Third Generation Mobile Radio Systems (IMT-2000) Using Wideband CDMA Technology and Interference Canceller for Its Base Station

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This paper introduces the IMT-2000 third generation mobile radio system, which is expected to become the new worldwide infrastructure for advanced mobile computing. This paper also introduces the multi-stage parallel interference canceller (MPIC) which has been developed for the IMT-2000 base station. MPIC is a powerful technique for enhancing the uplink channel capacity. Direct sequence code division multiple access (DS-CDMA) is one of the most promising radio access technologies for IMT-2000 because of its capability of flexible multi-rate transmission and its high spectrum efficiency. However, the channel capacity of a DS-CDMA system is restricted by co-channel interference due to imperfect orthogonality between channels. We confirmed by computer simulation that applying our proposed 2-stage MPIC to a DS-CDMA base station increases the cell capacity on a multi-path fading channel to about 2.2 times that of a conventional receiver under the same conditions.

1. Introduction

In Japan, the number of mobile telecommunication subscribers of the Personal Digital Cellular Telecommunication System (PDC) and Personal Handy Phone System (PHS) has been dramatically increasing. Wireless mobile communication using data transmission services of these systems is currently becoming popular. A packet data communication service at 28.8 kb/s is available in the PDC and a 32 kb/s data communication service is available in the PHS. These systems are categorized as second-generation systems. Due to the limit on data throughput, most applications will be restricted to text-based communication. In addition, the rapid increase in the number of subscribers will soon cause a spectrum shortage in current systems, especially in Japan.

The projected growth in the demand for larger capacity, higher data rates, and better services indicates the need to develop new network standards in the mobile communication infrastructure. The International Telecommunication Union (ITU) has for some years been promoting the Future Personal Land Mobile Telephone System (FPLMTS) project, which has now been renamed the IMT-2000 (International Mobile Telecommunication-2000). The IMT-2000 system will be a worldwide common standard of third generation cellular systems. The goals of the IMT-2000 system include a high maximum data rate (2 Mb/s), high capacity, packet transport capability, multimedia services, flexibility to accommodate variable Quality of Service (QoS) parameters, improved scalability, lower network granularity, and better economies of scale for the service providers.

Many radio access schemes for IMT-2000 have been studied.[1] Direct Sequence Code Division Multiple Access (DS-CDMA) is one of the most promising access schemes because of its high spectrum efficiency; the Japanese proposal for the IMT-2000 air interface is based on DS-CDMA.[2] Especially, wideband DS-CDMA (W-CDMA), whose spread spectrum bandwidth is greater than 5 MHz, has been considered suitable because it can provide a

Table 1. Minimum user bit rate required for IMT-2000.

Test environment	Indoor office	Outdoor to indoor and pedestrian	Vehicular	Satellite
Bit rate	2,048 kb/s	384 kb/s	144 kb/s	9.6 kb/s

higher cell capacity, enables easy realization of varied transmission rates, can combat multi-path reception, and has a flexible cell arrangement.

In cellular DS-CDMA mobile radio systems, multiple access interference (MAI) reduces the cell capacity, especially in uplink asynchronous transmission. The cell capacity is maximized by maintaining equal relative amplitudes among users at the base station receiver input, necessitating accurate transmission power control (TPC). In the presence of fast fading, the power of the received signal falls considerably from its average level. During this condition, TPC alone will not suffice. To further improve the cell capacity by suppressing MAI from the received signal, interference reduction techniques such as interference cancellation[3] and adaptive array antenna[4] have recently been studied. Interference cancellation at the base station jointly detects all the user data to cancel the MAI among users. The conventional interference canceller is very complex to implement and has a large processing delay. This paper presents a new interference cancellation which is less complex and has a short processing delay.

In Chapter 2, we present an overview of the third generation mobile system (IMT-2000) and its W-CDMA radio access technology. In Chapter 3, we describe the configuration of our proposed multi-stage parallel interference cancellation (MPIC), which employs new moderation techniques. Chapter 4 describes the results of computer simulations we conducted to evaluate the bit error rate performance of the DS-CDMA system with this MPIC in a fast multi-path fading channel.

