PAA: Pre-Allocation Assignment of Orthogonal Variable-Spreading-Factor Codes in W-CDMA

Pei-Wei Huang
Department of Computer Science and Information Engineering
Da-Yeh University, Taiwan
E-mail: moses@mail.dyu.edu.tw

Chien-Feng Li
Department of Computer Science and Information Engineering
Da-Yeh University, Taiwan
E-mail: r9106024@mail.dyu.edu.tw

Abstract

This study develops a novel code assignment scheme for orthogonal-variable-spreading-factor (OVSF) in wideband CDMA (W-CDMA). Specifically, a “Pre-Allocation Assignment” scheme is proposed to reduce the considerable time requirements of a code reassignment procedure. This study focuses not only on eliminating the code-blocking problem, but also on reducing the call setup delay. The concept of "pre-allocation" is applied to the reassignment procedure during the "gap" between two arriving calls. PAA thus outperforms other schemes by reducing the call setup delay. PAA dynamically pre-allocate a code with the largest available bit rate. This step enables the system to rapidly complete code assignment. By observing the simulation results, call setup delay is reduced by shifting the reassignment procedure.

Key Words: OVSF, code blocking, W-CMDA, IMT2000, UMTS

1. Introduction

Wireless communication systems [4] are evolving from second generation to third generation owing to the growing needs of modern life. The next generation of wireless communication systems is expected to be capable of transferring multimedia data at high rates. The ITU-R designed the 3G specifications, IMT2000, to help establish a global wireless infrastructure.

The UMTS/IMT2000 employs W-CDMA [7], which supports high-data-rate and variable-bit-rate. The W-CDMA system employs the OVSF codes [1] to provide variable-bit-rate services, in a scheme called OVSF-CDMA. In an OVSF-CDMA system, each user is assigned a single orthogonal variable-spreading-factor code. Data rates differ with spreading factors, and a smaller spreading factor enables a higher data-rate request to be accepted. The OVSF codes can be generated as a tree structure [3].

Despite the advantages of OVSF-CDMA, it suffers some constraints. The major constraint is the "code-blocking" problem. To maintain the orthogonality, once a code is assigned, it’s ancient and descendant codes should not be assigned before the release of the original code. The code-blocking problem [10] occurs given sufficient system capacity but insufficient codes available for request assignment. Therefore, code assignment schemes are important. Bad strategies impair spectrum efficiency.

There are several well-known schemes have been studied for solving the code-blocking problem. The process of these schemes can be divided into two parts. The first part improves the assignment of codes to prevent code blocking. If the code assignment is good, most requests can be accepted with minimal spectrum efficiency loss. To eliminate code blocking, the second part then selects a blocked code, and moves all the users occupying the descendant codes of this blocked code to other available codes. Releasing all of the descendant codes allows the code blocking to be solved and the calling request to be accepted. Both of these two parts are important, and should be combined to enhance performance. The well-known schemes are introduced below:

Assuming a new call with bit rate nR (bits/sec) arrives (where R is the minimum data-rate with the largest SF and $n = 2^{(K-k)}$), the behavior of different code assignment and reassignment schemes is explained and their advantages and disadvantages are compared.

1.1: Conventional Code Assignment (CONV)

If there is no special code assignment, the system checks whether codes are available for use. Provided codes are available, a code is selected and assigned to the user. Otherwise, the call is blocked. This scheme does not describe how the codes are selected from those available, because the implementation details differ among vendors. It is assumed that the code is selected arbitrarily from among those available.

1.2: First Fit Code Assignment

The First Fit (FF) code assignment [12] procedure resembles CONV, but the "first available code" is not selected randomly. The "first available code" is defined as the leftmost or the rightmost available code in layer k. Based on the definition of FF, the assigned code is gathered on the left or right side of the code tree, which empties its opposite side to accept high data-rate calls. However, the departure of calls fragments the well-arranged code tree and also causes code blocking.

1.3: Crowded-First Assignment

Yu-Chee, Chih-Min, and Shih-Lin designed this code selection method for code assignments [14]. If multiple codes are available in layer k, the one in the most crowded branch is selected. The simulation result shows that this scheme is superior to the Random (CONV) or First Fit assignment schemes in terms of code-blocking probability. On the other hand, this scheme requires more computation time for code selection than the Random or First Fit schemes. Therefore, the call setup delay is longer than for a simple code assignment scheme.

