







- [9] V. Weerackody, "Diversity for direct-sequence spread spectrum system using multiple transmit antennas", in Proc. IEEE ICC, pp. 1775–1779, May 1993.
- [10] J. Winters, J. Salz, and R. D. Gitlin, "The impact of antenna diversity on the capacity of wireless communication systems," IEEE Trans. Commun., vol. 42, no. 234, pp. 1740–1751, 1994.
- [11] R. U. Nabar, H. Bolcskei, and F. W. Kneubuhler, "Fading relay channels: Performance limits and space-time signal design," IEEE J. Selected Areas Commun., vol. 22, no. 6, pp. 1099–1109, Aug. 2004.
- [12] G. Kramer, M. Gastpar, and P. Gupta, "Cooperative strategies and capacity theorems for relay networks", IEEE Trans. Inf. Theory, vol. 51, no. 9, pp. 3037–3063, Sep. 2005.
- [13] M. Gastpar, and M. Vetterli, "On the capacity of large Gaussian relay networks", IEEE Trans. Inf. Theory, vol. 51, no. 3, pp. 765–779, March 2005.
- [14] A. J. Paulraj, R. U. Nabar and D. A. Gore, "Introduction to space-time wireless communications", Cambridge, UK, Cambridge Univ. Press, 2003.
- [15] G. B. Giannakis, Z. Liu, X. Ma and S. Zhou, "Space time coding for broadband wireless communications", Wiley, 2004.
- [16] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity—Part I: System description", IEEE Trans. Commun., vol. 51, no. 11, pp. 1927–1938, Nov. 2003.
- [17] —, "User cooperation diversity—Part II: Implementation aspects and performance analysis", IEEE Trans. Commun., vol. 51, no. 11, pp. 1938–1948, Nov. 2003.
- [18] J. N. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior", IEEE Trans. Inform. Theory, vol. 50, no. 12, pp. 3062–3080, 2004.
- [19] L. Cao, J. Zhang, N. Kanno, "Multi-user cooperative communications with relay-coding for uplink IMT-advanced 4G systems", IEEE GLOBECOM Proc. Honolulu, vol. 1, no. 1, pp. 1–6, Nov. 2009.
- [20] M. Janani, A. Hedayat, T. E. Hunter, and A. Nosratinia, "Coded cooperation in wireless communications: Space-time transmission and iterative decoding," IEEE Trans. Signal Process., vol. 52, no. 2, pp. 362–371, Feb. 2004.
- [21] J. N. Laneman and G. W. Wornell, "Distributed space-time block coded protocols for exploiting cooperative diversity in wireless networks," IEEE Trans. Inf. Theory, vol. 49, no. 10, pp. 2415–2425, Oct. 2003.
- [22] H. El Gamal and D. Aktas, "Distributed space-time filtering for cooperative wireless networks," in Proc. Global Telecommunications Conf., San Francisco, CA, Dec. 2003, pp. 1826–1830.
- [23] S. Yiu, R. Schober, "Distributed Space time block Coding", IEEE Trans. Commun., vol. 54, no. 7, pp. 1195–1206, July 2006.
- [24] X. B. Liang and X. G. Xia, "Unitary signal constellations for differential space-time modulation with two transmit antennas: Parametric codes, optimal designs, and bounds", IEEE Trans. Inform. Theory, vol. 48, no. 8, pp. 2291–2322, Aug. 2002.
- [25] H. Wang and X. G. Xia, "Upper bounds of rates of complex orthogonal space-time block codes", IEEE Trans. Inform. Theory, vol. 49, no. 10, pp. 2788–2796, Oct. 2003.
- [26] K. Lu, S. Fu, and X. G. Xia, "Closed form designs of complex orthogonal space-time block codes of rates  $(k+1)/(2k)$  for  $2k-1$  or  $2k$  transmit antennas", IEEE Trans. Inform. Theory, vol. 51, no. 12, pp. 4340–4347, Dec. 2005.
- [27] A. Bletsas, H. Shin, M. Z. Win, "Cooperative Communications with Outage Optimal Opportunistic Relaying", IEEE Trans. Wireless Commun., vol. 6, no. 9, September 2007.
- [28] P. Larsson and H. Rong, "Large-scale cooperative relay network with optimal coherent combining under aggregate relay power constraints," in Proc. Working Group 4, World Wireless Research Forum WWRF8 Meeting, Feb. 2004.
- [29] Y. Jing and B. Hassibi, "Distributed space-time coding in wireless relay networks", IEEE Trans. Wireless Commun., vol. 5, no. 12, pp. 3524–3536, Dec. 2006.