2. Third generation mobile system (IMT-2000)
2.1 Services and requirements

ITU standardization of IMT-2000 is in progress to establish a worldwide common standard; and Japan, Europe, and the U.S. are now making their candidate proposals for submission to the ITU. The minimum user bit rates required for IMT-2000 are shown in **Table 1**. In outdoor environments (vehicular and pedestrian), a minimum user bit rate of 144 to 384 kb/s will be available. However, the air interface specification being studied in each region has a mechanism to support data transmission up to 2 Mb/s even in outdoor environments. The service categories which will be available in the IMT-2000 system are as follows:

1) Speech and Audio services: telephony, high-quality speech, HiFi audio

2) Video and data services: video phone/conferencing, streamline video, broadcasting

3) Bearer service

4) Voice-band data and facsimile data service

5) Mobile-specific services: location service, emergency service, navigation

6) Internet access service

From the radio access point of view, the requirements for IMT-2000 are not only to solve the capacity issue, which is a major issue for the current generation systems, but also to meet potential market needs such as multimedia services, personalized services, and global roaming. The major requirements for IMT-2000 radio access are as follows:

1) Standardized common air interface

2) Multi-rate transmission from low to high bit rates
   (High bit rate: 144 to 384 kb/s, up to 2 Mb/s)

3) Flexible zone structure

4) Seamless coverage between indoors and outdoors

5) Easy frequency resource management

6) Highly efficient frequency utilization

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7)　　Low transmitting power capability

2.2 Radio transmission technology

In Japan, the Association of Radio Industries and Businesses (ARIB) has been searching since 1994 for a suitable radio transmission technology which satisfies the above requirements, and it is now recognized that DS-CDMA is the most promising access scheme for IMT-2000 due to its flexible multi-rate transmission capability.[2] In DS-CDMA systems, each user channel is spread by its spreading code, which is quasi-orthogonal to the other users' spreading codes. User channel data can be recovered by matched-filtering the received signal with the desired user spreading code sequence. By changing the spreading ratio of the channel, the transmission data rate can easily be controlled to realize multi-rate transmission. All the user channels share the same frequency band and the same time slots; this is in contrast to the Time Division Multiple Access (TDMA) method adopted in current cellular systems such as PDC, PHS, and GSM.

The DS-CDMA receiver uses a RAKE combining technique to mitigate the effect of multipath fading. Multi-path signals of a user can be extracted by de-spreading at the appropriate path timings. Then, they are coherently combined to maximize the output signal to interference plus noise ratio (SINR). This is one of the diversity combining techniques and improves the receiver performance.

However, insufficient orthogonality between spreading codes causes MAI and reduces the cell capacity. In recent years, to suppress the MAI from the received signal and improve the cell capacity, interference reduction techniques such as interference cancellation, which is occasionally called multi-user detection, and adaptive array antennas have been studied.

3.　 Interference cancellation

As described in the previous chapter, to realize a large cell capability, it is very important to develop efficient interference reduction techniques. This chapter describes our proposed interference cancellation scheme.

3.1 Background

Interference cancellation (IC) reduces the demands on power control and has been shown to increase the cell capacity.[3] Currently, there is a lot of research into IC schemes. A multi-stage cancellation scheme is a practical and promising solution for systems using a long spreading code, where a decorrelating type detector[5] or an adaptive matched filter[6] will be difficult to apply. Various multi-stage cancellation schemes are considered in the literature, two of which are successive (serial) cancellation[7]-[8] and parallel cancellation.[9]-[10] At each stage, the successive canceller successively subtracts the interference replicas of users having a higher received power from the received signal. The processing delay of the successive cancellation is proportional to the number of channels to be canceled and the number of stages. Usually, several cancellation stages are necessary for sufficient cancellation. This configuration therefore introduces an enormous processing delay. On the other hand, a parallel canceller simultaneously subtracts all of the users' interference from the received signal. The processing delay of parallel cancellation is proportional only to the number of stages and is therefore much shorter than that of successive cancellation.

Other types of multi-stage cancellation include decision directed cancellation and non-decision directed cancellation.[11]-[12] The decision directed algorithm applies hard decisions of the desired user's signal to generate the interference replica. This method requires an estimation of channel parameters and a coherent detection scheme. The non-decision directed algorithm uses the output of the correlation receivers to generate the interference replica and does not need channel parameter estimation. The non-decision directed IC scheme has a simpler structure than the decision directed IC scheme. However, since

this type of canceller cannot exploit the advantage of RAKE path diversity in the replica generation, it requires a relatively large number of stages to achieve sufficient performance, which results in increased complexity.

A hybrid successive/parallel configuration and a hybrid decision directed/non-decision directed algorithm that mitigate the respective drawbacks have been reported.[11)-12)] However, a processing delay that is short enough to realize an accurate closed-loop TPC could not be achieved even by using these configurations.

The purpose of our study is to design an interference cancellation algorithm which has a low complexity and offers a higher performance with a short processing delay for asynchronous DS-CDMA systems. We propose a fully parallel configuration using a hybrid decision directed algorithm in order to achieve a short processing delay of several symbols and sufficient performance in a multi-path environment.

3.2 Multi-stage parallel interference canceller (MPIC)

Figure 1 shows the block diagram of the pro-

posed multi-stage parallel interference canceller (MPIC). Each interference cancellation unit (ICU) in this figure consists of a digital matched filter (despreader), channel estimator, RAKE combiner, hybrid decision device, and re-spread device (**Figure 2**). The matched filter correlates the received baseband signal with the desired user's signature code. The channel parameter of each path is estimated using pilot symbols allocated at the head of each data frame (**Figure 3**).[13)] In addition, the decision symbols of the previous frame are also used for channel estimation to improve accuracy. The output symbols of the matched filters are RAKE combined using maximum ratio combining using the estimated channel parameters. Diversity combining is also performed in the same way as RAKE combining. The hybrid decision performs a type of soft decision of the output of the RAKE combiner for generating interference symbol replicas by multiplying this decision data with the estimated channel parameters and moderation factors explained later. These interference symbol replicas are then re-spread, generating interference chip replicas. In each ICU of the second and subsequent stages, the interference sym-
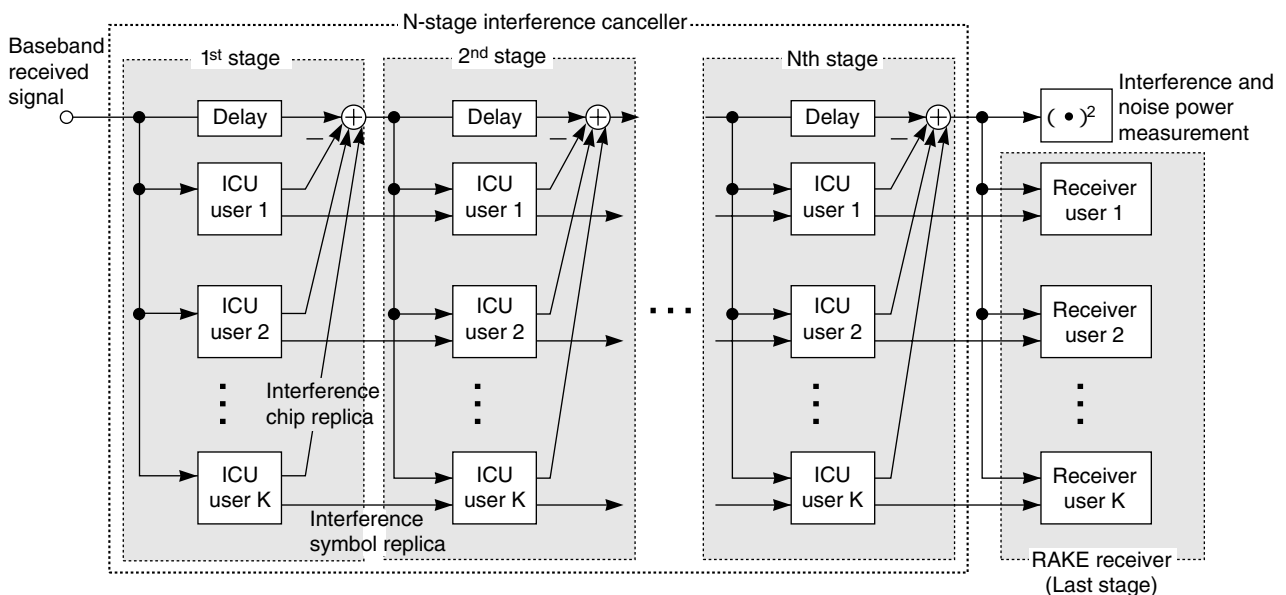

Figure 1.
Block diagram of multistage parallel interference canceller (N-stage).

ij Moderation parameter at replica generation
(I   stage number   j   RAKE finger)
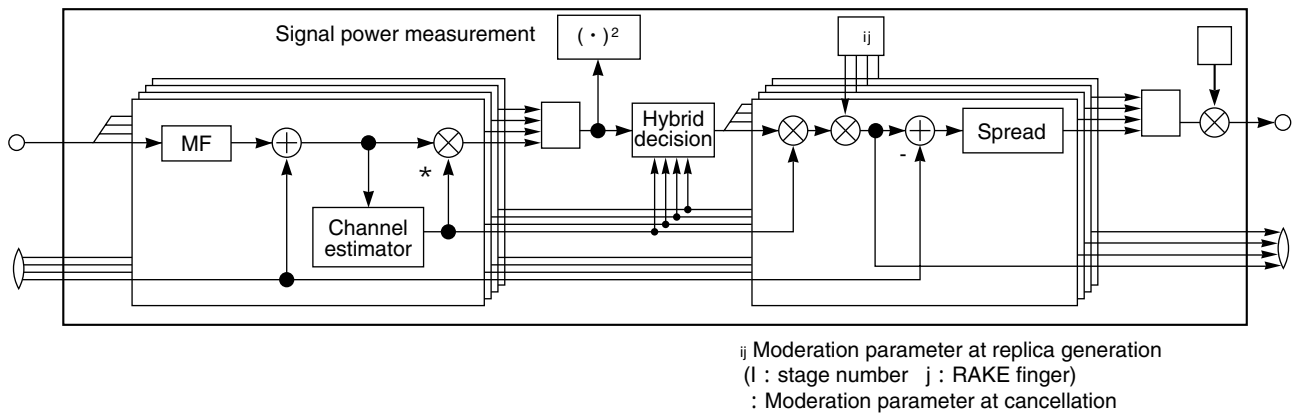Moderation parameter at cancellation

Figure 2.
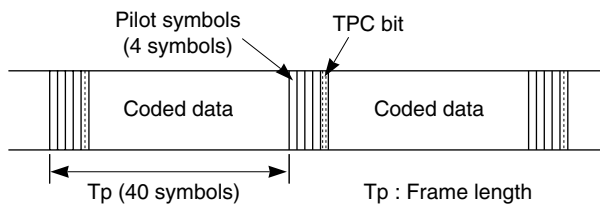Interference cancellation unit (ICU).

Figure 3.
Frame format.

bol replica of the previous stage is added to the matched filter output of the corresponding path.

At each stage, the interference chip replicas of all the channels are calculated in parallel and then subtracted from the output of the previous stage. Since only preamble pilot symbols of the current frame and decision data symbols of the previous frame are used for channel estimation, the total processing delay for channel estimation except for the last stage becomes several symbols or less. At the last stage, the pilot symbols of both the current and the next frame are used for better channel estimation, which introduces a one-frame processing delay.

The reliability of the estimated interference replica of each path depends on the SINR of the matched filter output for that path. An incorrect interference replica is generated by decision errors caused by low SINR path signals, and this degrades the SINR of the input signal at the next stage. To mitigate this degradation, we employed several moderation techniques that keep the in-terference replica at a level proportional to the reliability of that replica. These techniques greatly improve the performance, especially when the number of stages is small. The techniques consist of employing two types of fixed moderation factors and a hybrid decision technique that realizes dynamic symbol-by-symbol moderation. The techniques are shown in Figure 2.

A fixed moderation factor, α_{ij}, is applied to the symbol replica of the j-th finger in the i-th stage to control the amount of cancellation. The α_{ij} for the first stage is set smaller than that for the second stage, and the α_{ij} for the third and fourth fingers are set smaller than those of the first and second fingers. This is done because we have assumed that the average powers of the third and fourth path are lower in a general multi-path environment. A similar idea of weighted interfer-ence cancellation has been discussed previously.[14]

A fixed moderation factor, β, is commonly ap-plied to all the interference chip replicas. The in-terference chip replica is a differential component between the current frame interference symbol replica and the less reliable previous stage inter-ference symbol replica. This suggests that the chip replica should be further moderated by some de-gree. The optimal value determined by our com-puter simulation is $\beta = 0.85$.

The hybrid decision is a kind of soft decision that outputs the decision data weighted by its rel-ative amplitude against the average frame power of the desired user symbols. The decision func-

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tion, f, is defined as follows:

$$f\left(\sum_{n=1}^{Ld}\sum_{l=1}^{Lp}\xi^*_{k,n,l}R_{k,n,l}\right) = \begin{cases} Z_k\,(r_k \geq 1.0) \\ r_k Z_k\,(r_k < 1.0). \end{cases} \quad \cdots\cdots (1)$$

where L_d is the number of diversity branches, L_p is the number of resolved paths, $\xi_{k,n,l}$ denotes the estimated channel parameter, $R_{k,n,l}$ is the matched filter output symbol, Z_k is the hard decision symbol of the k-th user, and $*$ is the complex conjugate. r_k is the instantaneous power of the output symbol of the RAKE combiner normalized by the average frame power and is estimated as:

$$r_k = \frac{\left|\sum_{n=1}^{Ld}\sum_{l=1}^{Lp}\xi^*_{k,n,l}R_{k,n,l}\right|}{\sum_{n=1}^{Ld}\sum_{l=1}^{Lp}\left|\xi_{k,n,l}\right|^2} \quad \cdots\cdots (2)$$

After the hard decision of each symbol, its amplitude is weighted by r_k without changing the phase component if $r_k < 1$. This hybrid decision method is illustrated in **Figure 4**.

4. Simulation results

We have evaluated the bit error rate (BER)

$$r_k = \frac{\left|Y_k\right|}{\left|\,_{k,n,l}\right|^2}\text{ (if }r_k\quad 1\text{ then }r_k = 1\text{)}$$

Y_k : RAKE combined symbol
$_{k,n,l}$: Estimated channel
Z_k : Decision date symbol
r_k : Weighting coefficient
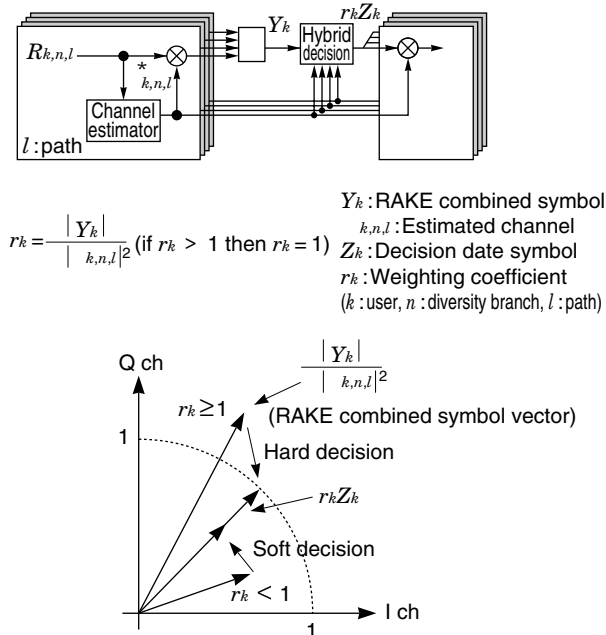(k : user, n : diversity branch, l : path)

Figure 4.
Illustration of hybrid decision.

performance of the DS-CDMA system with our proposed MPIC by computer simulation in a multipath Rayleigh fading channel.[17] The simulation parameters are listed in **Table 2**.

We carried out the simulation under the condition that the normalized maximum Doppler frequency, $f_d T_p$, is 0.05 and the TPC error, σ, is 2.3 dB. We assumed that σ is the standard deviation of the log-normal received power distributed around the perfect TPC level, where all signals are received at the same power.

Figure 5 shows the BER performance of the

Table 2. Parameters of computer simulation.

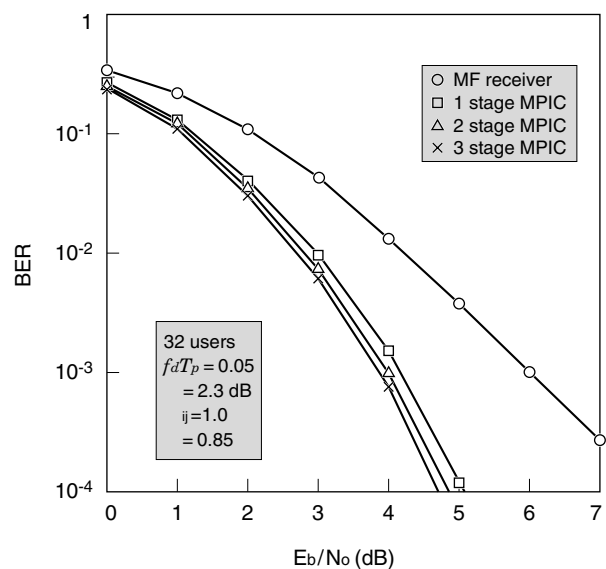|	
Spreading code (short) (long)	Orthogonal Gold (64) Gold
Modulation (data) (spreading)	QPSK QPSK
Symbol rate	64 ksps
Bit rate	32 kbps
Chip rate	4.096 Mcps
Channel model	FPLMTS vehicular model B
Diversity	4 finger RAKE + 2 branch space
FEC	Convolutional coding (R = 1/3, k = 7) Soft decision Viterbi decoding
Interleave	10 ms

Figure 5.
BER performance of MPIC.

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proposed MPIC receiver with various numbers of stages and the matched filter (MF) receiver with 32 users. In this simulation, α_{ij} is set to 1.0. Increasing the number of stages improves the BER performance; however, the advantage gained is small. This result shows that even a single-stage IC has a good enough performance.

To evaluate the performance of our moderation techniques described in the previous section, we simulated various two-stage IC schemes. The results, shown in **Figure 6**, indicate that these moderation techniques significantly improve the performance. When the MPIC is used without any moderation techniques, at a BER of 10^{-3}, the improvement is about 0.6 dB in comparison with an MF receiver. Applying a β value of 0.85 further improves the performance to about 0.9 dB. Adding the hybrid decision improves the performance to about 0.5 dB, and a further 0.3 dB can be obtained by using the moderation factor α_{ij}. When all of these techniques are used together, the overall improvement in performance is 2.3 dB.

Figure 7 shows the cell capacity of the proposed MPIC along with the capacities achieved by the hard decision MPIC scheme (β = 0.85) and the MF receiver. The simulation demonstrates
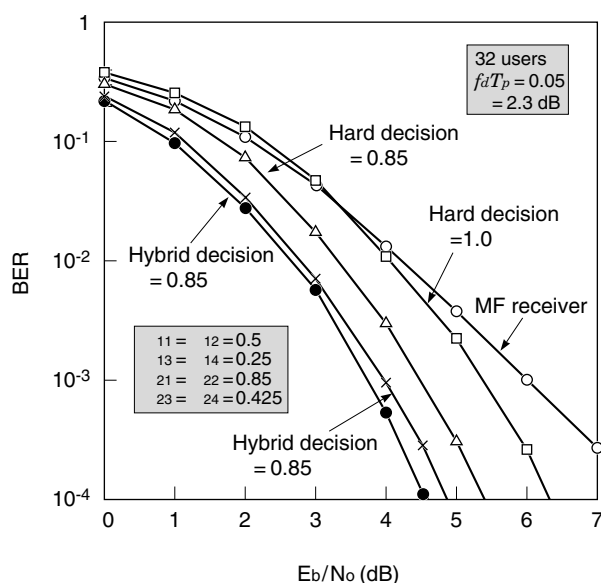
that the DS-CDMA system using the proposed MPIC accommodates around 68 users simultaneously when the value of the required E_b/N_0 at a BER of 10^{-3} is 6 dB. This capacity is 2.2 times that of the MF receiver; the hard decision MPIC increases the capacity by 1.5 times.

5. Conclusion

We have presented an overview of the next generation mobile radio system (IMT-2000) using wideband DS-CDMA technology. This system will be a common worldwide infrastructure that offers multimedia mobile communication and high-speed wireless mobile computing. As a key technology to realize a large cell capacity and to improve transmission quality, we have proposed an improved multi-stage parallel interference canceller (MPIC) designed for the base station of DS-CDMA mobile radio systems. The proposed MPIC employs the hybrid decision technique and some moderation factors proportional to the reliability of the estimated interference replica. Simulation results show that the proposed 2-stage MPIC, which has a short processing delay of several symbols, improves the bit error rate performance and increases the cell capacity considerably.
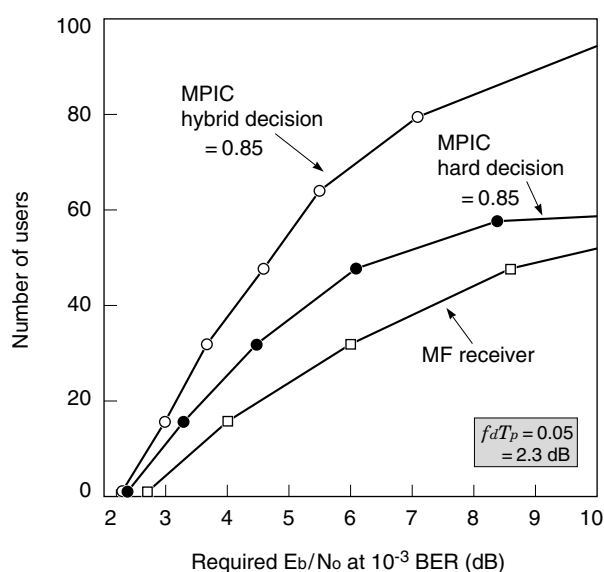

Figure 6.
BER performance of MPIC with moderation techniques.

Figure 7.
Comparison of cell capacities.

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