Efficient Adaptive Radio Resource Management Algorithms for Next Generation Wireless Systems

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Abstract— **The need for optimised utilisation of scarcely available radio resources is prevalent. An efficient use of radio resources could lead to higher spectral efficient transmission on wireless channels. A promising scheme for wireless multimedia transmission at a lower cost is adaptive modulation and coding (AMC). In this paper, a new scheme for AMC is devised. A prioritized adaptive CDMA modulation and a graded resource technique is proposed for the maximisation of radio resources and for the realisation of next wireless generation. Rate compatible punctured turbo-code (RCPT) method and diversity technique with power controlled error (PCE) are also employed for better results. Simulations were carried out and the proposed algorithms demonstrate an improved throughput and robustness over the existing systems. These improvements arise from efficient radio resource management algorithms.**

I. INTRODUCTION

Radio resource management (RRM) is the system level control of radio transmission characteristics in wireless communication systems [1], [2]. This system allows parameters such as transmit power, transmit rate and modulation schemes to be controlled in order to utilise the limited radio spectrum resources and radio network infrastructure efficiently. In order to achieve an improved and efficient utilisation of resources, adaptive radio resource management schemes that can adjust the radio communication parameters dynamically to the quality of service (QoS) and throughput requirements are considered. These schemes are particularly considered in the design of wireless systems [3], [4], in view of maximising the system spectral efficiency without sacrificing the system performance. This scheme has been considered as a better algorithm for fading channels [3], [5].

Radio resource management algorithm is described using the AMC scheme [6]-[11] and is proposed as the solution for the next generation wireless systems. Also, it is currently the major technique in the standards for 3rd-Generation (3G) wireless systems. The AMC scheme is deliberately developed to achieve high spectral efficiency on fading channels [12]-[14]. The approach adopted in achieving spectral efficiency using AMC on wireless communications is to match the modulation, coding and other signal parameters to the conditions on the radio wireless communication channel [15]. These conditions involve path loss, the interference due to signals coming from other transmitters, the sensitivity of the receiver and the available transmitter power margin [15].

This paper proposes an efficient adaptive radio resource management (ARRM) for better optimisation of wireless channel conditions. The approach employed a prioritised scheme whereby a parameter is given priority over another parameter. In this work a prioritised CDMA system is considered for adaptation in broadband direct sequence code division multiple access (DS-CDMA) wireless networks. This method has potential for optimising the utilisation of scarcely available radio resources for the realisation of next wireless generation. To achieve this, two processes have to be followed, which are to develop efficient adaptive CDMA schemes and evaluate the schemes via simulation. The adaptive CDMA system has the advantage of flexibility, and it can provide high transmission quality and throughput.

The remainder of this paper is organised as follows: In the next section, the system model is presented. Section III describes the proposed efficient ARRM algorithm. In Section IV, we discuss the simulation results, while conclusions are drawn in section V.

II. THE SYSTEM MODEL

A. The Channel Model

In this Section, the Corazza and Vatalaro model is considered [16] for the satellite wireless transmission systems. This wireless model is based on wide-band channels. In this model, low earth orbiting (LEO) satellite communication network systems and spread-spectrum based code division multiple access (CDMA)

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technologies are considered. The binary phase-shift keying (BPSK) and quadrature-shift keying (QPSK) are applied for the transmission in the Ka-band mobile satellite wireless systems.

Considering the diversity system, a fading signal envelop $\alpha_l, l = 1, 2, \ldots, L$ at the user's path is modeled. The α_l is used to a represent Rice-lognormal wireless channel. This can be defined as the product of two independent process written as $\alpha_l = S_l R_l$, where S_l represents lognormal random variable modelling long-term shadowing effects, and R_l represents Rice random variable modelling short-term diffuse multi-path fading over a direct signal component. The probability density function of the instantaneous received signal power is given by [16], [17]

$$\zeta_{\alpha_l^2}(\alpha) = \int_0^\infty \zeta_{\alpha_l^2|\beta_l}(\alpha|\beta_l)\zeta(\beta_l)d\beta_l \tag{1}$$

where $\zeta_{\alpha_l^2|\beta_l}(\alpha|\beta_l)$ is the probability density function of the instantaneous received signal power condition on the mean square value of the signal. The non-central chi-square distribution is given by