1.4: Region Division Assignment

Rujipum, Ken'ichi, Ushi, Yoshikuni, and Masahiko designed the Region Division Assignment (RDA). First, the code tree is divided into rate regions based on the probability of requests for each data rate. When performing code assignment, if a code is available in the corresponding region, it will be assigned to the request. Otherwise, if the call dropping probability in the corresponding region exceeds the threshold at that time, a code is borrowed from another region for assignment. The detail of RDA is presented in [5].

1.5: Dynamic Code Assignment

Minn and Kai-Yeung developed the Dynamic Code Assignment (DCA) scheme [10], which is used to relocate assigned codes and thus unblock desired codes. When a call suffers from the code-blocking problem, DCA selects a branch, and reassigns all codes in that branch to other branches to unblock a desired code. The point of reassignments is choosing the optimum code from among the blocked codes to serve the new call. Minn and Kai-Yeung described two methods, named "Code Pattern Search" and "Topology Search", which can identify a "minimum-cost branch" for reassignment.

There are other schemes, which are not introduced individually [11][13][15]. These schemes eliminate or mitigate the code-blocking problem. However, the additional cost of performing these OVSF code assignment/ reassignment procedures represents a new problem. The common disadvantage of these schemes is extra calculation time. If no assignment/reassignment scheme is performed, the code can be assigned using an easy and fast assignment scheme.

2. Pre-Allocation Assignment

The PAA scheme focuses on eliminating the problem of code-blocking as well as on reducing waiting time while requesting a new call. A tradeoff always occurs between code tree optimization and call setup time. If a simple assignment scheme is used, the spectrum efficiency is lower than for a complex scheme. On the other hand, if optimized code assignment and DCA schemes are used (an optimal topology search), the spectrum efficiency will be very good, but the call setup time may be very long. This study introduces an OVSF pre-allocation procedure for minimizing call setup time.

Fig.1 shows the PAA queuing model of the OVSF code assignment/reassignment. Server A checks whether the system has sufficient capacity for the new call. Moreover, server B assigns an OVSF code to the new call if available. Additionally, server C performs the main processing of DCA, which identifies a minimum-cost-branch and makes it vacant to accept the new call. Furthermore, serves 1 to n are in a multi-server system with infinite capacity. Mobiles that are assigned a channel serve themselves for their service time. Subsequently, server D performs a departure procedure that releases a code. Notably, servers B, C, and D lock the OVSF code table when one of the three is busy. Consequently, if any of these three servers is busy, the others must wait until that server has finished its work. Analyzing this queuing model reveals that server C is optional, since initially no dynamic assignment scheme existed. In an original DCA algorithm, if a user encounters the code-blocking problem, that user must wait until the DCA process is completed.

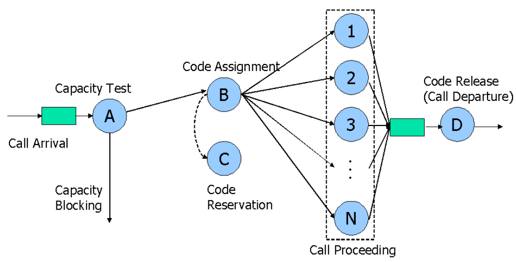

Fig. 1 Queuing model of the Pre-Allocation Assignment (PAA) procedure

If the DCA process is performed before an arrival, then the waiting time in subsystem C will not affect the user immediately. By adding a new mechanism named "Pre-Allocation Assignment", the DCA procedure is performed before code blocking occurs. Initially, one code with a maximum data-rate supported by the system (e.g. 8R Kb/s) is pre-allocated. This code is marked "pre-allocated" and is treated as "assigned" when performing an assignment procedure. After a new call arrives and passes the capacity test (server A), server B attempts to identify an available code by using an assignment scheme (Random, FF, Crowded-First...). Moreover, if no available code is found, Server B assigns the pre-allocated code or one of its descendent codes. The call then proceeds to the next stage. At this point, a pre-allocation process may occur in the background, meaning that the reassignment process is performed before the next arrival if necessary. This mechanism can easily reduce the call setup delay.

The pre-allocation process allocates an OVSF code whose rate does not exceed the maximum supported capacity. If multiple codes are pre-allocated, the computational complexity is increased, and negotiation among layers becomes more complex. Now that we only hope to perform the reassignment procedure earlier, a single code that supports all supported rates is sufficient.

The following is the PAA algorithm, which is divided into two parts: call setup and call termination.