- [30] J. Litva and T. K. Y. Lo, "Digital Beamforming in Wireless Communications", Artech House Publishers, 1996.
- [31] F. Gao, R. Zhang, and Y.-C. Liang, "Optimal channel estimation and training design for two-way relay networks," IEEE Trans. Commun., vol. 57, no. 10, pp. 3024–3033, Oct. 2009.
- [32] Y. Rong, M. R. A. Khandaker, Y. Xiang, "Channel estimation of dual-hop MIMO relay system via parallel factor analysis", IEEE Trans. Wireless Commun., vol. 11, no. 6, pp. 2224–2233, 2012.
- [33] F. Roemer, M. Haardt, "Tensor-based channel estimation and iterative refinements for two-way relaying with multiple antennas and spatial reuse", IEEE Trans. Signal Process., vol. 58, no. 11, pp. 5720–5735, 2010.
- [34] C. A. R. Fernandes, A. L. F. de Almeida, D. B. Costa, "Unified tensor modeling for blind receivers in multiuser uplink cooperative systems", IEEE Signal Process. Lett., vol. 19, no. 5, pp. 247–250, 2012.
- [35] A. L. F. de Almeida, C. A. R. Fernandes, D. Benevides da Costa, "Multiuser detection for uplink ds-cdma amplify-and-forward relaying systems", IEEE Signal Process. Lett., vol. 20, no. 7, pp. 697–700, 2013.
- [36] L. R. Ximenes, G. Favier, A. L. F. Almeida, Y. C. B. Silva, "PARAFAC-PARATUCK semi-blind receivers for two-hop cooperative MIMO relay systems", IEEE Trans. Signal Process., vol. 62, no. 14, pp. 3604–3615, 2014.
- [37] Xi Han, A. L. F. de Almeida and Z. Yang, "Cannel estimation for MIMO multi relay systems using a tensor approach", EURASIP J. Advances in signal processing, 2014.
- [38] Z. Fang and H. Shan "Comparison of channel estimation schemes for MIMO two-way relaying systems," in Proc. Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC), Ningbo, China, July 26–30, 2011, pp. 719–722.
- [39] Arti M. K., M. R. Bhatnagar, "Performance analysis of two way AF MIMO relaying of OSTBCs with imperfect channel gains", IEEE Trans. Vehicular Techn., vol. 63, no. 8, pp. 4118–4124, 2014.
- [40] A. Y. Panah and R. W. Heath, "MIMO two-way amplify-and-forward relaying with imperfect receiver CSI", IEEE Trans. Vehicular Techn., vol. 59, no. 9, pp. 4377–4387, Nov. 2010.

- [41] V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space-time codes for high data rate wireless communication: Performance analysis and code construction", *IEEE Trans. Inform. Theory*, vol. 44, no. 2, pp. 744–765, Mar. 1998.
- [42] S. M. Alamouti, "A simple transmitter diversity scheme for wireless communications", *IEEE J. Select. Areas Commun.*, vol. 16, pp. 1451–1458, Oct. 1998.
- [43] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs", *IEEE Trans. Inf. Theory*, vol. 45, pp. 1456-1467, July 1999.
- [44] —, "The application of orthogonal designs to wireless communication," in *Proc. IEEE Information Theory Workshop*, Killarney, Ireland, June 1998, pp. 46–47.
- [45] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block coding for wireless communications: Performance results", *IEEE J. Select. Areas Commun.*, vol. 17, no. 3, pp. 451-460, March 1999.
- [46] A. V. Geramita and J. Seberry, *Orthogonal Designs, Quadratic Forms and Hadamard Matrices*, Lecture Notes in Pure and Applied Mathematics, vol. 43. New York and Basel: Marcel Dekker, 1979.
- [47] M.O.Damen, A.Tewfik and J.C.Belfiore, "A construction of a space-time code based on number theory", *IEEE Trans. on Inform. Theory*, vol. 48, no. 3, pp. 753–60, Mar. 2002.
- [48] A.Shokrollahi, B.Hassibi, B.M.Hochwald, and W.Sweldens, "Representation Theory for High-Rate Multiple-Antenna Code Design", *IEEE Trans. on Inf. Theory*, vol. 47, no. 6, pp. 2335-67, Sep. 2001.
- [49] B.Hassibi and M.Khorrami, "Fully Diverse Multiple Antenna Signal Constellations and Fixed Point Free Lie Groups", in *proc. IEEE International Symp. on Inf. Theory*, 2001.