$$\zeta_{\alpha_l^2|\beta_l}(\alpha|\beta_l) = \frac{K_l+1}{\beta_l} exp\left[-\frac{(K_l+1)\alpha}{\beta_l} - K_l\right]$$

$$I_o\left(2\sqrt{\frac{K_l(K_l+1)\alpha}{\beta_l}}\right) \tag{2}$$

The Rice factor K_l is the ratio of the direct signal power to the diffuse multi-path power and $\beta_l = E[R_l^2]S_l^2 = (K_l+1)2\sigma^2 S_l^2$ is the mean power. In the presence of shadowing, S_l^2 represents a random variable with log-normal probability density function

$$\zeta_{S_l}(s) = \frac{1}{\sqrt{2\pi}h\sigma_{slS}} exp\left[-\frac{(InS-\mu_{sl})^2}{\sqrt{2}h\sigma_s l}\right] \tag{3}$$

where $h = (In10)/20$, μ_{sl} and σ_{sl} represent the mean and standard deviation (in dB) of the associated normal variate respectively.

Regarding the PCE, the closed-loop power control scheme proposed is adopted [18], [19]. The logarithm mean and the standard deviation of the power envelope $p = s$ of the received signal are assumed to be μ_{pl} and σ_{pl} respectively. In a power controlled algorithm, the received power is controlled to vary around the target power. $\mu_{pl} = 0dB$ is set and the PCE is measured by σ_{pl}. The channel model is validated by simulation and it is found that the performance of the system degraded with the decrease of Rice factor, K when PCE is constant, and with the increase of the standard deviation of the PCE when K is constant. This is illustrated in Figs. 1 and 2 respectively.

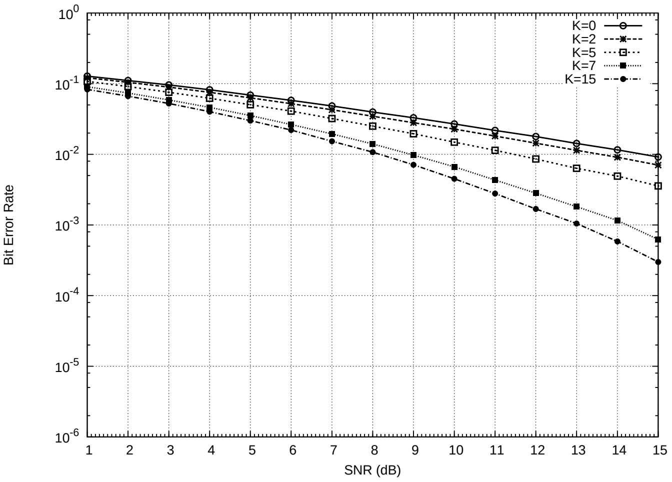

Fig. 1. Simulation results of the uncoded channel performance with Rice Factor, K = {0, 2 , 5, 7 , 15}dB, over Rice-lognormal wireless channel

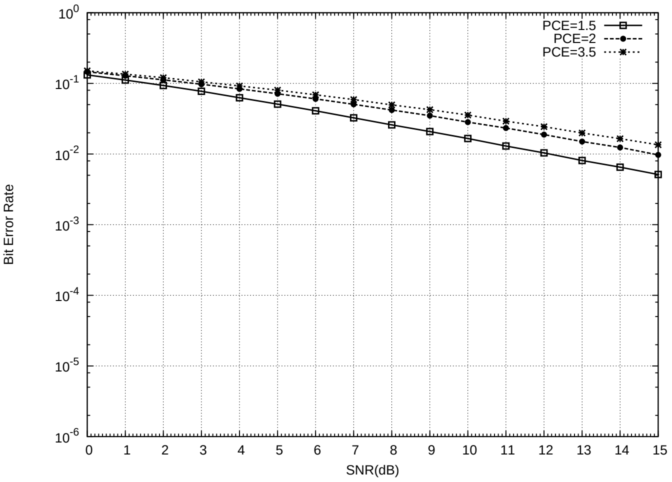

Fig. 2. Simulation results of the uncoded channel performance with power control error, PCE = {1.5, 2.0 , 3.5}dB over Rice-lognormal wireless channel