System Parameters

$\mathbf{C_t}$: Total system capacity (assumed to be 256R)

$\mathbf{C_{max}}$: Maximum supported data-rate (8R, R denotes the minimum supported data-rate)

$\mathbf{C_a}$: Remaining system capacity

$\mathbf{C_r}$: Data-rate of pre-allocated code

Call Setup

1. A subtree with capacity = C_{max} is pre-allocated, where the term "pre-allocate" means that the assignment procedure cannot assign any of the codes in this subtree.

2. If the new call with rate kR bit/sec can be supported, (that is, k <= C_a), then proceed to Step 3, otherwise block the call.

3. Find an available code with kR bit/sec for the user by using an assignment scheme (Random, First Fit, Crowded-First...). Notably, the pre-allocated code should not be assigned in this step. If a code is found, assign this code to the user. Update C_a and return to step 1. Otherwise, proceed to Step 4.

4. Assign a code in the pre-allocated subtree with the data-rate requested by the user and update C_a. Another subtree with capacity = C_r is pre-allocated based on the new C_a. The range C_r is from 1R bit/sec to C_{max}R bit/sec. If any reassignment is needed, DCA will be triggered to accomplish this pre-allocation.

- $C_r = C_{max}$, if $C_a \geq C_{max}$, e.g. C_a = 20R, a subtree with capacity = 8R should be pre-allocated
- $C_r = 2^{\lfloor \log_2 C_a \rfloor}$R, if $C_a < C_{max}$, e.g. Ca = 6R, a subtree with capacity = 4R should be pre-allocated.

This study also examines another scheme called PurePAA. The PurePAA algorithm differs only slightly from that discussed above. The third step is removed in PurePAA. This algorithm assigns a code in the pre-allocated branch, and performs pre-allocation after every assignment.

<u>Call Termination</u>

1. Update C_a. If C_a increases sufficiently to support a higher-level pre-allocation than the existing one, then make a new pre-allocation. For example, following a departure, C_a increases from 3R to 11R because of the release of a code supporting 8R bit/sec. The pre-allocated subtree should be changed from supporting 2R bit/sec to 8R bit/sec. If the departure event does not change the state, then C_a should simply be updated.

Two examples are presented to demonstrate how this algorithm works:

Scenario I:

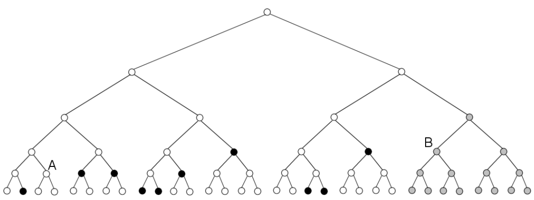

Fig. 2 Code tree of system in scenario I

Let C_t = 32, C_{max} = 8. Fig. 2 illustrates the system after a period of running. The black nodes represent occupied codes, while the gray ones represent pre-allocated ones. Clearly, C_a = 12, and the pre-allocated subtree has capacity C_r = 8R. If a new call with 2R bit/sec arrives, code "A" is assigned if using Leftmost Assignment. Moreover, if the new call requests not 2R bit/sec, but rather 4R bit/sec, then step 2 cannot find an available code. In this case, the pre-allocated code "B" is assigned instead in step 3, and C_a is updated to 8R. After the assignment, DCA becomes a trigger for pre-allocating a new subtree with capacity = 8R bit/sec.

Scenario II:

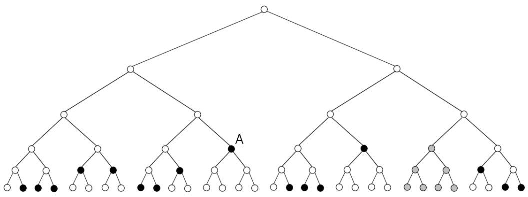

Fig. 3 Code tree of system in scenario II

Let C_t = 32 and C_{max} = 8. Fig. 3 presents the system after a period of running. Clearly, C_a = 6, and the pre-allocated subtree has capacity C_r = 4R. If the user who occupies code "A" terminates the call, C_a will increase from 6R to 10R. Consequently, the pre-allocation procedure with C_r = 8R will be triggered.

The Advantage of the proposed code assignment scheme is that the code reassignment procedure is delayed following code assignment procedure. That is, the reassignment procedure mostly is performed before the next arriving call. Therefore, the time of minimum-cost-branch search and reassignments will not affect the following users because the pre-allocation is performed between two arriving calls mostly. A simple code assignment scheme, such as First Fit, is preferable to a complex one for reducing call assignment time.

