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ABSTRACT

In the paper, we present simulation results for the 13 channel DS CDMA WATM LAN utilising optimized complex spreading signatures based on Walsh-Rademacher functions. The method to obtain those optimized spreading signatures, as well as the full set of the coefficients giving the minimum level of cross-correlation between any pair of the channels is shown. The resultant system BER as well as the distribution of errors within WATM cells is given. The obtained results indicate that with the application of a hybrid ARQ scheme, capable of correcting 10 errors, the number of WATM cells which would require retransmission is in the order of 0.6%.

I. INTRODUCTION

During the 1990s, direct sequence spread spectrum code division multiple access (DS CDMA) technology [1] has matured as a technique to provide multiple access to the radio channel for mobile communications. For example, it is used in mobile telephony compliant with IS-95 standard [2]. Recently, it has gained even more attention with ETSI approving it as a technology for the European third generation mobile system (UMTS) [3]. It is expected that wireless LANs will complement the third generation mobile telephony, providing a wireless vehicle for high rate multimedia applications.

ATM (Asynchronous Transfer Mode) is the technique being the commonly accepted standard for the broadband networks, and is also becoming accepted as a common nominator for all types of services and networks. Also, there has been widespread use of wireless communications to support users' requirements for wireless access and terminal mobility in such scenarios as cellular telephony networks and narrowband wireless LANs. As a further advancement, users are now beginning to require broadband services and terminal mobility to be provided together through wireless access to ATM networks.

The major benefits of many DS CDMA is that it can be effective in combating problems related to multi-path propagation, while providing good interference from other, narrowband devices operating in the same frequency band. This is, however, dramatically reduced if only a small processing gain [1] can be achieved, as in the case of WATM LANs where the ratio of available bandwidth to the proposed data rate is in the order of less than 20 (e.g. 2.4 GHz ISM band). Under such conditions, in-band jammers, like other channels of the same WLAN acquired by means of CDMA cause severe multiple access interference (MAI), which may block the communication.

In theory, cancellation of that type of interference is possible if each of the users utilise orthogonal signals to transmit the data [1]. If the delays between transmitters and receiver are anyhow different, as is generally the case of terminal to base station (BS) transmission, the signals received by the BS cannot be regarded as orthogonal. Within the 50 m coverage area those differences may be in the order of a few spreading code symbols (chips) depending on the data rate. This effect is particularly critical for very short spreading sequences, like 16-bit Walsh-Rademacher functions.

In [4] and [5] we have proposed the method to reduce the ISI and MAI for DS CDMA wireless networks, and in [6], we optimized the scheme for the system using 13 spreading signatures based on the 16-bit Walsh-Rademacher functions. This paper deals with further design of DS CDMA WATM LAN where an error control mechanism is employed.

The paper is organized as follows. In Section II, we briefly discuss the method of designing the complex multilevel spreading signatures based on 16-bit Walsh-Rademacher functions. Section III presents results of simulated error performance for the 13 channel ATM WLAN utilizing the complex multilevel spreading signatures. In Section IV, we describe the error control scheme optimized for our DS CDMA system, and Section V concludes the paper.

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II. DESIGN METHOD

In [4], we have described the method to reduce ISI and MAI for non-synchronized CDMA signals by means of a modification to the carrier waveform. The modified carrier has been obtained by a regular distortion to the frequency of the original carrier, resulting in the ith user line signal $s_i(t)$ expressed by:

$$s_i(t) = g_i(t) \cdot \cos\left[\omega_c t + \int_0^t w_i(\tau)d\tau + \phi_i(t)\right], \quad (1)$$

where $w_i(t)$ - frequency distorting function which can be optimized to achieve minimum value of cross-correlation among all users, and to minimize the off-peak auto-correlation of the ith line signal, $\phi_i(t)$ - information carrying phase component.

Later, we proposed in [5] a base-band equivalent of the method. It follows from the fact that for the real spreading code $g_i(t)$, equation (1) can be rewritten in the exponential form as:

$$s_i(t) = g_i(t) \cdot Re\left\{e^{j\omega_c t} \exp\left[j\int_0^t w_i(\tau)d\tau\right] e^{\phi_i(t)}\right\}. \quad (2)$$

The complex envelope [1] $\sigma(t)$ of such a signal is given by:

$$\sigma(t) = g_i(t)\exp\left[j\int_0^t w_i(\tau)d\tau\right] e^{\phi_i(t)} = \tilde{g}_i(t)e^{\phi_i(t)}, \quad (3)$$

Hence, the function

$$\tilde{g}_i(t) = g_i(t)\exp\left[j\int_0^t w_i(\tau)d\tau\right] \quad (4)$$

can be regarded as an analogue spreading waveform, leading, without any changes to the cosinusoidal carrier, to the same line signal $s_i(t)$, as the original binary spreading code $g_i(t)$ together with the previously described modification to the carrier waveform.