- [50] B.L.Hughes, "Optimal Space Time constellations from groups", *IEEE Trans. Inf. Theory*, vol. 49, no. 2, pp. 401-10, Feb. 2003.
- [51] A. Shokrollahi, "Design of Unitary Space-Time Codes from Representations of  $SU(2)$ ", in *proc. IEEE International Symp on Inf. Theory*, June 2001.
- [52] S. Galliou and J.-C. Belfiore, "A new family of full rate, fully diverse space time codes based on Galois theory", in *Proc. IEEE International Symp. Inform.Theory*, p. 419, IEEE, June 30-July 5, 2002.
- [53] B.A.Sethuraman, B.S.Rajan, and V. Shahsidhar "Full diversity high rate Space Time Block Codes from Division Algebras", *IEEE Trans.on Inf. Theory*, vol. 49, no. 10, pp. 2596-2616, Oct. 2003.
- [54] V. Shashidhar, K. Subrahmanyam, R. Chandrasekharan, B. Sundar Rajan, and B. A. Sethuraman, "High-rate, full-diversity STBC's from field extensions", in *Proc. IEEE Int. Symp. Information Theory*, Yokohama, Japan, pp. 126, June 29–July 4.
- [55] V. Shashidhar, B. Sundar Rajan, and B. A. Sethuraman, "STBC's using capacity achieving designs from cyclic division algebras", in *Proc. Communication Theory Symop., GLOBECOM*, San Francisco, CA, 2003.
- [56] H. Jafarkhani, "A quasi-orthogonal space-time block code", *IEEE Trans. Commun.*, vol. 49, no. 1, Jan. 2001.
- [57] O. Tirkkonen, A. Boariu, and A. Hottinen, "Minimal non-orthogonality rate 1 space-time block code for 3+ Tx antennas", in *Proc. International Symp. on Spread Spectrum Techniques and Applications*, vol. 2, pp. 429-432, Sept. 2000.
- [58] O. Tirkkonen, "Optimizing space-time block codes by constellation rotations", in *Proc. Finnish Wireless Commun. Workshop*, vol. 1, pp. 1-6, 2000.
- [59] W. Su and X. Xia, "Quasi-orthogonal space-time block codes with full diversity," in *Proc. Global Telecom. Conf.*, vol. 2, pp. 1098-1102, Nov. 2002.
- [60] H. Jafarkhani and N. Hassanpour, "Super-quasi-orthogonal space-time trellis codes for four transmit antennas," *IEEE Trans. Wireless Commun.*, vol. 4, pp. 215-227, Jan. 2005.
- [61] D. Wang and X. Xia, "Optimal diversity product rotations for quasi orthogonal STBC with MPSK symbols", *IEEE Commun. Lett.*, vol. 9, no. 5, pp. 420-422, May 2005.
- [62] N. Sharma and C. B. Papadias, "Improved quasi-orthogonal codes through constellation rotation", *IEEE Trans. Commun.*, Oct. 2001.
- [63] D. Rainish, "Diversity transform for fading channels", *IEEE Trans. Commun.*, vol. 44, pp. 1653-1661, Dec. 1996.
- [64] Y. Xin, Z. Wang, and G. B. Giannakis, "Space-time diversity systems based on linear constellation precoding", *IEEE Trans. Wireless Commun.*, vol. 2, no. 2, Mar. 2003.
- [65] S. Sandhu, R. W. Heath Jr., A. Paulraj, "Space time block codes versus space time trellis codes", *IEEE International conference on commun.*, vol.4, pp. 1132-1136, June 2001.
- [66] J. Cheng, H. Wang, M. Chen, S. Cheng, "Performance comparison and analysis between STTC and STBC", *IEEE Vehicular Tech. Conf.*, vol. 4, pp. 2487-2491.
- [67] S. Siwamogsatham and M. P. Fitz, "Improved high rate space time codes via orthogonality and set partitioning", *IEEE wireless commun. and networking conf.*, vol.1, pp. 264-70, March 2002.
- [68] H. Jafarkhani, N. Seshadri, "Super orthogonal space time trellis codes", *IEEE Trans. Inform. Theory*, vol. 49, no. 4, pp. 937-50, April 2003.
- [69] G. Ungerboeck, "Trellis coded modulation with redundant signal sets, part I: Introduction", *IEEE commun. Magazine*, vol. 25, no. 2, Feb. 1987.
- [70] S. Alamouti, V. Tarokh and P. Poon, "Trellis-coded modulation and transmit diversity: design criteria and performance evaluation", *IEEE International Conference on Universal Personal Communication*, vol.1, pp. 703-707, 1998.
