Multi-rate Traffic Accommodation Using Multicode Transmission in CDMA Cellular Systems

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Abstract- **In CDMA cellular systems, multicode transmission is an effective way of accommodating multimedia traffic having various transmission rates. We proposed a common searcher configuration at a base station to successfully handle multicode signals. The number of searchers needed in a base station can be reduced because a multicode signal needs only one searcher. We evaluated the call blocking probability and communications quality when the number of searchers is restricted.**

I. INTRODUCTION

With a view to multimedia transmission, several methods have been proposed for efficiently accommodating voice/data-integrated traffic having various transmission rates in code division multiple access (CDMA) cellular systems [1][2]. Variable process gain transmission and multicode transmission are two practical methods. In variable process gain transmission, the spreading factor of a signal is adjusted according to its information rate. The RAKE receiver has to be able to handle signals at various rates by changing the despreading factor. Feasible transmission rates in this method, however, are determined by the basic process gain. Transmission rates of 1, 2, 4, 8 .. times can be used when the basic process gain is 128. The multicode transmission method increases the transmission rate by increasing the number of multiplexed codes in accordance with the information rate. Multicode transmission thus allows flexible-rate transmission. Transmission rates of 1, 2, 3, 4 .. times can be used regardless of the basic process gains. Multicode transmission can be implemented by simply extending the systems that currently mainly handle voice users. However, several receivers are needed to demodulate a multicode signal. In this paper, our focus is on multicode transmission for accommodating voice/data-integrated traffic.

In multicode transmission in an uplink, because a reference signal identifying each mobile station (MS) is transmitted with a multicode signal, only one searcher is needed at the base station (BS) to acquire the reference signal, while several demodulators are needed to demodulate the multicode signal. We proposed a common searcher configuration at BS in which a single searcher and several demodulators are adaptively combined to handle variable-rate multicode signals.

The characteristics of CDMA systems are usually determined by the communications quality. They are also determined by the call blocking probability when the number of receivers at a BS is limited. When multicode transmission is used for voice/data-integrated traffic, a single MS, transmitting at a higher rate, corresponds to several-concentrated single-code MSs, and this causes non-uniform traffic in the cellular system. The call blocking probability increases because of the requirement for multiple vacant receivers at the connecting BS. Some schemes to efficiently accommodate multicode signals have been studied [3]-[5]. In this paper, we evaluate the performance of multicode transmission in terms of call blocking and communications quality when using the proposed common searcher configuration. We compare this performance to that of conventional configuration.

We first describe the BS configuration we used in our simulation. The characteristics for voice/data-integrated traffic were evaluated when the number of receivers and searchers were limited. We also estimated the number of searchers and demodulators needed in the BS to meet system requirements.

II. BASE STATION CONFIGURATION

An example of multicode transmission from an MS is shown in Fig. 1. A four-code signal is assumed, and each

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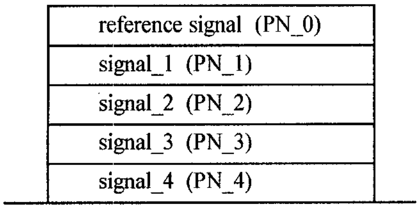


Fig. 1. An example of multicode transmission.

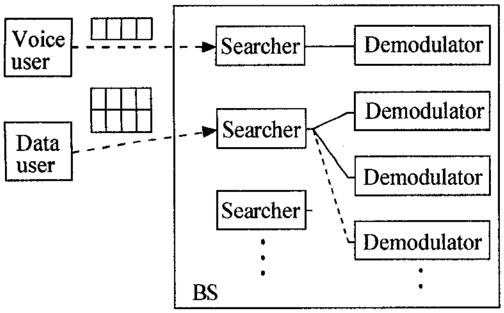


Fig. 2. Common searcher configuration for integrated traffic.

signal is spread by a spreading code orthogonal to the others. The MS adds a reference signal that is spread by PN_0 to the multicode signal. The reference signal is used to acquire the synchronization and to measure the communications quality at the BS. In Fig. 1, the reference signal is added in parallel to the information signal.

In our simulation, we assumed that a voice user transmitted a signal at a basic information rate and a data user transmitted a signal at several times the basic rate. The data user transmits the signal by using multicode, and the signal spread by each code is despread at a receiver in the BS. For instance, in a conventional configuration, a four-code data user will need four receivers and, hence, at least four receivers must be available at the destination BS to prevent call blocking at the start of communication or at handoff.