3. Simulation and Results

The present simulation considers the code assignment/reassignment schemes in sections 2 and 3. Two main comparisons are made to determine scheme performance. This study first analyzes the spectrum efficiency using different code assignment schemes in an OVSF-CDMA system. Next, the average call setup time of new calls is analyzed. All code assignment schemes employ DCA for code reassignments. The simulation is a discrete-event simulation [6], which uses the following parameters.

- The call arrival process is Poisson with mean arrival rate λ=1-20 call/unit time.
- Call duration is exponentially distributed, with a mean value of $1/\mu$=0.2 units of time.
- Maximum spreading factor =256
- Possible OVSF code rates: R, 2R, 4R, 8R
- DCA scheme: code pattern search
- 100,000 pieces of user data collected per run

The simulation program involves two estimations of time. Each step in determining a code status (busy or idle) is assumed to be a single clock cycle. The processor that performs assignments is assumed to be running 1 MHz. That is it needs 1 x 10^{-6} seconds to complete each step. Another estimation of time is the time required by a code reassignment procedure. From reference [2], the length of the channel establishment and channel release messages averaged are 17 bytes. One code assignment is assumed to use ten messages, and the data-rate of a primary common control physical channel (P-CCPCH) is 30k bit/s. Completing each reassignment thus takes approximately 45.33 ms.

Figures 4, 5, and 6 show the call setup time. The call setup time is the sum of queue waiting time and assignment time during code assignment. FF+PAA has a stable and small call setup time, meaning the system loading does not affect its performance. Moreover, the reassignments are done in the "background", meaning calling requests do not have to wait for all the reassignment signaling procedures. Therefore, FF+PAA outperform PureDCA or FF+DCA.

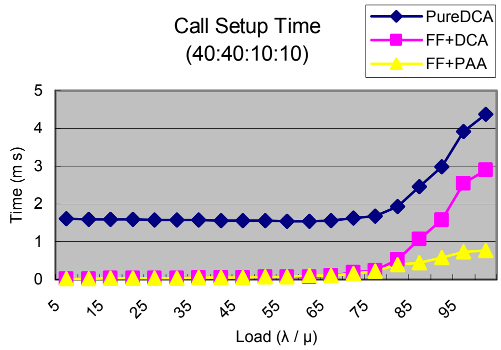

Fig 4: Call Setup Time

(R:2R:4R:8R) = (40%:40%:10%:10%)

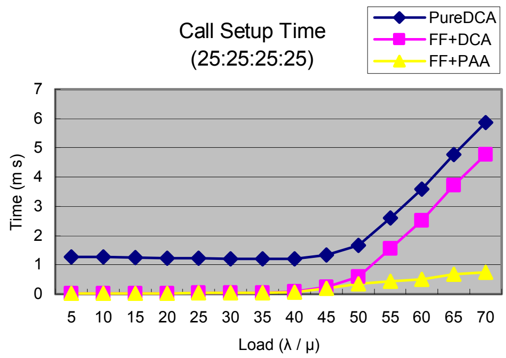

Fig 5: Call Setup Time

(R:2R:4R:8R) = (25%:25%:25%:25%)

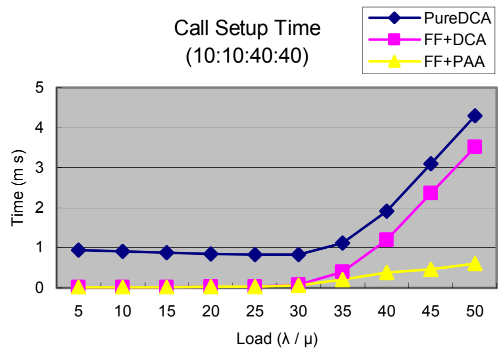

Fig 6: Call Setup Time

(R:2R:4R:8R) = (10%:10%:40%:40%)

System Requirements

Because PAA employs DCA for OVSF pre-allocation, additional signaling is needed to inform a user of the reassigned code. This additional signaling can be achieved by control channel signaling. Two signaling options generally exist, namely: in-band signaling and out-of-band signaling. An in-band control-signaling mode exists for third generation CDMA systems. In this mode, the power control, pilot signal, rate information, and other control signals are time-multiplexed with the user data. This format can be used to include code information, making OVSF code reassignments possible [10].

4. Conclusion and Future Research Directions

This study proposes a method that maximizes the spectrum efficiency with minimal call setup delay. The DCA scheme is extremely effective for eliminating the code-blocking problem, but is time consuming. However, the PAA scheme performs the reassignment procedure during the time interval between two arriving calls, thus accelerating the code assignment.