- [71] V.Tarokh, A. Naguib, N. Seshadri, and A. R. Calderbank, "Space-time codes for high data rates wireless communications: performance criteria in the presence of channel estimation errors, mobility and multiple paths", *IEEE Trans. on Commun.*, vol. 47, no. 2, pp. 199–207, Feb. 1999.
- [72] T. Himsoon, W. Su, and K. J. R. Liu, "Differential Transmission for Amplify-and-Forward Cooperative Communications", *IEEE Signal Proc. lett.*, vol. 12, no. 9, pp. 597–600, Sep. 2006.
- [73] K. L. Clarkson, W. Sweldens, and A. Zheng, "Fast multiple antenna differential decoding", *IEEE Transactions on Commun.*, vol. 49, no. 2, pp. 253-261, Feb. 2001.

- [74] G. Ganesan and P. Stoica, "Space-time block codes: a maximum SNR approach", *IEEE Trans. on Inform. Theory*, vol. 47, no. 4, pp. 1650-1656, 2001.
- [75] B. L. Hughes, "Differential space-time modulation", *IEEE Trans. on Inform. Theory*, pp. 2567-2578, Nov. 2000.
- [76] M. R. Bhatnagar, A. Hjørungnes, L. Song, R. Bose, "Double-Differential decode and forward cooperative communications over Nakagami-m channels with carrier offsets", *IEEE Sarnoff Symposium*, pp. 1-5, April 2008.
- [77] G.J.Foschini, Jr., "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas", *Bell Labs Technical Journal*, pp. 41-59, Autumn 1996.
- [78] G.J.Foschini, Jr., D.Chizhik, M.J.Gans, C.Papadias, and R.A. Valenzuela, "Analysis and performance of some basic space-time architectures", *IEEE Journal on Selected Areas in Commun.*, vol. 21, no. 3, pp. 303-20, Apr. 2003.
- [79] P. W. Wolniansky, G. J. Foschini, G. D. Golden, and R. A. Valenzuela, "V-Blast: An architecture for realizing very high data rates over the rich-scattering channel", in *Proc. Int. Symp. Signals, Systems and Electronics*, pp. 295-300, 1998.
- [80] E.Viterbo and J.Boutros, "A universal lattice code decoder for fading channels", *IEEE Trans. on Information Theory*, vol.45, no.5, pp. 1639-42, July 1999.
- [81] M.Pohst, "On the computation of lattice vectors of minimal length, successive minima and reduced bases with applications", *ACM SIGSAM Bull.*, vol. 15, pp. 37-44, Feb. 1981.
- [82] U.Fincke and M.Pohst, "Improved methods for calculating vectors of short length in a lattice, including a complexity analysis", *Math. Comput.*, vol. 44, pp. 463-471, Apr. 1985
- [83] B.Hassibi and H.Vikalov, "On the Sphere-Decoding Algorithm I, Expected Complexity", *IEEE Trans.on Signal Process.*, vol. 53, no. 8, Aug. 2005.
- [84] J.G.Proakis, *Digital Communications*, McGraw-Hill Inc., 1989.
- [85] L. Zheng and D. Tse, "Diversity and multiplexing: a fundamental tradeoff in multiple antenna channels", *IEEE Trans. Inform. Theory*, vol. 49, pp. 1073-1096, May 2003.
- [86] R. W. Heath and A. Paulraj, "Diversity versus multiplexing in narrow-band MIMO channels: a tradeoff based on euclidean distance", *IEEE Trans. Commun.*, submitted 2002.
- [87] G.L. Stuber, J.R. Barry, S. W. McLaughlin, M.A.Ingram, T.G. Pratt, "Broadband MIMO-OFDM wireless communications", in *Proc. of IEEE*, vol. 92, no. 2, Feb. 2004.
- [88] A. F. Molisch, M. Z. Win, and J. H. Winters, "Space-time-frequency (STF) coding for MIMO-OFDM systems", *IEEE Commun. Lett.*, vol. 5, pp. 2465-2476, Oct. 2002.
- [89] D.Agrawal, V.Tarokh, A.Naguib and N. Seshadri, "Space-time coded OFDM for high data-rate wireless communication over wideband channels", *IEEE Vehicular Tech. Conf.*, pp. 2232-6, May 1998.
- [90] H. Bolcskei and A. J. Paulraj, "Space-frequency coded broadband OFDM systems," in *Proc. IEEE Wireless Commun. & Networking Conf.*, vol. 1, pp. 1-6, 2000.
