. This provides an option to steer radiated power in an optimal direction of propagation. By doing this, we maintain high capacity through efficiency of propagation.

In Figure 3, we provide simulated results of pattern diversity. The radiation patterns are provided through relative phase changes of three radiators colocated in a tri-orthogonal arrangement. Tri-orthogonal polarization techniques [8] may provide the benefit of polarization diversity, and hence pattern diversity, over an increased range of link directions. A design has been constructed and tested at 6 GHz. The design is based on a slot antenna [9] and, due to symmetry and orthogonality, is scalable to higher operating frequencies.

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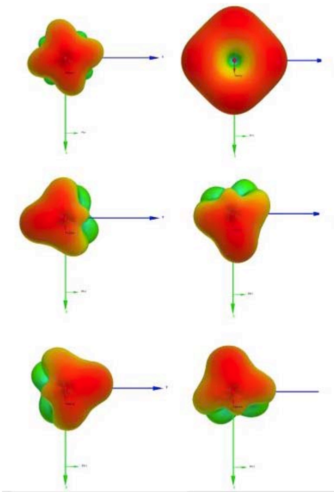

Fig. 3. Polarization isolation allows pattern diversity, or beamsteering, in three orthogonal directions through relative phasing techniques [4]. Simulated results are shown here of a physical design with 35 dB polarization isolation.

Polarization diversity provides a solution for compact antennas with reduced mutual coupling [10]. Our design provides polarization isolation of no less than 35 dB in a frequency band of overlapping operation.

In [11], two identically polarized dipoles illuminated by a single plane wave are brought together, increasing the mutual coupling between the dipoles as a consequence. Capacity depends on received signal power, and for small spacings the capacity is seen to be higher than that of widely spaced dipoles, before dropping significantly as the limit of no dipole spacing is reached. This is highlighted in Figure 4. In an increasingly mobile world, polarization alignment of antenna and incoming signal is typically not the case, and in this instance high mutual coupling is detrimental to system performance.

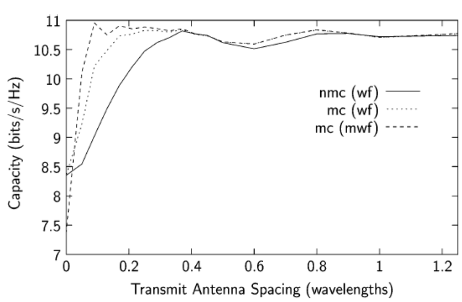

Fig. 4. Capacity is seen to increase when two identically polarized dipoles are closely spaced, as a consequence of mutual coupling. Mutual coupling is detrimental to pattern diversity and beamsteering of antenna radiation. After [11].

In Figure 5, we provide simulated results of normalized capacity enhancement for a tri-orthogonal arrangement as a function of mutual coupling over a field of view, or all receive antenna orientations, in a LoS channel using a modeling technique as observed in Figure 1 [12].

III. SUMMARY

A classical analysis based on received power suggests that capacity enhancement is maintained using colocated tri-orthogonal radiators for a mutual coupling coefficient of 0.3 or less, corresponding to a polarization isolation of 10.5 dB or greater. This is in line with similar studies [13]. Additional studies, however, point to the necessity to maintain mutual coupling as low as possible [14], and our physical design provides this, which in turn provides pattern diversity.

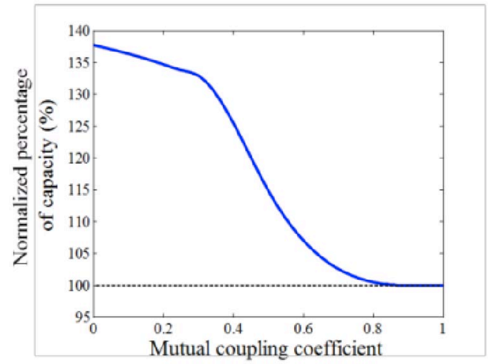

Fig. 5. Normalized capacity enhancement over all antenna orientations in a circularly polarized transmit antenna field of view (see Figure 1) for a tri-orthogonal receive antenna over a circularly polarized receive antenna, as a function of mutual coupling.

REFERENCES

[1] Samsung Electronics Inc., http://www.samsung.com/global/business-images/insights/2015/Samsung-5G-Vision-0.pdf

[2] University of Surrey, UK. Source: http://www.v3.co.uk/v3-uk/news/2396249/exclusive-university-of-surrey-achieves-5g-speeds-of-1tbps

[3] K. M. Mak, H. W. Lai, K. M. Luk, and C. H. Chan, "Circularly polarized patch antenna for future 5G mobile phones," *IEEE Access*, vol. 2, pp. 1521–1529, 2014.

[4] P. Hall, "Application of sequential feeding to wide bandwidth, circularly polarised microstrip patch arrays," *Microwaves, Antennas and Propagation, IEE Proceedings H*, vol. 136, no. 5, pp. 390–398, Oct 1989.

[5] T. Rappaport , S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. Wong, J. Schulz, M. Samimi, F. Gutierrez, "Millimeter wave mobile communications for 5G cellular: it will work!", *IEEE Access*, 1:335–349, 2013.

[6] Goldsmith A. *Wireless Communications.* Cambridge University Press: Cambridge, UK, 2005.

[7] Quotient Associates Ltd., "5G candidate band study: study on the suitability of potential candidate frequency bands above 6GHz for future 5G mobile broadband systems," Final Report to Ofcom (UK), March 2015.

[8] M. Andrews, P. Mitra, and R. de Carvalho, "Tripling the capacity of wireless communications using electromagnetic polarization," *Nature*, vol. 409, pp. 316–318, 2001.

[9] R. Paryani, P. Wahid, and N. Behdad, "A wideband, dual-polarized, substrate-integrated cavity-backed slot antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 645–648, 2010.

[10] R. Nabar, H. Bolcskei, V. Erceg, D. Gesbert, and A. Paulraj, "Performance of multiantenna signaling techniques in the presence of polarization diversity," *IEEE Transactions on Signal Processing*, vol. 50, no. 10, pp. 2553–2562, Oct 2002.

[11] J. W. Wallace and M. A. Jensen, "Mutual coupling in MIMO wireless systems: a rigorous network theory analysis," *IEEE Transactions on Wireless Communications*, vol. 3, no. 4, pp. 1317–1325, 2004.

[12] N. P. Lawrence, B. W.-H. Ng, H. J. Hansen, D. Abbott, "Analysis of millimetre-wave polarization diverse multiple-input multiple-output capacity", *Royal Society Open Science*, 2, 150322, 2015. doi: 10.1098/rsos.150322.

[13] Y. Gao, S. Wang, O. Falade, X. Chen, C. Parini, and L. Cuthbert, "Mutual coupling effects on pattern diversity antennas for MIMO femtocells," *International Journal of Antennas and Propagation*, vol. 2010, Article ID 756848, 2010.

[14] C. Y. Chiu, C. H. Cheng, R. D. Murch and C. R. Rowell, "Reduction of mutual coupling between closely-packed antenna elements," in *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 6, pp. 1732–1738, June2007.