

References

- [1] V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space-time codes for high data rate wireless communications: performance criterion and code construction," *IEEE Trans. Inform. Theory*, vol. 44, no. 2, pp. 744-765, Mar. 1998.
- [2] A. R. Calderbank, "The art of signaling: Fifty years of coding theory," *IEEE Trans. Info. Theory*, vol. 44, no. 6, pp. 2561-2595, October 1998.
- [3] S. Verdu, "Wireless bandwidth in the making," *IEEE Commun. Mag.*, vol. 38, no. 7, pp. 53-58, July 2000.
- [4] A. F. Naguib, N. Seshadri, and A. R. Calderbank, "Increasing data rate over wireless channels," *IEEE Signal Processing Mag.*, vol. 17, no. 3, pp. 76-92, May 2000.
- [5] W. C. Jakes, *Microwave Mobile Communication*, 2nd ed. Piscataway, NJ: IEEE Press, 1994.
- [6] G. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," *Bell Labs Technical Journal*, vol. 1, no. 2, pp. 41-59, 1996.
- [7] E. Telatar, "Capacity of multi-antenna Gaussian channels," *Europ. Trans. Telecommu.*, vol. 10, no. 6, pp. 585-595, Nov. 1999.
- [8] G. Foschini and M. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Communications*, vol. 6, no. 3, pp. 311-335, Mar. 1998.
- [9] S. M. Alamouti, "A simple transmit diversity technique for wireless communications", *IEEE J. Select. Areas Commun.*, vol. 16, no. 8, pp.1451-1458, Oct. 1998.
- [10] E. Biglieri, J. Proakis, and S. Shamai, "Fading channels: Information-theoretic and communications aspects," *IEEE Trans. Info. Theory*, vol. 44, no. 6, pp. 2619-2692, October 1998.
- [11] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Trans. Inform. Theory*, vol. 45, no. 5, pp. 1456-1467, July 1999.

- [12] S. Baro, G. Bauch and A. Hansmann, "Improved codes for space-time trellis coded modulation," *IEEE Commun. Lett.*, vol. 4, no. 1, pp. 20-22, Jan. 2000.
- [13] A. Sendonaris, E. Erkip, and B. Aazhang, "User Cooperation Diversity, Part I: System description," *IEEE Trans. on Commun.*, vol. 51, no. 11, pp. 1927-1938, Nov. 2003.
- [14] Sendonaris, E. Erkip, and B. Aazhang, "User Cooperation Diversity, Part II: Implementation Aspects and Performance Analysis," *IEEE Trans. on Commun.*, vol. 51, no. 11, pp. 1939-1948, Nov. 2003.
- [15] R. U. Nabar and H. Bolcskei, "Fading relay channels: performance limits and space-time signal design," *IEEE J. on Selected Area in Comm.*, vol. 22, no. 6, pp. 1099-1109, Aug. 2004.
- [16] 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, Dec. 2004.
- [17] R. U. Nabar and H. Bolcskei, "Space-time signal design for fading relay channels," *IEEE GLOBECOM*, vol. 4, San Francisco, CA, pp. 1952-1956, Dec. 2003.
- [18] Chao Wang, John S. Thompson, Yijia Fan, H. Vincent Poor, "On the diversity multiplexing tradeoff of concurrent decode-and-forward relaying," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 582-587, 2008.
- [19] Abdulkareem Adinoyi and Halim Yanikomeroglu, "Cooperative relaying in multi-antenna fixed relay networks," *IEEE Trans. on Wireless Commun.*, vol. 6, no. 2, pp. 533-544, Feb. 2007.
- [20] Khuong Ho-Van and Tho Le-Ngoc, "Bandwidth-efficient cooperative relaying schemes with multi-antenna relay," *EURASIP Journal on Advances in Signal Processing, Volume 2008*, Article ID 683105, 11 pages doi: 10.1155/2008/683105.
- [21] A. F. Dana and B. Hassibi, "On the power efficiency of sensory and ad hoc wireless networks," *IEEE Trans. Inform. Theory*, vol. 52, no. 7, pp. 2890-2914, July 2006.
- [22] N. Laneman and G. W. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless network," *IEEE Trans. Inform. Theory*, vol. 49, no. 10, pp. 2415-2425, Oct. 2003.