- [91] W. Su, Z. Safar, M. Olfat, and K. J. R. Liu, "Obtaining full-diversity space-frequency codes from space-time codes via mapping", *IEEE Trans. Signal Process.*, vol. 51, pp. 1451-1458, Nov. 2003.
- [92] W. Su, Z. Safar and K. J. R Liu, "Full-rate full-diversity space-frequency codes with optimum coding advantage", *IEEE Trans. Inf. Theory*, Jan. 2005.
- [93] W.Genyuang, Zhang, M.Amin, "Space-Time Block Code Designs Based on Quadratic Field Extension for Two-Transmitter Antennas", *IEEE Trans. Information Theory*, vol. 8, no.6, pp. 4005-13, Jan. 2012.
- [94] B.A.Sethuraman and B.Sundar Rajan, "Optimal STBC over PSK Signal Sets from Cyclotomic Field Extensions", in *proc. IEEE International conf. on Commun.*, vol. 3, pp. 1783-87, 2002.
- [95] J.-C. Belfiore, G. Rekaya and E. Viterbo, "The Golden Code: A  $2 \times 2$  Full-Rate Space-Time Code with Non-Vanishing Determinants", in *proc. IEEE International Symp. Inform. Theory*, p. 310, 2004.
- [96] X. Dong, J.K. Zhang, S. Dumitrescu, and F.K.Gong, "Full diversity non coherent Alamouti based Toeplitz Space Time Block Codes", *IEEE Trans. Signal process.*, vol. 0, no. 10, pp. 5241-53, July 2012.
- [97] L.P.Natarajan and B.S.Rajan, "Asymptotically-Good, Multigroup Decodable Space-Time Block Codes", *IEEE Trans. Wireless Commun.*, vol. 12, no. 10, pp. 5035-47, Sep. 2013.
- [98] 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.
- [99] S. B. Korada, "Polar Codes for Channel and Source Coding", Ph.D. dissertation, EPFL, Lausanne, Switzerland, Jul. 2009.
- [100] I. Tal and A. Vardy, "How to Construct Polar Codes", *IEEE Trans. Inf. Theory*, vol. 59, no. 10, pp. 6562-82, July 2013.
- [101] Z.Shengmei, S.Qian, F.Ming-Kun and Z.Baoyu, "A concatenation scheme of Polar codes and space-time block codes in multiple-input multiple-output channels", 6<sup>th</sup> International Congress on Image and signal processing, vol. 3, pp. 1216-20, Dec. 2013.
- [102] J.Harshan and E.Viterbo, "Integer Space-Time Block Codes for Practical MIMO Systems", *IEEE Wireless Commun. Lett.*, vol. 2, no. 4, pp. 455-58, June 2013.
- [103] J.Akhtar, "Doppler compensated space time block coding for multistatic radar systems", in *proc. IEEE Conf. on Radar*, pp. 1-5, 2013.
- [104] Minh-Tuan Le, Vu-Duc Ngo, Hong-Anh Mai, Xuan-Nam Tran and M.D.Renzo, "Spatially Modulated Orthogonal Space-Time Block Codes with Non-Vanishing Determinants", *IEEE Trans. Commun.*, vol. 62, no. 1, pp. 85-99, Jan. 2014.
- [105] T. Kiran and B. S. Rajan, "STBC-scheme with non vanishing determinant for certain number of transmit antennas", *IEEE Trans. Info.Theory*, vol. 51, no. 8, pp. 2984-2992, Aug. 2005.
- [106] G. Rekaya, J.-C. Belfiore, and E. Viterbo, "Algebraic  $3 \times 3$ ,  $4 \times 4$ ,  $6 \times 6$  space-time codes with non-



- vanishing determinants”, in Proc. IEEE Int.Symp.Information Theory and its Applications, Parma, Italy, pp. 325–329 Oct. 10-13, 2004.
- [107] Minh-Tuan Le, Vu-Duc Ngo, Hong-Anh Mai, and Xuan-Nam Tran, "High rate space time block coded spatial modulation,"in Proc. International Conf. Advanced Tech. for Commun., ATCIREV 2012, Hanoi, Vietnam, pp. 278-282, Oct. 2012.
- [108] A. J. Salomon and O. Amrani, “Increased diversity space time coding using the diversity transform”, EURASIP J. on wireless communication and networking, Jan. 2014.
- [109] D. Rainish, “Diversity Transform for fading channels”, IEEE Trans. Commun., vol. 44, no. 12, pp. 1653-61, 1996.
- [110] W.Zhanji and G.Xiang, “An efficient MIMO scheme with signal space diversity for future mobile communications”, EURASIP J. on wireless communication and networking, 2015.

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