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the Schwarz inequality for $\varphi_{a_u a_u}(0) = N$ is

$$2\sum_{m=1}^{N-1} |\varphi_{a_u a_u}(mT)| \leq 2\sqrt{N-1}\sqrt{\sum_{m=1}^{N-1} |\varphi_{a_u a_u}(mT)|^2}$$
$$= N\sqrt{\frac{2(N-1)}{MF_u}} \qquad (16)$$

For $u \in \{1, ..., N-1\}$ it is now possible to write

$$\frac{1}{N}\left|\sum_{n=0}^{N-1} a_{u,n} e^{-j2\pi\nu nT}\right| \leq \frac{1}{\sqrt{N}}\sqrt{1+\sqrt{\frac{2(N-1)}{MF_n}}} \qquad (17)$$

The sidelobes of $A(\tau, \nu)$ can be upper bounded with eqn. 17 in the case of time-limited pulse shaping by the lowest merit factor $MF_{min} = \min_{u \in \{1,...,N-1\}} MF_u$. If a constant value is assumed for MF_u, eqn. 17 can be easily evaluated. From the results of [2] it follows that the best asymptotic merit factor for $N \rightarrow \infty$ of binary sequences tends to 6 while it tends to 3 in the case of *m*-sequences. Fig. 3 shows the right hand side of eqn. 17 for $MF_u = 3$ in comparison with the largest sidelobes of the *m*-sequences with the generator polynomials (octal representation) 7, 13, 23, 45, 103, 211.

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Erlang capacity of ATM-based CDMA satellite system

G. Brussaard

The capacity and throughput of an ATM-based CDMA system offering flexible access rates on demand are analysed. Extending the existing analysis of traffic capacity of a power-controlled CDMA cellular system, it is shown that offering multiple access rates may result in higher throughput efficiency. An example given of a satellite system shows that the gain in capacity may be some 10%.

Introduction: The use of CDMA for multiple access and ATM for variable-rate transmission has the potential to achieve high efficiency in network throughput. System and channel capacity may be allocated to the user in response to customer demands and priorities. In this case, total capacity in terms of bandwidth or number of channels that can be provided by the system is not the best performance indicator. The throughput of the system must be analysed in terms of traffic loads. Viterbi and Viterbi [1] presented such an analysis for a CDMA cellular system. In a cellular system, single channels of fixed rate are allocated in general. In a recent study, Farserotu [2] extended the Erlang capacity calculations to the case where data rates may be reserved and allocated per user. Since the results of this analysis were shown in terms of Erlangs corresponding to different channel rates, they were difficult to compare and overall conclusions regarding the efficiency of spectral usage were absent. In the following analysis a CDMA system using flexible access rates is studied using the concept of equivalent number of channels to calculate Erlang capacity and throughput.

Erlang capacity: For a multiuser system with fixed-rate channels, the Erlang capacity is defined as the average traffic load that can be handled for a given blocking probability $P_{blocking}$. The traffic in Erlang is the product of the number of transmissions ('calls') per unit of time and the average duration of a transmission. If a single, fixed-rate channel is allocated for each transmission, the capacity in Erlang may be associated with the average number of fully occupied channels or the average number of active users that the system can handle for the blocking probability (grade of service) required. In a multirate system, the data rate of the transmission has to be taken into account. If channels (access rates) are allocated to individual users in multiples of a basic rate R, it is convenient to measure traffic in terms of the equivalent number of basic channels, where a basic channel is a channel operating at the basic rate. The traffic A in Erlang is then given by the product of transmission request rate λ (transmissions/s), transmission duration $1/\mu$(s), and access rate k (multiple of the basic bit rate):

$$A = k\left(\frac{\lambda}{\mu}\right) \qquad (1)$$

and the throughput is $A \times R \times (1 - P_{blocking})$ [bit/s].

CDMA capacity for fixed-rate channels: Following the analysis of Viterbi and Viterbi, blocking is assumed to occur when the collective interference created by the users exceeds the background noise by a predefined factor or, equivalently, for a given noise level the signal-to-interference ratio drops below a predetermined threshold. If the signal power and spectrum are identical in all channels, the maximum number of basic channels that can be in use simultaneously at any one time before blocking occurs is then bounded by

$$M_c = \frac{W/R}{E_b/I_0}(1-\eta) \qquad (2)$$

where W is the spread-spectrum bandwidth, R the data rate, E_b the bit energy, I_0 the spectral interference density, $\eta = N_0/I_0$, the noise-to-interference ratio, and N_0 is the spectral noise density. M_c may be considered to be the total channel (trunking) capacity available to the CDMA system. For a fixed channel rate of $k \times R$, the maximum number of indiviual channels would be M_c/k.

Under the assumptions of a Poisson arrival process for the transmissions, exponentially distributed transmission duration and log-normally distributed signal-to-noise ratio, the analysis by Viterbi and Viterbi leads to the following expression for the traffic capacity of a CDMA data communication system using identical channels of fixed rate $k \times R$:

$$A = k\frac{\lambda}{\mu} = k\frac{M_c}{k}F(B,\sigma) = M_c F(B,\sigma) \qquad (3)$$

where M_c is the channel capacity corresponding to the median value of E_b/I_0 and basic rate R, σ is the standard deviation (in dB) of the signal power, $B = Q^{-1}(P_{blocking})/M_c$ is determined by the grade of service and the channel capacity, and $F(B, \sigma)$ is a reduction factor corresponding to the standard deviation of the signal distribution, the required grade of service and the channel capacity (see [1] for details).

Capacity for multirate channels: If the bit rate offered to individual users on request is flexible, the distribution of the bit rate requests must be taken into account. If the bit rate to be used is a multiple k of the basic rate R with a maximum of K, the distribution of the integer k must be modelled. If we assume the probability of request for the bit rate to be exponentially distributed, the distribution of k is given by

$$g(k) = \Pr\{\text{bit rate} = kR\} = \frac{\exp(-k/k_0)}{\sum_{n=1}^{K}\exp(-n/k_0)} \qquad (4)$$
$$(k, n = 1, ..., K)$$

The average bit rate requested is given by

$$k_{av} = \sum_{k=1}^{K} k \cdot g(k) \qquad (5)$$

and the traffic capacity in Erlang follows from eqns. 1, 3 and 4 as

$$A = \sum_{k=1}^{K} g(k) M_c F(kB, \sigma) \qquad (6)$$

Throughput of CDMA-ATM satellite service: To analyse the efficiency improvement obtained by the use of flexible access rates, we consider the following satellite system:

(i) total bandwidth $W = 204.8$MHz

(ii) basic data rate $R = 64$kbit/s

(iii) grade of service required $P_{blocking} = 0.01$

(iv) quality of service required $E_b/I_0 = 6$dB for $\eta = 0.1$

(v) standard deviation of $E_b/I_0 = 0$dB (perfect power control)

(vi) access rates offered are 1, 2, 4, 8 and multiples of 16 times the basic rate.

The maximum capacity of this system is $M_c = 720$ basic channels (which gives a maximum bit rate of 46.08Mbit/s).

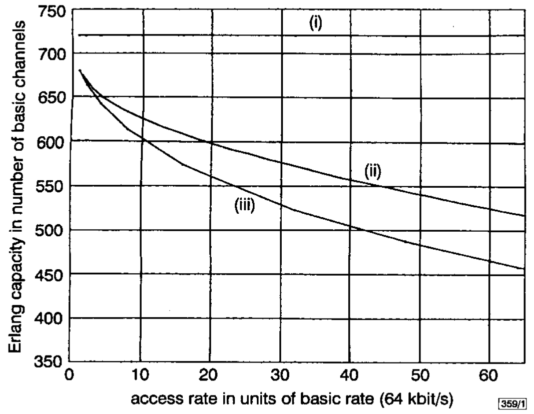

Fig. 1 *Erlang capacity of CDMA system*

(i) maximum capacity
(ii) variable access rate
(iii) fixed access rate

Fig. 1 shows the Erlang capacity (in equivalent number of basic channels) for this system, both for a fixed access rate of k basic channels and for flexible access rates with the same average rate. The capacity decreases with increasing access rate as a result of the reduced trunking efficiency. A system offering a flexible rate is more efficient than a fixed-rate system with the same average rate, due to the higher efficiency in dealing with low-rate messages.

Conclusions and comments: It has been shown that offering a flexible bit rate on request, as is feasible in an ATM-based CDMA system, may improve the traffic capacity of a wideband system, when compared with an equivalent fixed-rate system. In the example shown of a satellite-based system an improvement of up to 10% is possible, depending on the requirements. The capacity decreases with increasing access rate, of course; this is the penalty paid for offering higher access rates and shorter transmission times to the user. Offering flexibility in access rate may reduce this penalty and serve to further optimise a service in relation to market requirements.

In the publication by Farserotu referred to earlier [2], the results suggest an increase of capacity of several hundreds of percent by applying flexible bit rates. This is because, in calculating the Erlang capacity for a flexible-rate system, no distinction was made between accesses at different rates. Given a certain distribution of message lengths, the number of messages per unit of time that can be processed is proportional to the access rate. This is taken into account by the concept of equivalent number of basic channels and leads to a result that is more meaningful for the analysis of system capacity and efficiency.

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Experimental CDMA data overlay of GSM network

L. Noël and T. Widdowson

A broadband 64Kbit/s DS-CDMA overlay which operates on the same carrier frequency as a downlink GSM signal is proposed. Error free operation of both systems has been demonstrated over a 70dB power range. A novel CDMA receiver architecture allowed programmable digital notch filters to be implemented directly at RF. It is shown that the overall network capacity is increased by a factor of 3.3 compared to the case of a single GSM carrier only, as detailed in a previous theoretical analysis. This represents the first experimental demonstration of a CDMA overlay of a GSM network.

Introduction: It is anticipated that the dramatic increase in demand for mobile communications will continue such that by the year 2000 there will be 400 million handsets in OECD countries. One way of coping with growth is to use the complementary nature of a low power spectral density (PSD) CDMA signal sharing the frequency band of a high PSD GSM network. The overlay concept has been studied in detail in previous papers [1–4], where high-speed data are carried by the CDMA network, while the GSM network provides low-speed data or speech services. Providing that there is negligible interference between the two systems, the overall capacity is increased. The principal advantage of this approach is to allow the sharing of the existing infrastructure. This Letter describes a novel CDMA receiver architecture which allows digital notch filtering directly at RF in the CDMA receiver and transmitter to prevent jamming of the GSM receiver by the CDMA signal and vice versa. It is shown that, in a perfect radio channel and with perfect power control, the overlay of the two systems is not feasible without the use of notch filters. It is believed that this represents the first experimental demonstration of a true GSM network overlay.

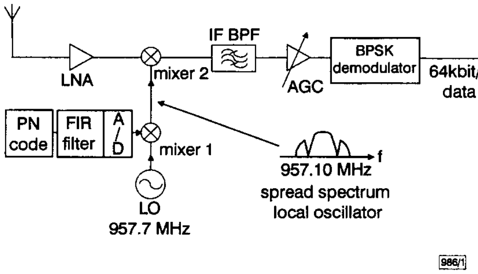

Fig. 1 *Interference suppression architecture at direct sequence receiver*

CDMA receiver architecture: In conventional overlays, digital notch filters are used at IF or at baseband. Saturation and distortion effects caused by the high PSD GSM in the CDMA receiver limit the power range over which the two systems can operate. To alleviate this problem, we present in Fig. 1 a novel approach which allows interference suppression to be performed as close to the front end of the receiver as possible, therefore minimising the effects of distortion. The local pseudo-noise (PN) sequence is filtered using an 8bit 120 tap digital FIR notch filter. The filter is programmed to generate a 40dB notch, offset by 1MHz from the carrier frequency, and with a 3dB bandwidth of 50kHz. After upconversion, the notch depth is 30dB at 957.7MHz. The output of mixer 1 is fed to mixer 2 where it simultaneously acts as a local oscillator for downconversion purposes, a local PN sequence to