- [23] J. N. Laneman and G. W. Wornell, "Energy-efficient antenna sharing and relaying for wireless networks," *IEEE Wireless Commun. and Networking Conf.*, vol. 1, Chicago, IL, pp. 7-12, Sep. 2000.
- [24] O. Hasna and M. -S. Alouini, "A performance study of dual-hop transmissions with fixed gain relays," *IEEE Trans. on Wireless Commun.*, vol. 3, no. 6, pp. 1963-1968, Nov. 2004.
- [25] A. Ribeiro, X. Cai, and G. B. Giannakis, "Symbol error probabilities for general cooperative links," *IEEE Trans. on Wireless Commun.*, vol. 4, no. 3, pp. 1264-1273, May 2005.
- [26] A. Zhao and M. C. Valenti, "Distributed turbo coded diversity for the relay channel," *IEE Electronics Letters*, vol. 39, no. 10, pp. 786-787, May 2003.
- [27] R. Liu, P. Spasojevic, and E. Soljanin, "Punctured turbo code ensembles," *IEEE Information Theory Workshop (ITW) Conf.*, Paris, France, pp. 249-252, Mar. 2003.
- [28] Janani, A. Hedayat, T. E. Hunter, and A. Nersisyan, "Coded cooperation in wireless communications: Space-time transmission and iterative decoding," *IEEE Transaction On Signal Processing*, vol. 52, no. 2, pp. 362-371, Feb. 2004.
- [29] A. Wittneben, "A new bandwidth efficient transmit antenna modulation diversity scheme for linear digital modulation," *IEEE International Conf. Comm. (ICC93)*, vol. 3, pp. 1630-1634, May 1993.
- [30] Thomas M. Cover and Joy A. Thomas, *Elements of Information Theory*, John Wiley & Sons, Inc., New York, 1991.
- [31] E. C. van der Meulen, "Three-terminal communication channels," *Advances in Applied Probability*, vol.3, no. 1, pp. 120-154, 1971.
- [32] Edward C. van der Meulen, *Transmission of Information in a T-Terminal Discrete Memory less Channel*, Department of Statistics, University of California, Berkeley, CA, 1968.
- [33] Thomas M. Cover and Abbas A. El Gamal, "Capacity theorems for the relay channel," *IEEE Trans. Inform. Theory*, vol. 25, no. 5, pp. 572-584, Sep. 1979.
- [34] Schein and R. Gallager, "The Gaussian parallel relay network," *IEEE Int. Symp. Information Theory (ISIT)*, Sorrento, Italy, page 22, June 2000.

- [35] T. Hunter and A. Nosratinia, "Cooperation diversity through coding," *IEEE Int. Symp. Information Theory (ISIT)*, Lausanne, Switzerland, page 220, Jun. 2002.
- [36] R. Liu, P. Spasojevic, and E. Soljanin, "User cooperation with punctured turbo codes," in *Proc. 41st Allerton Conf. Commun. Control, Comput.*, Monticello, IL, Oct. 2003.
- [37] A. Stefanov and E. Erkip, "Cooperative coding for wireless networks," *IEEE Trans. on Commun.*, vol. 52, no. 9, pp. 1470-1476, Sep. 2004.
- [38] R. Knopp and P. A. Humblet, "On coding for block fading channels," *IEEE Trans. Inform. Theory*, vol. 46, no. 1, pp. 189-205, Jan. 2000.
- [39] A. Stefanov and E. Erkip, "Cooperative space-time coding for wireless networks," *IEEE Trans. on Commun.*, vol. 53, no. 11, pp. 1804-1809, Nov. 2005.
- [40] T. E. Hunter and A. Nosratinia, "Diversity through coded cooperation," *IEEE Trans. on Wireless Commun.*, vol. 5, no. 2, pp. 283-289, Feb. 2006.
- [41] T. E. Hunter and A. Nosratinia, "Performance analysis of coded cooperation diversity," *ICC 2003*, vol. 4, pp. 2688-2692, 11-15 May 2003.
- [42] Erik G. Larsson and Branimir R. Vojcic, "Cooperation transmit diversity based on superposition modulation," *IEEE Commun. Letters*, vol. 9, no. 9, pp. 778-780, Sep. 2005.
- [43] Lei Xiao, Thomas E. Fuja, Jorg Kliewer, and Daniel J. Costello, "A network coding approach to cooperative diversity," *IEEE Trans. Inform. Theory*, vol. 53, no. 10, pp. 3714-3722, Oct. 2007.
- [44] P. Frenger, P. Orten, and T. Ottosson, "Convolutional codes with optimum distance spectrum," *IEEE Commun. Letters*, vol. 3, no. 11, pp. 317-319, Nov. 1999.
- [45] A. Ghrayeb and T. M. Duman, "Performance analysis of MIMO systems with antenna selection over quasi-static fading channels," *IEEE Trans. Veh. Techn.*, vol. 52, no. 2, pp. 281-288, March 2003.
- [46] X. Zeng and A. Ghrayeb, "Performance bounds for space-time block codes with antenna selection," *IEEE Trans. Inform. Theory*, vol. 50, no. 9, pp. 2130-2137, Sept. 2004.
- [47] W. Hamouda and A. Ghrayeb, "Performance of combined channel coding and space-time block coding systems with antenna selection," *IEEE Veh. Technol. Conf.*