The handoff is important in any kind of cellular system. In second generation cellular systems, a guard channel mechanism is an important method for dealing with handoff calls. This study can inherit this idea and to be modified for channel guarding by providing a capacity threshold. If the system capacity is below the threshold, the pre-allocated code is no longer assigned to new calls. Unless the system capacity exceeds the threshold, the remaining capacity is used to support only handoff calls. Furthermore, if a priority mechanism [8][9] is considered, the system can make the code tree more flexible, allowing it to suit call pattern in different situations.

Acknowledgment

The authors would like to thank the National Science Council of the Republic of China, Taiwan for financially supporting this research under Contract No. NSC 92-2213-E-212 -020.

References

[1] 3GPP, “Spreading and Modulation.” 3GPP 3rd Generation Technical Specification 25.213 (Release 2002).

[2] 3GPP, “GERAN RRC Messages and Integrity Protection”, *Joint meeting 3GPP TSG GERAN/S3*, Madrid, Spain. 27th, April 2001.

[3] F. Adachi, M. Sawahashi, and K. Okawa, “Tree-structured generation of orthogonal spreading codes with different lengths for the forward link of DS-CDMA mobile radio,” *IEE Electronics Letters*, vol. 33, no. 1, pp. 27-28, January 1997.

[4] Dharma Prakash Agrawal, Qing-An Zeng, “Introductions to Wireless and Mobile Systems,” *Thomson*, 2003.

[5] Rujipun Assarut, Ken’ichi Kawanishi, Ushio Yamamoto, Yoshikuni Onozato, Masahiko Matsushita, “Region Division Assignment of Orthogonal Variable-Spreading-Factor Codes in W-CDMA,” *Vehicular Technology Conference*, 2001.

[6] Jerry Banks, John S. Carson, II, Barry L. Nelson, David M. Nicol “Discrete-Event System Simulation 3rd Edition”, *Prentice Hall*, 2001

[7] E. Dahlman, B. Gudmundson, M. Nilsson, and J. Skold. “UMTS/IMT-2000 based on

wideband CDMA." *IEEE Commun. Mag*, 36:70–80, Sept., 1998.

[8] Fossa, C.E., Jr.; Davis, N.J., IV "A dynamic code assignment algorithm for quality of service in 3G wireless networks" *Wireless Communications and Networking Conference, 2002*. WCNC2002. 2002 IEEE, Volume: 1, 2002

[9] R. Fantacci, and S. Nannicini, "Multiple Access Protocol for Integration of Variable Bit Rate Multimedia Traffic in UMTS/IMT-2000 Based on Wideband CDMA", *IEEE J, Select. Areas Commun.*, vol.18, pp. 1441-1454, aug.2000

[10] Thit Minn and Kai-Yeung Siu, "Dynamic Assignment of Orthogonal Variable-Spreading-Factor Codes in W-CDMA,"*IEEE Journal on Selected areas in communications*, vol. 18, no. 8, August 2000

[11] Dell'Amico, M.; Merani, M.L.; Maffioli, F. "Efficient algorithms for the assignment of OVSF codes in wideband CDMA" *IEEE International Conference on ICC 2002 Communications*, 2002. Volume: 5, 2002 Page(s): 3055 -3060 vol.5

[12] Rouskas, A.N.; Skoutas, D.N.; "OVSF codes assignment and reassignment at the forward link of W-CDMA 3G systems," *The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, 2002. Volume: 5, Sep. 15-18, 2002 Page(s): 2404 -2408

[13] Assarut, R.; Kawanishi, K.; Deshpande, R.; Yamamoto, U.; Onozato, Y. "Performance evaluation of orthogonal variable-spreading-factor code assignment schemes in W-CDMA" *IEEE International Conference on ICC 2002 Communications*, 2002. Volume: 5, 2002

[14] Yu-Chee Tseng, Chih-Min Chao; Shih-Lin Wu "Code Placement and Replacement Strategies for W-CDMA OVSF Code Tree Management," *Global Telecommunications Conference*, 2001. GLOBECOM '01. IEEE , 2001

[15] Yang Yang; Yum, T.-S.P. "Rearrangeable compact assignment of orthogonal variable-spreading-factor codes for multi-rate traffic" *Global Telecommunications Conference*, 2002. GLOBECOM '02. IEEE , Volume: 1 , Nov 17-21, 2002 Page(s): 824 -829