B. *The Receiver Model*

For the receiver model, asynchronous simultaneously active users of a spot beam transmitting via satellite wireless transponders and L-order path diversity are considered and is given as[17].

$$r(t) = \sqrt{2P_t}\sum_{k=1}^{M}\sum_{l=1}^{L}\alpha_l^k b^k(t-\tau_l^k)$$

$$c^k(t-\tau_l^k)\cos(\omega_c t + \phi_l^k) + n(t). \tag{4}$$

The P_t is used to represent the transmitted power, $c^k(t)$ is used to represent the spreading sequence of the kth user, $b^k(t)$ is used to denote the message generated at rate $1/T$, τ_l^k and ϕ_l^k represents independent time delays and carrier phases respectively. The fading envelope $\alpha_l(t)$ describes the Rice-lognormal statistics, and can be written as $\alpha_l^k = S_l^k R_l^k$ where S_l^k is a lognormal PCE due to shadowing and R_l^k is the independent flat fading present at lth path of the kth user, which are generated at rate $1/T_c$. The $n(t)$ represents the additive white Gaussian noise (AWGN) with two-sided power spectral density of $N_0/2$. The processing gain is chosen to be G_c.

Considering the case of a BPSK modulated DS-CDMA system, the output of the nth transmitted bit of user 1, assuming that acquisition has been achieved is given by

$$Z_l^1(n) = \int_{nT+\tau_l^1}^{(n+1)T+\tau_l^1} 2r(t)\alpha_l^1$$

$$c^1(t-\tau_l^1)\cos(\omega_c t + \phi_l^1) \tag{5}$$

Assuming perfect estimates of the channel gains, the above equation becomes

$$Z_l^1(n) = \sqrt{P_t} T b_n^1 \left\{\alpha_l^1\right\}^2 + \sqrt{2P_t}\alpha_l^1$$

$$\sum_{i=2}^{M}\sum_{k=1}^{L} \alpha_i^k I_{il}^{kl}(T) cos\phi_{il}^{kl} + \alpha_l^1 N(T) \tag{6}$$

where $I_{il}^{kl}(T)$ represents the cross correlation of ith path of the kth user and $N(T)$ represents zero mean Gaussian process with variance $N_0 T\{\alpha_l^1\}^2$.

III. THE PROPOSED ARRM ALGORITHM

A. Description of The Proposed ARRM Algorithm

In this Section an algorithm, which combine CDMA modulation adaptation with MCS parameter adaptation is described. In the traditional adaptive CDMA algorithm the parameters such as Rician K factor, $SINR$, N_u are input into the system followed by the MSC and CDMA modulation parameters. That is, the channel parameters are set first and after the acquisition, the MSC with CDMA modulation parameters are assigned. The algorithm is executed sequentially until the channel situation changes.

In the proposed algorithm, the channel parameters are set first as in the traditional adaptive scheme but the processing gain is prioritised over the MCS. The processing gain is used to increase the granularity for the channel adaptation and thereby provide a smoother adaptation system. Unlike ordinary AMC that provides a coarse adaptation to the channel, the use of processing gain provides the fine tuning to the selected MCS. This is illustrated in Fig. 3. Also as shown in layer 2 of the Figure, a puncturing method is used to select the coding rate based on the channel conditions. Many papers have presented the puncturing techniques [20]-[27]. This work is therefore focused on the development of an efficient algorithm and simulation of the proposed AMC. The algorithm is designed to select MCS and the number of processing gain. The objective of this algorithm is to maximise the bit rate by selecting the right combination for the number of processing gain j and the MCS i, given a channel condition α.

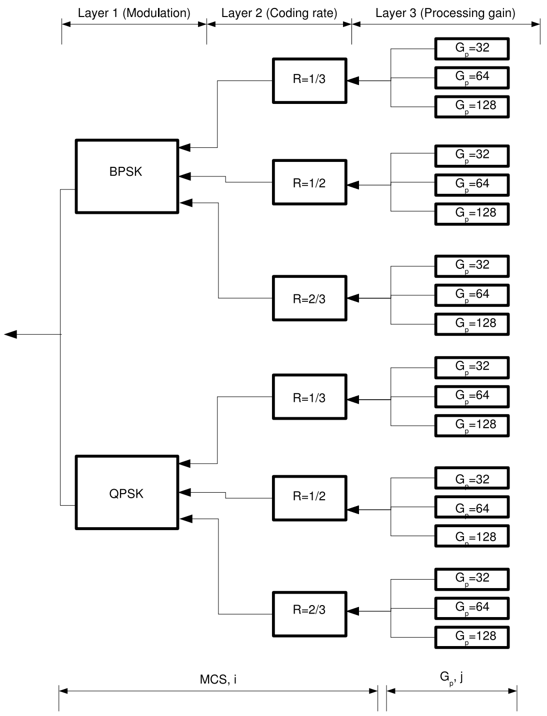

Fig. 3. Block diagram of ARRM system with a prioritised G_p

B. Design of The Proposed ARRM Algorithm

In this Section, the design process of the proposed algorithm is explained. The flowchart of the algorithm is presented in Fig. 4. The algorithm highlights how the processing gain and the MCS are selected in order to increase the transmission bit rate. The selection process is based on the channel condition subjected to a certain threshold value Γ.

The adaptive processing gain algorithm firstly initialised the processing gain and MCS. Secondly, the algorithm checks the channel conditions based on minimum threshold value, and increases the value of processing gain accordingly in order to increase the bit rate. This is dependent on the situation of the channel. The next higher MCS would be examined only when the maximum value of processing gain is reached. If given a channel condition, higher MCS with a given

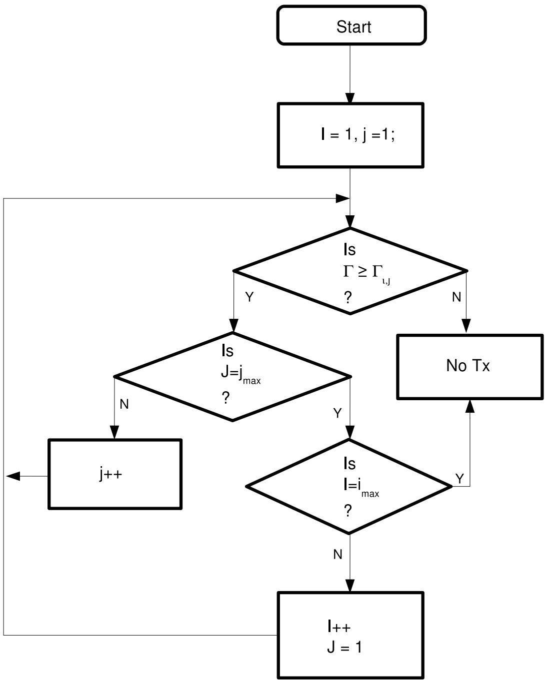

Fig. 4. Flowchart of ARRM algorithm with a prioritised G_p

value of processing gain does not necessarily give a higher bit rate than the previous MCS with a maximum value of processing gains. Thus, the last step in the algorithm is to check and make sure that the state with the highest bit rate is selected. In this algorithm, a higher priority is given to increase the value of processing gains instead of the MCS. This adaptive CDMA algorithm for wireless channels is designed to get as much throughput as possible while guaranteeing a BER of 10^{-3}. In other words, it means that the algorithm will first exploit the processing gain starting with the lowest. The lower the processing gain, the higher the spectral efficiency (throughput). The algorithm considered the MCS after all the processing gains have been exploited. The algorithm sets its parameters based on this rule.

IV. SIMULATION RESULTS

The parameters considered in this simulation are rate $= 1/3$ and turbo encoder, which is based on the parallel recursive systematic convolutional (RSC) encoders. This turbo encoder is constructed from generator polynomials $(G1; G2) = (37; 23)_8$. Other parameters include the information sequence length (k), which represents the encoded sequence length = 1,024 bits. The turbo encoded sequence is interleaved with a size $2^p \cdot 2^q$ block-interleaver, where 'p' and 'q' are the maximum allowable integers for a given sequence size. BPSK/QPSK modulation is assumed for data demodulation at the receiver. $G_c = 32, 64, 128$ is assumed for CDMA systems. The uplink channel is assumed to be composed of $L = 16$ paths and uncorrelated, wireless faded paths.