Because signal is usually processed using digital signal processing (DSP) technology in the receiver, instead of the analogue spreading waveform $\tilde{g}_i(t)$, one can use the multilevel complex spreading signature $\hat{g}_i(t)$. The length of the signature $\hat{g}_i(t)$ equals to the length of the original signature $g_i(t)$ multiplied by the number of samples per chip used in the receiver, and its pulse levels are weighted by the factor

$$W_i(t) = \exp\left[j\int_0^t w_i(\tau)d\tau\right]. \quad (5)$$

Such an approach allows for the baseband correlational detection of the signals, easier optimization of the functions $w_i(t)$ for the given set of binary signatures, and facilitates implementation of the receivers.

In order to optimize the spreading sequences for the use in a 13 channel DS CDMA ATM WLAN, we have chosen a subset of 13 orthogonal Walsh-Rademacher functions [1] as a set of binary spreading codes $g_i(t)$, $i = 1, 2, \ldots, 13$. These functions are listed in Table 1.

Table 1: Set of 13 binary spreading sequences.

Number	Binary spreading sequence
1	++++----++++----
2	++----++++----++
3	--++++--++----++
4	--++--++++--++--
5	++--++--++--++--
6	+--++--++--++--+
7	-++--++-+--++--+
8	-++-+--++--+-++-
9	+--+-++-+--+-++-
10	+-+--+-++-+--+-+
11	-+-++-+-+-+--+-+
12	-+-+-+-++-+-+-+-
13	+-+-+-+-+-+-+-+-

To minimize the cross-correlation between any pair of the spreading signatures, independently of the relative delay (for a delay different than zero the sequences are, in general, not orthogonal), we applied the described method with the functions $w_i(t)$, $i = 1, 2, \ldots, 13$, being of the form:

$$w_i(t) = 2\pi[\alpha_i\zeta(t/16) + \beta_i\zeta(t/8) + \gamma_i\zeta(3t/16)], \quad (6)$$

where the triangular wave $\zeta(t)$ is defined as:

$$\zeta(t) = \sum_{n=-\infty}^{\infty} \lambda(t-n), \quad (7)$$

and

$$\lambda(t) = \begin{cases} 0, & t<0 \\ 4t-1, & 0 \le t < 0.5 \\ -4t+3, & 0.5 \le t < 1 \\ 0, & t \ge 1 \end{cases} . \quad (8)$$

The obtained values of the parameters α_i, β_i, γ_i, $i = 1, \ldots, 13$ are given in Table 2. The algorithm used to obtain them has been presented in [6].

Table 2: Set of the optimized coefficients.

Number	α	β	γ
1	-4.2315	-2.1554	-2.8487
2	-4.2040	-2.0251	-2.7369
3	-4.2127	-2.0521	-2.7685
4	-4.2597	-2.0233	-2.8507
5	-4.1610	-2.1498	-2.8281
6	-4.1504	-2.1694	-2.8278
7	-4.2512	-2.1321	-2.7522
8	-4.3205	-2.0186	-2.6968
9	-4.2259	-2.0962	-2.7669
10	-4.2763	-2.0668	-2.7818
11	-4.2678	-2.1340	-2.9848
12	-4.1794	-2.1598	-2.8193
13	-4.2054	-2.0276	-2.7752

III. SIMULATION OF DS CDMA WATM LAN

In order to simulate the 13 channel DS CDMA WATM LAN we assumed the following:

- a WATM cell consisted of 524 bits (424 bits of an ATM cell plus 100 bits of an overhead),
- BPSK was used as a modulation technique,
- the information contents of each WATM cell was random,
- relative delay between the signals corresponding to different channels was random with the delay step of 0.25 of a chip duration,
- the received power was equal for all of the channels.

The receiver antenna was simulated as a sum of the signals arriving from different channels, and the detection was a correlational one. The simulation was repeated for 2000 cells for each of the channels.

The obtained results show that the quality of transmission depends slightly on the signature used to spread the signal, so the achieved BER is not uniform for all of the channels, which is reflected by the number of errors occurring in the received WATM cells.

For all 13 channels, the obtained BER is equal to 2.6×10^{-3}, ranging from 1.3×10^{-3} to 4.0×10^{-3}, and the histogram presenting the distribution of errors in the received WATM cells is presented in Figure 1.

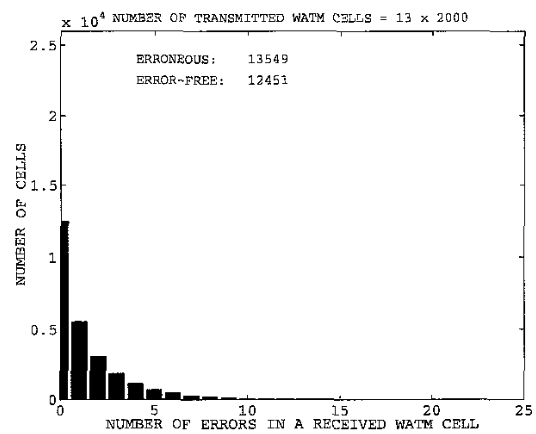

Figure 1: Histogram of the numbers of transmission errors in a received WATM cell for all 13 channels.

IV. ERROR CONTROL SCHEME

In order to combat the errors experienced in the wireless medium [7], all information is coded for error detection or correction and then transmitted through a DS CDMA channel. Furthermore, we distinguish between signalling and traffic channels. