行政院國家科學委員會專題研究計畫成果報告

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IMT-2000 軟體無線電架構之研究-子計畫七:多碼/多速率分碼多工之多媒體通訊(II)

Multi-Code/Multi-Rate CDMA Multimedia Communication (II)

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計畫類別: 整合型計畫

計畫編號: NSC 89-2219-E-002-022

執行期間: 88 年 08 月 01 日至 89 年 07 月 31 日

計畫主持人: 陳光禎教授

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行政院國家科學委員會專題研究計畫成果報告
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一、 中文摘要

多碼及可變展度是兩種在分碼多工系統中最廣泛被用來實現多速率傳輸的兩重多工接取方式。我們研究此兩種多速率方式在衰退通道中運作的結果，為了評估系統表現，我們根據最大可能序列偵測推導最小錯誤率的邊界值，多用戶漸近效率也同時分析作為另一系統評估指標。此外，也分析了採用線性多用戶接收器並可支援多媒體通訊的分碼多工系統的容量，藉著採用廣義的等效用戶資料模型以及延伸過去對單類服務分碼多工系統的分析，我們研究了在蜂巢式環境中多媒體分碼多工系統的容量。我們也提出了一套資源、功率分配的方法論，此方法可控制多維度的容量分布且影響多媒體系統的效率。

關鍵詞：分碼多工，多用戶漸近效率，多速率分碼多工系統，多重路徑衰退，線性多用戶偵測，功率配置，資源分配，容量，多媒體分碼多工系統

Abstract:

Multi-code (MC) access and Variable-Spreading-Length (VSL) access are two widely applied realizations for multi-data-rate services in direct-sequence code-division multiple-access (DS/CDMA) systems. We study the behavior of these two multi-rate realizations operating in multi-path fading channels. Bounds of minimum probability of error based on maximum-likelihood sequence detection are developed for performance evaluations. Asymptotic multiuser efficiency is also analyzed as another performance index. In addition, the capacity of a CDMA system supporting multimedia services with linear multiuser detectors (MUD) is analyzed. By adopting the generalized effective user data model for multi-rate CDMA and extending the capacity analysis for CDMA systems supporting single class of services with linear MUDs in earlier works, we investigate the capacity of a multimedia CDMA system in cellular environment. The methodology of resource assignment or power allocation is also developed, which will be demonstrated to control the multi-dimensional capacity distribution and to affect the efficiency of the multimedia systems.

Keywords: CDMA, AME, multi-rate CDMA, multipath fading, linear multiuser detection, power allocation, resource assignment, capacity, multi-media CDMA system

二、緣由與目的

Multimedia communication will be the main stream in the future communication services and it introduces challenges in effective transmission. As CDMA being utilized for the third generation and future communication systems, it is an important subject to realize multimedia services based on CDMA. Among the previous researches, Multi-Code and Various-Spreading-Length access schemes are the two most fundamental and widely applied multi-rate schemes [1]. Different access schemes will affect the design of receiver and different communication environments will cause different results. In wireless CDMA systems, multi-path fading and multiple-access interference (MAI), which is induced by co-channel users, limit the performance. Some previous researches, such as [2], have discussed multi-rate CDMA systems in additive white Gaussian (AWGN) channels and VSL scheme is shown to outperform MC scheme by analyzing

the performance of jointly optimal detection. However, the behaviors of these two schemes in more practical environments are not yet studied and it is important to the design of efficient multiuser detectors in real applications. Multi-path fading effect is inevitable in wireless communications and it results in the phenomenon that the correlation of signature waveforms will exist even between the signals from different paths. We investigate the property of multiuser detection of these two access schemes, support the minimum probability of error and asymptotic multiuser efficiency (AME) by maximum likelihood design strategy as evaluations of performance, and finally analyze the results under different channel environments.

In addition, the capacity analysis of multimedia CDMA systems has received a lot of attention as a result of the rapid emergence of multimedia applications. The previous research on Erlang capacity calculations was mainly based on the signal-to-interference power ratio (SIR) analysis for conventional detectors. It has been assumed that the required SIR for each class of services is independent of the number of users in each class [3]. However, this remains valid only for multimedia CDMA systems employing conventional detectors whose BER performance only depend on the SIR attained. Based on their assumption and analysis, the maximum numbers of voice and data users in a dual-rate CDMA system follow a linear relationship [3][4]. The linear relationship between high rate and low rate users in a dual-rate system has also been found in [1]. In [4], the definition of ``system outage'' for multimedia systems was presented, however, the system outage probability analysis in does not provide insight to the behavior of each class since different classes of services may have different QoS requirements. In [5], a more detailed ``class outage'' probability for voice-only users was analyzed in a CDMA system supporting voice and data services. However, to provide a complete understanding of the capacity of a CDMA system supporting multimedia traffics, the outage probabilities of other classes have to be analyzed as well. The power control algorithms in the forward and reverse links were investigated to optimize the parameter of their concerns. The idea of controlling the 2D capacity distribution of voice and data services by way of power or resource allocation was also presented in [6]. We shall generalize the capacity analysis of CDMA systems supporting single class of services with linear MUDs to CDMA systems supporting multimedia services. The development of power allocation that is critical in CDMA cellular operation is introduced, and we clarify radio resource or power allocation in CDMA cellular systems employing multi-rate multiuser detection.

三、結果與討論

In multi-path channels, from the concept that each symbol can be viewed as a generalized user, the inter-symbol interference from the same original user can be also viewed as multiple access interference. By the analysis method of error vector [7][8], we found that the error probability is determined by not only the inner-path correlation but also the inter-path correlation. Specifically, the product of the eignvalues of correlation matrix dominates the error probability, and the larger the product is the better it behaves. Comparing the signal structure in MC and VSL transmissions, there exist more nonzero terms in the correlation matrixes of MC transmission which results in smaller product of eignvalues for high-rate users. Therefore, the error probability of the high-rate users is smaller in VSL systems than in MC systems. As for the low-rate users, under the case that all the transmitted symbol energy are the same, the cross-correlation between a high-rate generalized user and a low-rate generalized user in VSL systems is generally smaller than the cross-correlation between two generalized users in MC systems. Thus, the VSL system is still expected to outperform the MC system in detection error probability under multi-path fading environments due to the inherent better signal structure. Asynchronous receiving in a manner destructs the advantageous structure of VSL access scheme while compared with MC access scheme in the viewpoint of signal correlations. The BER and AME results of our dual-rate numerical examples are shown in fig. 1 and fig. 2.

Extra paths just increase the number of equivalent generalized users and thus the VSL system is generally more robust to the multi-path

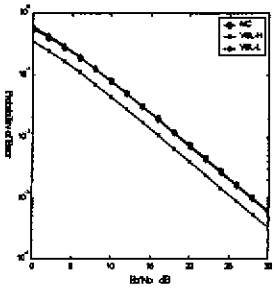


Fig.1 BER performance comparison of MC and VSL systems in multi- path fading channels. MC: user in MC systems VSL-H: high-rate user in VSL systems VSL-L: low-rate user in VSL systems

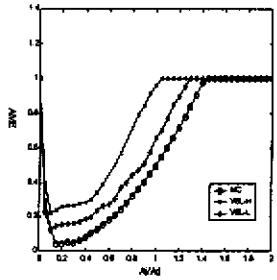


Fig.2 Asymptotic performance comparison of MC and VSL systems in multi-path fading channels. Ai/Ad: amplitude ratio of interferers over desired user

effect than the MC system. Employing the information of all the paths in multi-path channels for detection in VSL systems is not as critical as in MC systems. Therefore, utilization of only one dominant path in the design of detector for complexity reduction is more appropriate in VSL systems, especially for detecting high-rate users.

For capacity analysis, consider a dual-rate DS-CDMA system with $\overline{NL}$ low rate users transmitting at data rate R, and $\overline{NH}$ high rate users transmitting at data rate MR with different QoS requirements, where M is an integer. Conditioned on the number of active high rate users in the system, the maximum number of active low rate users the system can support with some power constraints can be found. Equations to describe the relation of $\overline{NL}$ and $M\overline{NH}$ can be considered as three possible simple cases of the system behavior:

1. Suppose the multi-rate system possess a linear function: To maximize the capacity with such a system behavior, we should allocate all the spectrum resource or power to either high rate or low rate users depending on the slope of the linear function. Suppose the slope is greater than -1, the system resource should be all allocated to the high rate transmissions, and vice versa.
2. Convex function: This kind of system behavior also suggests we allocate all the system resource to either high rate or low rate users as in the previous case. The source allocation depends on whether $\overline{NL}$ or $M\overline{NH}$ is greater.
3. Concave function: Unlike the previous discussed cases, the multi-rate system with a concave system behavior suggests that it support combined data rates services to maximize its capacity. The maximum capacity is achieved at the operating point at which the slope equals -1.

It is shown in [3] that the system behavior follows a linear function for a dual-rate DS-CDMA system. However, the assumption that the required SIR for high rate and low rate users remain constant regardless of the distribution of users at each data rate holds true only for systems employing single-user detectors. For a system with single user detection, the BER for each user is directly related to the SIR attained, therefore the SIR required by each user remains constant irrespective of the data rate distribution. It is well known that by employing multiuser detection, the BER and the system capacity can be considerably increased for DS-CDMA systems. However, to maximize the system capacity of a multi-rate system with some power constraints, we should not only consider the power allocation, but also take multiuser detections into account while past research did not successfully investigate. It is also known that all the multiuser detectors possess some degrees of near-far resistance. This means the SIR attained by each user cannot be treated as a direct QoS measure anymore. Therefore, the system behavior generally does not follow a linear function as observed in [3]. Consequently, we developed general framework of power allocation in a multi-rate CDMA system employing linear multiuser decorrelating detector. As the decorrelating detector is adopted, each user's BER can be expressed in terms of its power and the correlation matrix R only, which facilitates the power allocation for multi-rate systems. Two power-allocation scenarios are proposed to maximum the system capacity: the per user power constraint on the uplink and the total power constraint on the downlink, which are valid for practical systems wherein the maximum transmitted power are limited for each handset on the uplink, and for each base station on the downlink.

To calculate the capacity of a multi-rate CDMA system, we derived the capacity of a multi-rate CDMA system employing multi-user detections with ideally effective power allocation. An example for the capacity of a system supporting two classes of services is shown in Fig. 3. The two curves in correspond to the outage probability constraints of Class 1 and Class 2 respectively, where (λ_i/μ_i) denotes the parameter of Poisson requesting rate of service.

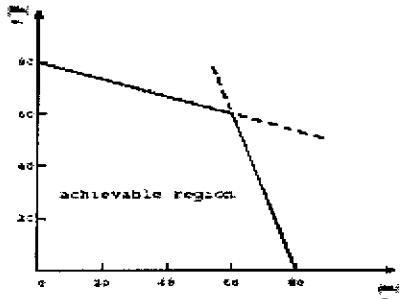
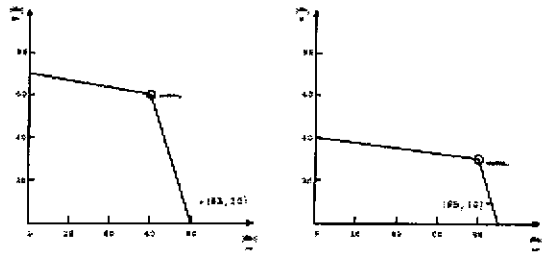


Fig.3. A possible 2-D capacity for two classes of service.



(a) π_1 (b) π_2

Fig. 4 Two possible 2D capacity distributions for sys- tems supporting two classes of service with

The resource or power allocation in systems supporting multimedia services should be performed according to the requested traffic of each class rather than some other algorithms, e.g., to maximize the system throughput defined as the total data rates of users in the system. This can be illustrated as the example in Fig. 4 with resource allocation vectors π_1 and π_2.

四、計畫成果自評

We studied the behavior of two widely applied multi-rate realizations operating in multi-path fading channels. Bounds of minimum probability of error based on maximum-likelihood sequence detection are developed for performance evaluations. We found that VSL access scheme is more robust to multi-path fading effect for high rate users. Assigning orthogonal spreading codes for each effective user supports the MC systems an occasion to rival VSL systems in detection performance, though the orthogonal property is hard to maintain in real environments. Therefore, good design on spreading codes for low auto-correlation and cross-correlation is relatively recommended while choosing the MC access scheme. Detectors operated by utilizing only one dominant path are more appropriate in VSL systems for high-rate users because the remainder paths does not degrade the detection performance in VSL systems as much as in MC systems in multi-path environments.

Besides, the capacity analyses for linear MUDs are extended to CDMA systems supporting multimedia services, and the idea of resource or power allocation is developed, which is crucial in systems supporting multimedia traffics. An operational definition of power mis-allocation is further presented. Future works should include the mathematical analysis of capacity for linear MUDs in multimedia systems, the extension of capacity analysis to more realistic fading channel models, and the development of algorithms for resource allocations.

五、參考文獻

[1] T. Ottosson and A. Svensson, "Multi-rate schemes in DS/CDMA systems", *Proc. IEEE Vehic. Tech. Conf.*, pp. 1006-1010, 1995.

[2] U. Mitra, "Comparison of maximum-likelihood-based detection for two multi-rate access schemes for CDMA signals", *IEEE Trans. on Comm.*, Vol. 47, pp. 64-77, Jan. 1999.

[3] C. L. I, G. P. Pollini, L. Ozarow, and R. D. Gitlin, ``Performance of Multi-Code CDMA Wireless Personal Communications Networks," *Proc. IEEE VTC'95*, pp. 907-911, 1995.

[4] A. Sampath, N. B. Mandayam, and J. M. Holtzman, ``Erlang Capacity of a Power Controlled Integrated Voice and Data CDMA System," *Proc. IEEE VTC'97*, pp. 1557-1561, 1997.

[5] N. B. Mandayam, J. Holtzman, and S. Barberis, ``Erlang Capacity for an Integrated Voice/Data DS-CDMA Wireless System with Variable Bit Rate Sources," *Proc. IEEE PIMRC'95*, pp. 1078-1082, 1995.

[6] S. Yao and E. Geraniotis, ``Optimal Power Control Law for Multi-Media Multi-Rate CDMA Systems," *Proc. IEEE VTC'96*, pp. 392-396, 1996.

[7]S. Verdú, "Minimum probability of error for asynchronous Gaussian multiple-access channels", *IEEE Trans. on IT*, pp. 85-96, Jan. 1986.

[8]Z. Zvonar, D. Brady, "Multiuser detection in single-path fading channels", *IEEE Trans. on Comm.*, Vol. *42*, pp. 1729-1739, /Feb./March/ Apr., 1994.