1) Effect of Throughput on Radio Resource Management Algorithms: The result in Fig. 5 presents the different grading of radio resources. The adaptive modulation is an instance of grade-1 with one resource and it is denoted by 'a'. The AMC is a traditional adaptive scheme and it is represented as grade-2 with two resources, that is modulation and coding. This is denoted by 'b'. The adaptive CDMA provide additional dimension to AMC and this is represented as grade-3 with three resources. It is denoted by 'c'. Given the maximum transmission time of a codeword as time t, the throughput performance of the adaptive algorithms is examined for grade-1, grade-2 and grade-3 sets of transmitter parameters as shown. It is observed that as E_b/N_0 increases the adaptation algorithm responds by selecting transmit parameters that enable spectral efficiency improvement. That is, increasing the number of parameters/resources available for adaptation at the transmitter lead to better spectral efficiency. Thus the grade-3 adaptation achieves higher spectral efficiency than the grade-2 and grade-1 adaptation algorithms. This algorithm is desirable for a fading channel. Thus some resources can be conserved by the transmitter when the channel conditions are good and increases resources as the channel conditions become bad.

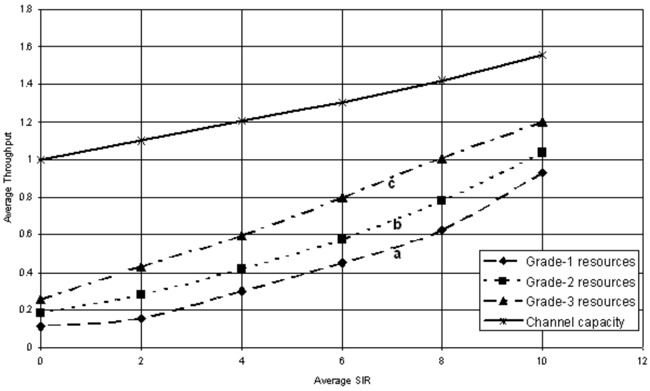

Fig. 5. Simulation results showing the throughput of different resource grading schemes

2) Percentage Usage of Radio Resources in adaptive CDMA System: The percentage contributions of the parameters and values in terms of their usage in adaptive CDMA systems in an ideal condition are measured. Figs. 6, 7 and 8 shows the percentage of the usage of the processing gain G_c, modulation M, as well as modulation and coding schemes, MCS during the sim-