All code signals from an MS propagate through the same paths, so all the code signals have the same synchronization timings and the same propagation losses. Hence, they can be acquired by a searcher using a common reference signal. By separating the searchers and demodulators in the receivers at BS, the number of searchers can be reduced because only a single common searcher is needed to acquire a multicode signal. An example of the common searcher configuration is shown in Fig. 2. There is a voice user and a two-code data user. The two-code signal from the data user is acquired by a searcher, and each code signal is despread and demodulated by a demodulator. One searcher and several demodulators are adaptively combined to handle the multicode signal. For variable-rate transmission using multicode, BS can easily deal with the change in the number of code signals by connecting or disconnecting demodulators while continuing to use a single searcher.

Table 1. Integrated traffic conditions.

User type	Voice	Data
Average transmission rate	1	2, 4, or 8 (I_D)
User ratio	0.8	0.2 (R_D)
Average holding time [s]	120	200
Interval of rate change [s]	none	20

III. SIMULATION CONDITIONS

In our simulation model, 81 BSs were systematically arranged in hexagonal cells, and the seven cells at the center were evaluated. The MSs made calls according to a Poisson distribution; they were located randomly within the simulation area. The distance attenuation constant along the propagation path was 3.5, and the standard deviation in the shadowing fluctuation was 7 dB. We did not consider multipath fading. The processing gain was 100, and the signal-to-interference ratio (SIR) threshold, SIR_{th}, was –15 dB. We applied SIR-based power control and assumed perfect power control.

We evaluated the communications quality and call blocking only in the uplink. The temporal probability that the communications quality exceeds SIR_{th} was used as the quality guarantee rate, *QGR*. An MS experienced call blocking when the destination BS did not have enough receivers or demodulators available for communications. We also evaluated the blocking at the searchers for the proposed common searcher configuration. Call blocking due to SIR falling below the threshold during the communication was not considered. When an MS changes its transmission rate, however, some code signals are dropped due to a lack of receivers. The code dropping rate was also evaluated by measuring the average number of dropped codes during a communication for data users.

The conditions for the voice/data-integrated traffic are

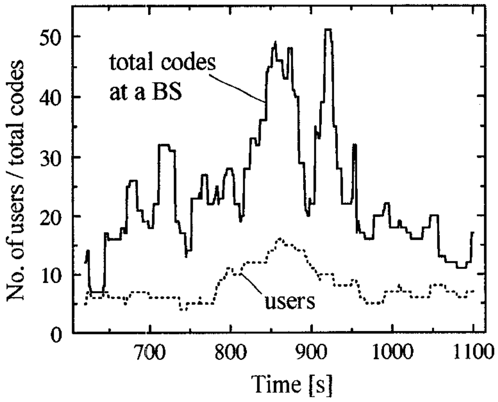
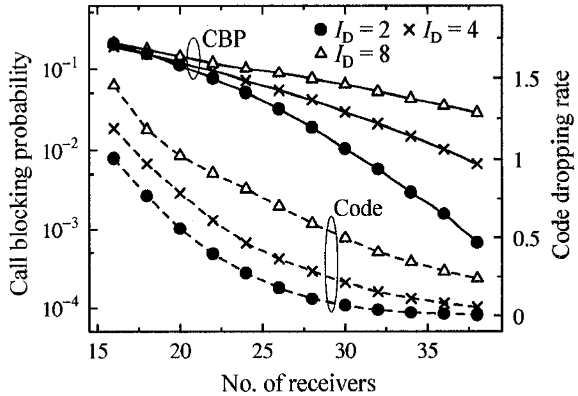
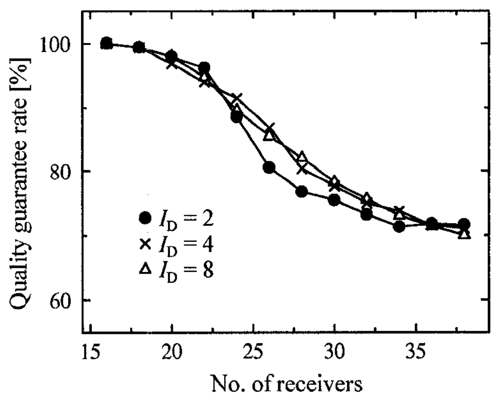


Fig. 3. An example of time-varying characteristics.



(a) Call blocking and code dropping



(b) Quality guarantee rate

Fig. 4. Evaluation of conventional configuration for limited number of receivers.

listed in Table 1. We did not consider any specific application for data transmission (such as Internet or video). The data only required a higher transmission rate than that for voice and had no specific required quality or allowable delay time. The average transmission rate of the data users was 2, 4, or 8 times that of the voice users. The data users transmitted the signals by using multicodes in accordance with the transmission rate. Each code signal controlled its transmission power according to the desired power level at the connecting BS, so a four-code data user transmitted the signal at four times the power of a voice user at the same location. In multicode transmission, there was no interference between the multiplexed codes because all code signals were orthogonal to each other, and we did not consider multipaths that might have disturbed the orthogonality between the codes. If the average transmission rate of the data users, relative to that of the voice users, is I_D, and the ratio of the data users to all the users is R_D, the average amount of traffic per cell is given by

$$Load = (1 - R_D) \cdot N + R_D \cdot N \cdot I_D, \quad (1)$$

where N is the average number of MSs, and R_D was assumed to be 0.2.

The transmission rate of a data user could be varied by changing the number of code signals. We assumed that the rates varied randomly within the range 1 to $2 \times I_D$. If the average transmission rate is 8, the number of multicodes is between 1 and 16. The rate for a data user was assumed to change every 20 s. Figure 3 shows the time variation of the number of users and the number of total codes at a BS. In this range, the number of users varied from 4 to 16. This means that at most 16 searchers were needed. The number of total codes received at a BS, on the other hand, varied greatly from 7 to 51. In this case, at least 51 demodulators were needed for signal accommodation with no blocking. Because our simulation had a limited number of receivers or demodulators, code dropping also occurred.

IV. PERFORMANCE EVALUATION FOR MULTICODE TRANSMISSION

A. *Characteristics of Conventional Configuration*

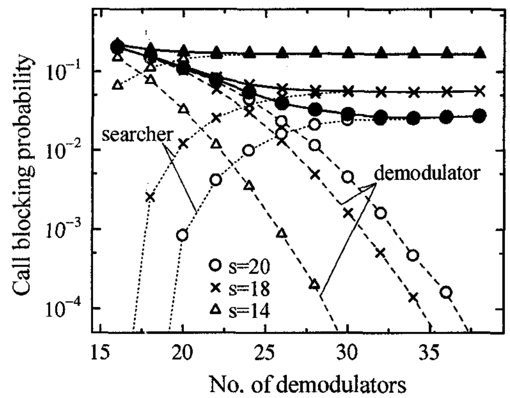
In this section, we describe the results for a conventional BS configuration, in which the receiver consists of a searcher and a demodulator. Figure 4(a) shows the call blocking probability and code dropping rate. The code dropping rate was normalized by the average transmission rate of the data users. The avarage traffic load was assumed to be 16 erl. The average transmission rate of the data users was assumed to be 2, 4, or 8 times that of the voice rate. As the transmission rate of the data users increased, both the call blocking probability and code dropping rate increased because more vacant receivers were needed at the BS to accommodate the higher multicode signals. To achieve a call blocking probability of 3%, 27 receivers were needed when $I_D = 2$; 30 when $I_D = 4$ and 38 when $I_D = 8$. The BS needed ten more receivers for I_D of 8 than for I_D of 2. At these points, the code dropping rate of data users was about 0.15 when $I_D = 2$, and 0.25 when $I_D = 8$. This means that the average number of dropped codes during communication was 0.3 when $I_D = 2$, and 2 when $I_D = 8$. The average rate is not exceptionally high, but in some cases more than ten-code signals at a time dropped due to a lack of receivers.

Figure 4(b) shows the quality guarantee rate. The *QGR* for I_D of 2 was worse than for I_D of 4 or 8. This is due to call blocking – a higher transmission rate results in a higher call blocking probability, so the total traffic load in the simulation area falls. At a call blocking probability of 3%, the *QGR* was 79% for I_D of 2 and 70% for I_D of 8. Communications quality is highly dependent on the location of data users with a higher transmission rate. If an eight-code data user is near the cell egde, the transmission power is quite high, and the resulting interference degrades the quality in the neighboring cell. The variance in quality due to users location, however, can nearly be reduced by SIR-based power control. In this simulation, the required quality of data users was assumed to be the same as that of voice users. In general, however, the required quality of data users is higher, so the *QGR* may be degraded, especially for higher transmission rate data users.

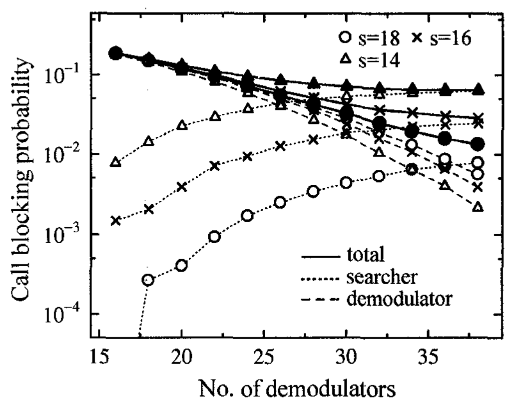
B. Characteristics of Common Searcher Configuration

We now describe the results when the number of searchers was restricted in the common searcher configuration. Figures 5(a), (b), and (c) show the call blocking probability when I_D = 2, 4, and 8. The average traffic load was 16 erl. The dotted lines indicate the probability at the searchers, and the broken lines the probability at the demodulators. The solid lines indicate the total call blocking. In (a), the number of searchers was assumed to be 14, 18, and 20. The call blocking probability at the searchers increased, and that at demodulators decreased as the number of searchers decreased. When the number of searchers was 14, the total call blocking probability could not decrease to a level lower than 16.7%, even by using more than 40 demodulators because the requests for connection were refused at the searchers.

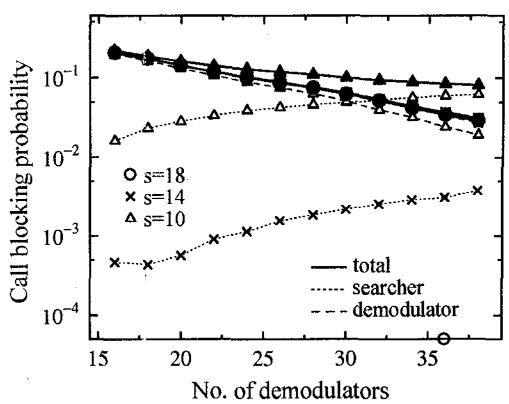
The call blocking characteristics depend on the combination of the number of searchers and demodulators. Figure 5(b) shows the results when the number of searchers



(a) $I_D = 2$



(b) $I_D = 4$



(c) $I_D = 8$

Fig. 5. Evaluation of common searcher configuration for limited number of demodulators.

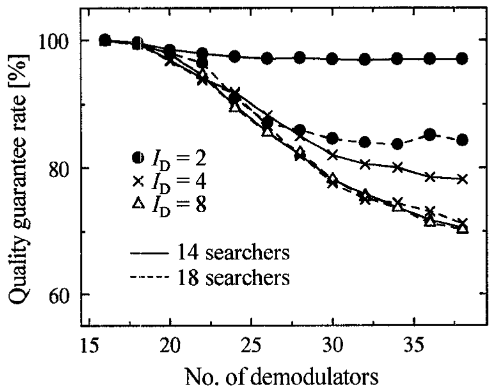


Fig. 6. Evaluation of common searcher configuration for quality guarantee rate.

was 14, 16, and 18. Figure 5(c) shows the results when the number was 10, 14, and 18. As the transmission rate of the data users decreased, the call blocking probability at the seachers increased because the number of total users was large compared with the case for a higher transmission rate assuming the same traffic load. In (c), the blocking at the searchers was almost zero with 18 searchers. Altering the combinations of seachers and demodulators allows us to obtain a 3% total call blocking probability. We express those combinations as a set of (the number of searchers, demodulators). When I_D is 2, a (20, 29) combination provides a 3% total call blocking probability. For $I_D = 4$, the combinations (18, 31) or (16, 36) give the same rate, and (18, 38) or (14, 39) for $I_D = 8$. When I_D is 2, nine searchers was reduced compared with the number of demodulators, and 25 searchers was reduced for $I_D = 8$. Data users are blocked with the same possiblity as voice users at the searchers. At the demodulators, data users are blocked with a greater possibility because more vacant demodulators are needed for data users.

Figure 6 shows the quality guarantee rate when the number of searchers was 14 or 18. At 14, the *QGR* for I_D = 2 was much better than in Fig. 4 because the blocking probability at the searchers was high. At 18 searchers, the *QGR* for I_D = 2 improved by about 12% with 36 demodulators. The improvement for I_D = 4 was small. When I_D = 8, there was no improvement in the *QGR* because the blocking probability at the searchers was negligible. The number of searchers and demodulators needed in the BS differed according to the transmission rate of the data users.

V. CONCLUSION

We have evaluated communications quality and call blocking probability in CDMA systems for multicode transmission in voice/data-integrated traffic environments. We found that high-rate transmission by data users increases the call blocking probability. We also estimated the number of searchers and demodulators needed in a BS for various integrated traffic conditions when using our proposed common searcher configuration. The number of searchers needed can be reduced by using the proposed configuration because a multicode signal needs only one searcher. As the number of searchers is reduced, the blocking probability at the searchers increases and the blocking probability at the demodulators decreases. As a result, the quality guarantee rate is improved. By adaptively combining one searcher and several demodulators, we can change the number of codes by simply connecting or disconnecting demodulators to accommodate multicode signals with variable-rate transmission.

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