- (VTC), Milan, Italy, vol. 2, pp. 623-627, May 2004.
- [48] A. Gore and A. Paulraj, "MIMO antenna subset selection with space-time coding," *IEEE Trans. Signal Proc.*, vol. 50, no. 10, pp. 2580-2588, Oct. 2002.
- [49] Zhuo, Y. Jinhong, B. Vucetic, and Z. Zhendong, "Performance of Alamouti scheme with transmit antenna selection," *IEE Electron. Lett.*, vol. 39, no. 23, pp. 1666-1668, Nov. 2003.
- [50] A. F. Naguib, V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space-time coding modem for high data rate wireless communications," *IEEE J. Select. Areas Commun.*, vol. 16, no. 8, pp. 1459-1478, Oct. 1998.
- [51] A. Fragouli, N. Al-Dhahir, and W. Turin, "Training-based channel estimation for multiple-antenna broadband transmissions," *IEEE Trans. Wireless Commun.*, vol. 2, no. 2, pp. 384-391, Mar. 2003.
- [52] A. Hassibi and B. M. Hochwald, "How much training is needed in multiple antenna wireless links?" *IEEE Trans. Inform. Theory*, vol. 49, no. 4, pp. 951-963, Apr. 2003.
- [53] Y. Jing and B. Hassibi, "Wireless networks, diversity and space-time codes," *IEEE Inform. Theory Workshop*, San Antonio, Texas, pp. 463-468, Oct. 2004.
- [54] T. Kiran and B. S. Rajan, "Partially-coherent distributed space-time codes with differential encoder and decoder," *IEEE J. Selected Areas Commun.*, vol. 25, no. 2, pp. 426-433, Feb. 2007.
- [55] C. S. Patel and G. L. Stuber, "Channel estimation for amplify and forward relay based cooperation diversity systems," *IEEE Trans. on Wireless Commun.*, vol. 6, no. 6, pp. 2348-2356, June 2007.
- [56] G. S. Rajan and B. S. Rajan, "Leveraging coherent distributed space-time codes for non coherent communication in relay networks via training," *IEEE Trans. on Wireless Commun.*, April 2008.
- [57] Feifei Gao, Tao Cui, and A. Nallanathan, "On channel estimation and optimal training design for amplify and forward relay networks," *IEEE Trans. on Wireless Commun.*, vol. 7, no. 5, pp. 1907-1916, May 2008.
- [58] Y. Jing and H. Jafarkhani, "Distributed differential space-time coding for wireless relay networks," *IEEE Trans. Commun.*, vol. 56, no. 7, pp. 1092-1100, July 2008.

- [59] K. Simon and M.-S. Alouini, *Digital Communication over Fading Channels: A Unified Approach to Performance Analysis*, Wiley, New York, 2000.
- [60] J. G. Proakis, *Digital Communication*, McGraw-Hill, Inc., 1995.
- [61] W. C. Jakes, *Microwave Mobile Communication*, 2nd ed. Piscataway, NJ: IEEE Press, 1994.
- [62] S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*, 5th ed., San Diego, CA: Academic, 1994.
- [63] G. E. Roberts and H. Kaufman, *Table of Laplace Transform*, Philadelphia, PA: Saunders, 1966.
- [64] Mohamed Elfituri, Walaa Hamouda, and Ali Ghrayeb, "A convolutional-based distributed coded cooperation scheme for relay channels," *IEEE Trans. Veh. Techn.*, vol. 58, no.2, pp. 655-669, Feb. 2009.
- [65] Mohamed Elfituri, Walaa Hamouda, and Ali Ghrayeb, "Distributed coded cooperation for relay channels operating in the decode-and-forward mode," *IEEE International Conference on Communications (ICC 2008)*, Beijing, China, pp. 4586-4590, May 2008.
- [66] Mohamed Elfituri, Ali Ghrayeb, and Walaa Hamouda, "Antenna/relay selection for coded wireless cooperative networks," *IEEE International Conference on Communications (ICC 2008)*, Beijing, China, pp. 840-844, May 2008.
- [67] Mohamed Elfituri, Ali Ghrayeb, and Walaa Hamouda, "Antenna/Relay selection for coded cooperative networks," *IEEE Trans. Commun.*, *accepted for publication*, Mar. 2009.
- [68] Mohamed Elfituri, Ali Ghrayeb, and Walaa Hamouda, "Analysis of a distributed coded cooperation scheme for multi-relay channels," *IEEE International Symposium on Signal Processing and Info. Techn. (ISSPIT 2007)*, Cairo, Egypt, pp. 454-459, Dec. 2007.
- [69] Mohamed Elfituri, Walaa Hamouda, and Ali Ghrayeb, "Outage probability analysis of distributed coded cooperation for relay channels operating in the DF mode," *IEEE International Symposium on Personal Indoor and Mobile Radio Commu. (PIMRC 2007)*, Athens, Greece, pp. 1-5, Sep. 2007.

- [70] Mohamed Elfituri, Walaa Hamouda, and Ali Ghrayeb, "Performance analysis of a new transmission scheme for multi-relay channels," *IEEE Workshop on Signal Processing Systems (SiPS 2006)*, Banff, Alberta, Canada, pp. 34-38, Oct. 2006.

Appendices

Appendix A: Proof of Equations (3.20) and (3.31)-(3.33)

A.1 Proof of Equation (3.20)

The average pairwise error probability of (3.19), $P(d)$, can then be written as

$$\begin{aligned}
 P(d) = & \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \int_0^\infty \exp\left(\frac{-g_{PSK}(R_{C_1}d_1 + R_{C_2}d_2)\gamma_{SD}}{\sin^2\theta}\right) p_{\gamma_{SD}}(\gamma_{SD}) d\gamma_{SD} d\theta \\
 & \cdot \prod_{m=1}^L \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \int_0^\infty \exp\left(\frac{-g_{PSK}R_{C_1}d_1\gamma_{SR_m}}{\sin^2\theta_m}\right) p_{\gamma_{SR_m}}(\gamma_{SR_m}) d\gamma_{SR_m} d\theta_m \right) \\
 & + \sum_{L=1}^{L-1} \sum_{\Omega} \left[\prod_{j \notin \Omega} \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \int_0^\infty \exp\left(\frac{-g_{PSK}R_{C_1}d_1\gamma_{SR_j}}{\sin^2\theta_j}\right) p_{\gamma_{SR_j}}(\gamma_{SR_j}) d\gamma_{SR_j} d\theta_j \right) \right. \\
 & \cdot \prod_{j \in \Omega} \left(1 - \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \int_0^\infty \exp\left(\frac{-g_{PSK}R_{C_1}d_1\gamma_{SR_j}}{\sin^2\theta_j}\right) p_{\gamma_{SR_j}}(\gamma_{SR_j}) d\gamma_{SR_j} d\theta_j \right) \\
 & \cdot \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \prod_{j \in \Omega} \int_0^\infty \int_0^\infty \exp\left(\frac{-g_{PSK}\left(R_{C_1}d_1 + \frac{R_{C_2}}{(L+1)}d_2\right)\gamma_{SD}}{\sin^2\theta}\right) \\
 & \cdot \exp\left(\frac{-g_{PSK}(R_{C_1}d_1 + R_{C_2}d_2)\gamma_{SD}}{\sin^2\theta}\right) p_{\gamma_{SD}}(\gamma_{SD}) p_{\gamma_{R_jD}}(\gamma_{R_jD}) d\gamma_{SD} d\gamma_{R_jD} d\theta \Big] \\
 & + \prod_{m=1}^L \left(1 - \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \int_0^\infty \exp\left(\frac{-g_{PSK}R_{C_1}d_1\gamma_{SR_m}}{\sin^2\theta_m}\right) p_{\gamma_{SR_m}}(\gamma_{SR_m}) d\gamma_{SR_m} d\theta_m \right)
 \end{aligned}$$

$$\begin{aligned} & \cdot \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \prod_{m=1}^L \int_0^\infty \int_0^\infty \exp \left(\frac{-g_{PSK} \left(R_{C_1} d_1 + \frac{R_{C_2}}{(L'+1)} d_2 \right) \gamma_{SD}}{\sin^2 \theta} \right) \\ & \cdot \exp \left(\frac{-g_{PSK} R_{C_2} d_2 \gamma_{R_m D}}{(L+1) \sin^2 \theta} \right) p_{\gamma_{SD}}(\gamma_{SD}) p_{\gamma_{R_m D}}(\gamma_{R_m D}) d\gamma_{SD} d\gamma_{R_m D} d\theta. \end{aligned} \quad (A.1)$$

Using (3.13), (A.1) can then be written

$$\begin{aligned} P(d) &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{g_{PSK} (R_{C_1} d_1 + R_{C_2} d_2) \bar{\gamma}_{SD}}{\sin^2 \theta} \right)^{-1} d\theta \\ & \cdot \prod_{m=1}^L \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{g_{PSK} R_{C_1} d_1 \bar{\gamma}_{SR_m}}{\sin^2 \theta_m} \right)^{-1} d\theta_m \right) \\ & + \sum_{l=1}^{L-1} \sum_{\Omega} \left[\prod_{j \notin \Omega} \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{g_{PSK} R_{C_1} d_1 \bar{\gamma}_{SR_j}}{\sin^2 \theta_j} \right)^{-1} d\theta_j \right) \right. \\ & \cdot \left. \prod_{j \in \Omega} \left(1 - \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{g_{PSK} R_{C_1} d_1 \bar{\gamma}_{SR_j}}{\sin^2 \theta_j} \right)^{-1} d\theta_j \right) \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \right. \\ & \cdot \left. \left(1 + \frac{g_{PSK} \left(R_{C_1} d_1 + \frac{R_{C_2}}{(L'+1)} d_2 \right) \bar{\gamma}_{SD}}{\sin^2 \theta} \right)^{-1} \prod_{j \in \Omega} \left(1 + \frac{g_{PSK} R_{C_2} d_2 \bar{\gamma}_{R_j D}}{(L'+1) \sin^2 \theta} \right)^{-1} d\theta \right] \\ & + \prod_{m=1}^L \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{g_{PSK} R_{C_1} d_1 \bar{\gamma}_{SR_m}}{\sin^2 \theta_m} \right)^{-1} d\theta_m \right) \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \right. \\ & \cdot \left. \left(1 + \frac{g_{PSK} \left(R_{C_1} d_1 + \frac{R_{C_2}}{(L'+1)} d_2 \right) \bar{\gamma}_{SD}}{\sin^2 \theta} \right)^{-1} \prod_{m=1}^L \left(1 + \frac{g_{PSK} R_{C_2} d_2 \bar{\gamma}_{R_m D}}{(L+1) \sin^2 \theta} \right)^{-1} d\theta, \end{aligned} \quad (A.2)$$

where $\bar{\gamma}_{SR_m} = \frac{E_{SR_m}}{N_0} E[|h_{SR_m}|^2]$ is the average SNR.

A.2 Proof of Equation (3.31)-(3.33)

From (3.30), I_1 , $I_2(j)$, I_3 can be written as

$$\begin{aligned} I_1 &= Pr\{(1 + \gamma_{SD})^\beta (1 + \gamma_{SD})^{(1-\beta)} < 2^{R_c}\} \\ &= \int_0^{2^{R_c}-1} \frac{1}{\bar{\gamma}_{SD}} \exp\left(\frac{-\gamma_{SD}}{\bar{\gamma}_{SD}}\right) d\gamma_{SD} = 1 - \exp\left(\frac{(1-2^{R_c})}{\bar{\gamma}_{SD}}\right), \end{aligned} \quad (\text{A.3})$$