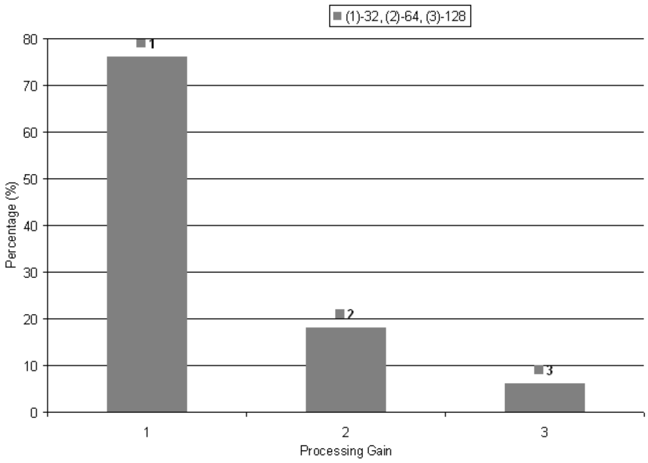

Fig. 6. Percentage of processing gain used

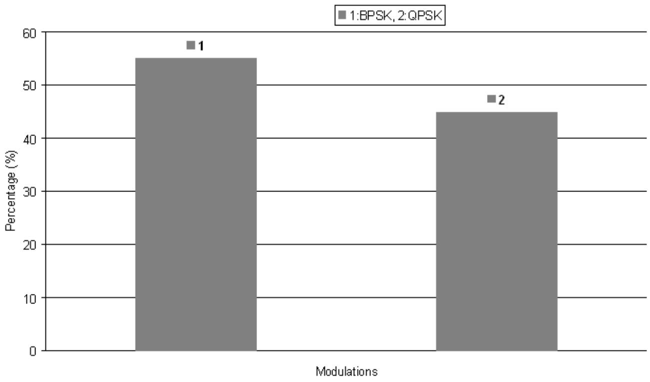

Fig. 7. Percentage of modulation used

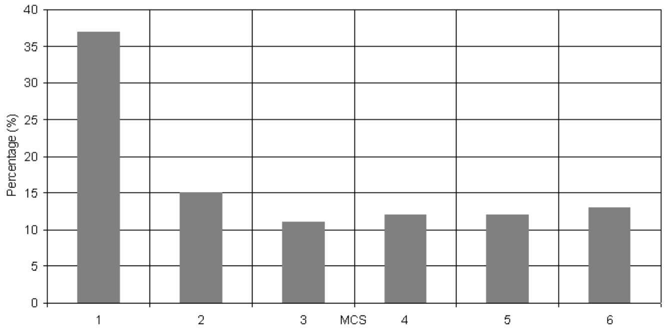

Fig. 8. Percentage of each MCS used

ulation. From Fig. 6, it is found that our algorithm assigned a processing gain of 32 for 75.33% of the transmissions, a processing gain of 64 for 18.12% of the transmissions, and a processing gain of 128 for 6.55% of the transmissions. Fig. 7 shows the percentage of usage of each of the modulation levels during the simulation. BPSK was used for 56.31% and QPSK for 43.69% of the transmissions. Fig. 8 presents the percentage of usage of each of the MCS. In our simulations, 36.87% of the transmissions exploited MCS1, 15.50% MCS2, 10.81% MCS3, 11.97% MCS4, 11.97% MCS5 and 12.88% MCS6. All settings can be changed with the channel situation. The essence of this measurement are to conserve energy during transmissions, and to improve throughput and QoS.

V. CONCLUSIONS

In this paper, an efficient adaptive radio resource management algorithm for next generation wireless systems is proposed. The objective of these algorithms is to get as much throughput as possible under the condition of guaranteeing a certain transmission quality. The simulation results indicated that significant throughput can be obtained by the algorithms. The proposed adaptive CDMA algorithm is a resources-control algorithm. The difference between the algorithm and the other adaptive CDMA algorithm for wireless channels is that this algorithm is developed so that the processing gain is prioritised over the modulation and coding scheme. Furthermore, it is observed that by increasing the number of resources available for adaptation at the transmitter, better spectral efficiency across the entire E_b/N_0 range is achieved. Radio resources have been evaluated based on percentage of the parameters and values in term of their usage in adaptive CDMA system. These measurements are necessary for the radio resources management. Thus the amount of the resources used during transmission, and the energy saved, could be determined.

REFERENCES

[1] G. Fodor, A. Eriksson, A. Tuoriniemi, “Providing Quality of Service in Always Connected Networks”, IEEE Communications Magazine, July 2003.

[2] S.Dixit, Y. Guo, and Z. Antoniou,”Resource Management and Quality of Service and Quality of Service in Third-Generation Wireless Networks” IEEE Communications Magazine, February 2001, pp 125-133.

[3] T. Tjelta, A. Nordbotten, M. Annoni, E. Scarrone, S. Bizzarri, L. Tokarchuk, J. Bigham, C. Adams, K Crag, M. Dinis, “Future Broadband Radio Access Systems for Integrated Services with Flexible Resources Management”, IEEE Communications Magazine, August 2001, pp. 56-63.

[4] A. Hills and B. Friday, “Radio Resource Management in Wireless LANs”, IEEE Radio Communications, December 2004. pp S09-S14.

[5] A. A. Shaikh, B. S. Chowdhry, A. K. Baloch, and A. H. Pathan,”Radio Resource Management Strategies in 3G UMTS Network” National Conference on Emerging Technologies, 2004, pp 48-51.

[6] A. J. Goldsmith and S.G.Chua, “Adaptive Coded Modulation for Fading Channels,” IEEE Trans. Commun., vol. 45, May 1998, pp. 595-602.

[7] V. Lau and M. Macleod, “Variable Rate Adaptive Trellis Coded QAM for High Bandwidth Efficiency Applications in Rayleigh Fading Channels,” IEEE Proc., April 1998, pp. 348-352.

[8] S. M. Alamouti and S. Kallel, “Adaptive Trellis-Coded Multiple-Phased-Shift Keying for Rayleigh Fading Channels,” IEEE Trans. Commun., vol. 42, June 1994, pp. 2305-2314.

[9] K. J. Hole and G.E. Qien, “Spectral Efficiency of Adaptive Coded Modulation in Urban Microcellular Networks,” IEEE Transaction Vehicular Technology, vol. 50, January 2001, pp. 205-220.

[10] S. Vishwanath and A. J. Goldsmith, “Exploring Adaptive Turbo Coded Modulation for Flat Fading Channels,” Proc. VTC, vol.4, Fall 2000, pp. 1778-1783.

[11] Doroslovacki, M., “Constrained adaptive algorithms for code acquisition and interference cancellation in asynchronous DS-CDMA systems”, The Thirty-Fourth Asilomar Conference on Signals, Systems and Computers, vol.1, 29 Oct.- 1 Nov. 2000, pp, 792 - 796.

[12] Motorola and Nokia, “Proposal for standardization of very high rate mixed voice-data traffic capabilities, based on extending and enhancing 1X systems”, 3GPP2,S00-200003210-020,March,2000.

[13] Motorola,Nokia,Philips,TI and Altera, “Point 1XTREME Proposal for 1XEV-DV”, 3GPP2,C50-20010611-008a,June,2001.

[14] Motorola,Nokia,Texas Instruments,Altera,and Philips Semiconductors, “1XTREME Physical Specification for Integrated Data and Voice Ser-vices in cdma2000 Spread Spectrum Systems”, 3GPP2,C50-200010611-013R1,June,2001.

[15] S. G. Wilson, “Digital Modulation and Coding,” Upper Saddle River, NJ: Prentice Hall Inc, 1996.

[16] G. E. Corazza and F. Vatalaro, “A statistical model for land mobile satellite channels and its application to nongeostatonary orbit systems,” IEEE Trans. Veh. Technol., Vol. 43, Aug. 1994, pp. 738-742.

[17] G. P.Efthymoglou and V. A.Aalo “Path Diversity Performance of DS-CDMA Systems in a Mobile Satellite Channel” IEEE Trans. on Veh.Tech., Vol.49, No.6, Nov.2000, pp 2051-2059.

[18] W. Li, V. K. Dubey, and C. L. law “A new generic multistep power control algorithm for the LEO satellite channel with high dynamics,” IEEE Commun. Lett., Vol.5, Oct. 2001, Oct. 2001.

[19] L. Wenzhen et al.”The performance of Turbo Coding Over Power-Controlled Fading Channel in Ka-Band LEO Satellite Systems” Wenzhen Li et al. IEEE Trans. on Veh Tech., vol.52, No.4, July 2003, pp 1032-1043.

[20] P. Jung and J. Plechinger, ”Performance of rate compatible punctured turbo-codes for mobile radio applications,” IEE - Electronics Letters, vol. 33, no. 25, 1997, pp. 2102-2103.

[21] F. Babich, G. Montorsi, and F.Vatta, “On Rate-Compatile Puncture Turbo Codes Design,” EURASIP Journal on Applied Signal Processing, 2005, pp. 784-794.

[22] W. Li, V. K. Dubey, and C. L. law “The Performance of turbo Coding Over Power-Controlled Fading Channel in Ka-Band LEO Satellite Systems” IEEE Trans. on Veh.Tech., Vol.52, No.4, July 2003, pp 1032-1043.

[23] S. Benedetto, R. Garello, and G. Montorsi, ”A search for good convolutional codes to be used in the construction of turbo codes,” IEEE Trans. Commun., vol. 46, no. 9, 1998, pp. 1101-1105.

[24] J. Hagenauer, ”Rate-compatible punctured convolutional codes (RCPC codes) and their applications,” IEEE Trans. Commun., vol. 36, no. 4, 1988, pp. 389-400.

[25] A. S. Barbulescu and S. S. Pietrobon, ”Rate compatible turbo codes,” IEE - Electronics Letters, vol. 31, no. 7, 1995, pp. 535-536.

[26] D. N. Rowitch and L. B. Milstein, ”Rate compatible punctured turbo (RCPT) codes in a hybrid FEC/ARQ system,” in Proc. IEEE Communication Theory Mini-Conference , held in conjunction with GLOBECOM ’97, Phoenix, Ariz, USA, November 1997, pp. 55-59.

[27] D. N. Rowitch and L. B. Milstein, ”On the performance of hybrid FEC/ARQ systems using rate compatible punctured turbo (RCPT) codes,” IEEE Trans. Commun., vol. 48, no. 6, 2000, pp. 948-959.

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