and

$$\begin{aligned} I_2(j) &= Pr\left\{(1 + \gamma_{SD})^\beta \left(1 + \frac{1}{(L' + 1)} \left[\gamma_{SD} + \sum_{j \in \Omega} \gamma_{R_j D}\right]\right)^{(1-\beta)} < 2^{R_c}\right\} \\ &= \int_0^{A'_1} \frac{1}{\bar{\gamma}_{SD}} \exp\left(\frac{-\gamma_{SD}}{\bar{\gamma}_{SD}}\right) d\gamma_{SD} \\ &\quad \cdot \int_0^{A_2} \cdots \int_0^{A_2} \prod_{j \in \Omega} \left(\frac{1}{\bar{\gamma}_{R_j D}}\right) \exp\left(-\sum_{j \in \Omega} \frac{\gamma_{R_j D}}{\bar{\gamma}_{R_j D}}\right) \prod_{j \in \Omega} d\gamma_{R_j D} \\ &= \left(1 - \exp\left(\frac{-A'_1}{\bar{\gamma}_{SD}}\right)\right) \prod_{j \in \Omega} \left(\int_0^{A'_2} \frac{1}{\bar{\gamma}_{R_j D}} \exp\left(\frac{-\gamma_{R_j D}}{\bar{\gamma}_{R_j D}}\right) d\gamma_{R_j D}\right) \\ &= \left(1 - \exp\left(\frac{-A'_1}{\bar{\gamma}_{SD}}\right)\right) \prod_{j \in \Omega} \left(1 - \exp\left(\frac{-A'_2}{\bar{\gamma}_{R_j D}}\right)\right) \\ &= \left(1 - \exp\left(\frac{(1-2^{R_c})(L' + 1)}{\bar{\gamma}_{SD}}\right)\right) \prod_{j \in \Omega} \left(1 - \exp\left(\frac{\left(1 - 2^{\left(\frac{R_c}{1-\beta}\right)}\right)(L' + 1)}{\bar{\gamma}_{R_j D}}\right)\right), \end{aligned} \quad (\text{A.4})$$

and

$$I_3 = Pr\left\{(1 + \gamma_{SD})^\beta \left(1 + \frac{1}{(L + 1)} \left[\gamma_{SD} + \sum_{m=1}^L \gamma_{R_m D}\right]\right)^{(1-\beta)} < 2^{R_c}\right\}$$

$$\begin{aligned}
 &= \int_0^{A_1} \frac{1}{\bar{\gamma}_{SD}} \exp\left(\frac{-\gamma_{SD}}{\bar{\gamma}_{SD}}\right) d\gamma_{SD} \\
 &\cdot \int_0^{A_2} \cdots \int_0^{A_2} \prod_{m=1}^L \left(\frac{1}{\bar{\gamma}_{R_m D}}\right) \exp\left(-\sum_{m=1}^L \frac{\gamma_{R_m D}}{\bar{\gamma}_{R_m D}}\right) \prod_{m=1}^L \gamma_{R_m D} \\
 &= \left(1 - \exp\left(\frac{-A_1}{\bar{\gamma}_{SD}}\right)\right) \prod_{m=1}^L \left(\int_0^{A_2} \frac{1}{\bar{\gamma}_{R_m D}} \exp\left(\frac{-\gamma_{R_m D}}{\bar{\gamma}_{R_m D}}\right) d\gamma_{R_m D}\right) \\
 &= \left(1 - \exp\left(\frac{-A_1}{\bar{\gamma}_{SD}}\right)\right) \prod_{m=1}^L \left(1 - \exp\left(\frac{-A_2}{\bar{\gamma}_{R_m D}}\right)\right) \\
 &= \left(1 - \exp\left(\frac{(1-2^{R_c})(L+1)}{\bar{\gamma}_{SD}}\right)\right) \prod_{m=1}^L \left(1 - \exp\left(\frac{\left(1-2^{\left(\frac{R_c}{1-\beta}\right)}\right)(L+1)}{\bar{\gamma}_{R_m D}}\right)\right), \quad (\text{A.5})
 \end{aligned}$$

Appendix B: Proof of Equations (4.38) and (4.40)

B.1 Proof of Equation (4.38)

From (4.37), the CDF of Z , $P_Z(z)$, is given by

$$P_Z(z) = \frac{2^{n_R}}{z \sqrt{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}} \sum_{i=0}^{n_R-1} \binom{n_R-1}{i} \frac{(-1)^{n_R-1-i}}{\sqrt{n_R-i}} \exp\left(-\left[\frac{n_R-i}{\bar{\gamma}_{SR}} + \frac{1}{\alpha \bar{\gamma}_{RD}}\right] \frac{1}{z}\right) K_1\left(\frac{1}{z} \sqrt{4(n_R-i)}\right), \quad (\text{B.1})$$

Taking the derivative of (B.1) with respect to z and using the expression for the derivative of the modified Bessel function, given in [62] as

$$z \frac{d}{dz} K_\nu(z) + \nu K_\nu(z) = -z K_{\nu-1}(z). \quad (\text{B.2})$$

yields (4.38).

B.2 Proof of Equation (4.40)

From (4.39), the PDF of γ_{SRD} is given by

$$\begin{aligned}
 p_{\gamma_{SRD}}(\gamma_{SRD}) &= \frac{2\gamma_{SRD} n_R}{\sqrt{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}} \sum_{i=0}^{n_R-1} \binom{n_R-1}{i} \frac{(-1)^{n_R-1-i}}{\sqrt{n_R-i}} \\
 &\cdot \exp\left(-\left[\frac{(n_R-i)}{\bar{\gamma}_{SR}} + \frac{1}{\alpha \bar{\gamma}_{RD}}\right] \gamma_{SRD}\right) \left\{ \left[\frac{(n_R-i)}{\bar{\gamma}_{SR}} + \frac{1}{\alpha \bar{\gamma}_{RD}}\right] K_1\left(\gamma_{SRD} \sqrt{\frac{4(n_R-i)}{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}}\right) \right. \\
 &\quad \left. + \sqrt{\frac{4(n_R-i)}{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}} K_0\left(\gamma_{SRD} \sqrt{\frac{4(n_R-i)}{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}}\right) \right\}. \tag{B.3}
 \end{aligned}$$

The MGF of γ_{SRD} , $\Psi_{\gamma_{SRD}}(-s)$, can be shown as

$$\begin{aligned}
 \Psi_{\gamma_{SRD}}(-s) &= \int_0^\infty p_{\gamma_{SRD}}(\gamma_{SRD}) \exp(-s\gamma_{SRD}) d\gamma_{SRD} \\
 \Psi_{\gamma_{SRD}}(-s) &= \frac{4n_R}{\sqrt{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}} \sum_{i=0}^{n_R-1} \binom{n_R-1}{i} \frac{(-1)^{n_R-1-i}}{\sqrt{n_R-i}} \\
 &\cdot \left\{ \sqrt{\frac{(n_R-i)}{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}} f_1(s, i) + \frac{1}{2} \left[\frac{(n_R-i)}{\bar{\gamma}_{SR}} + \frac{1}{\alpha \bar{\gamma}_{RD}} \right] f_2(s, i) \right\}, \tag{B.4}
 \end{aligned}$$

where

$$f_1(s, i) = \int_0^\infty \gamma_{SRD} \exp\left(-\left[\frac{n_R-i}{\bar{\gamma}_{SR}} + \frac{1}{\alpha \bar{\gamma}_{RD}} + s\right] \gamma_{SRD}\right) K_0\left(\gamma_{SRD} \sqrt{\frac{4(n_R-i)}{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}}\right) d\gamma_{SRD}$$

and

$$f_2(s, i) = \int_0^\infty \gamma_{SRD} \exp\left(-\left[\frac{n_R-i}{\bar{\gamma}_{SR}} + \frac{1}{\alpha \bar{\gamma}_{RD}} + s\right] \gamma_{SRD}\right) K_1\left(\gamma_{SRD} \sqrt{\frac{4(n_R-i)}{\alpha \bar{\gamma}_{SR} \bar{\gamma}_{RD}}}\right) d\gamma_{SRD}$$

Using [62] we obtain the result in (4.40).

Appendix C: Proof of Equations (5.27) and (5.35)

C.1 Proof of Equation (5.27)

From (5.26), the average pairwise error probability, $P(d)$, is given by

$$P(d) = \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{g_{PSK}}{\sin^2 \theta} \left(\frac{R_{C_2} d_2 \alpha \left(\frac{E_{RD}}{N_0} \right)}{R_{C_2} \left[(1-\alpha) \left(\frac{E_{SD}}{N_0} \right) + \alpha \left(\frac{E_{RD}}{N_0} \right) \right] + k_p \left(\frac{E_p}{N_0} \right)} \right) \right)^{-1} \cdot \left(1 + \frac{g_{PSK}}{\sin^2 \theta} \left(\frac{R_{C_1} d_1 \left(\frac{E_{SD}}{N_0} \right)}{R_{C_1} \left(\frac{E_{SD}}{N_0} \right) + k_p \left(\frac{E_p}{N_0} \right)} + \frac{R_{C_2} d_2 (1-\alpha) \left(\frac{E_{SD}}{N_0} \right)}{R_{C_2} \left[(1-\alpha) \left(\frac{E_{SD}}{N_0} \right) + \alpha \left(\frac{E_{RD}}{N_0} \right) \right] + k_p \left(\frac{E_p}{N_0} \right)} \right) \right)^{-1} d\theta. \quad (C.1)$$

From (C.1), the average pairwise error probability can be shown as

$$\begin{aligned} P(d) &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{A(d)}{\sin^2 \theta} \right)^{-1} \left(1 + \frac{B(d)}{\sin^2 \theta} \right)^{-1} d\theta \\ &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(\frac{\sin^2 \theta}{\sin^2 \theta + A(d)} \right) \left(\frac{\sin^2 \theta}{\sin^2 \theta + B(d)} \right) d\theta \\ &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{A(d)}{\sin^2 \theta + A(d)} \right) \left(1 - \frac{B(d)}{\sin^2 \theta + B(d)} \right) d\theta \\ P(d) &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{A(d)}{\sin^2 \theta + A(d)} - \frac{B(d)}{\sin^2 \theta + B(d)} + \frac{A(d)B(d)}{(\sin^2 \theta + A(d))(\sin^2 \theta + B(d))} \right) d\theta, \quad (C.2) \end{aligned}$$

Applying a partial fraction expansion into the last term of (C.2), the average pairwise error probability, $P(d)$, is given by

$$\begin{aligned}
 P(d) &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{A(d)}{(\sin^2 \theta + A(d))} - \frac{B(d)}{(\sin^2 \theta + B(d))} + \frac{B(d)}{(B(d) - A(d))} \frac{A(d)}{(\sin^2 \theta + A(d))} \right. \\
 &\quad \left. + \frac{A(d)}{(A(d) - B(d))} \frac{B(d)}{(\sin^2 \theta + B(d))} \right) d\theta \\
 &= \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{A(d)}{(B(d) - A(d))} \frac{A(d)}{(\sin^2 \theta + A(d))} + \frac{B(d)}{(A(d) - B(d))} \frac{B(d)}{(\sin^2 \theta + B(d))} \right) d\theta. \quad (C.3)
 \end{aligned}$$

Using [62] we obtain the result in (5.27).

C.2 Proof of Equation (5.35)

From (5.34), the average pairwise error probability is given by

$$\begin{aligned}
 P(d) &= \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{C(d)}{\sin^2 \theta_1} \right)^{-1} d\theta_1 \right) \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{D(d)}{\sin^2 \theta_2} \right)^{-1} d\theta_2 \right) \\
 &\quad + \left(1 - \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{D(d)}{\sin^2 \theta_1} \right)^{-1} d\theta_1 \right) \\
 &\quad \cdot \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{A(d)}{\sin^2 \theta_2} \right)^{-1} \left(1 + \frac{B(d)}{\sin^2 \theta_2} \right)^{-1} d\theta_2 \right), \quad (C.4)
 \end{aligned}$$

The average pairwise error probability, $P(d)$, can be written as

$$\begin{aligned}
 P(d) &= \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{C(d)}{\sin^2 \theta_1 + C(d)} \right) d\theta_1 \right) \\
 &\quad \cdot \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{D(d)}{\sin^2 \theta_2 + D(d)} \right) d\theta_2 \right)
 \end{aligned}$$

$$\begin{aligned}
 & + \left(1 - \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{D(d)}{\sin^2 \theta_1 + D(d)} \right) d\theta_1 \right) \\
 & \cdot \left(\frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} \left(1 - \frac{A(d)}{\sin^2 \theta_2 + A(d)} \right) \left(1 - \frac{B(d)}{\sin^2 \theta_2 + B(d)} \right) d\theta_2 \right). \quad (C.5)
 \end{aligned}$$

Applying a partial fraction expansion into the last term of (C.5) and using [62] we obtain the result in (5.35).

Introduction

Whenever size, power, or other constraints preclude the use of multiple-input multiple-output (MIMO) systems, wireless systems cannot benefit from the well-known advantages of space-time coding (STC) methods. Also the complexity (multiple radio-frequency (RF) front ends at both the transmitter and the receiver), channel estimation, and spatial correlation in centralized MIMO systems degrade the performance. In situations like these, the alternative would be to resort to cooperative communications via multiple relay nodes. When these nodes work cooperatively, they form a virtual MIMO system. The destination receives multiple versions of the same message from the source and one or more relays, and combines these to create diversity.



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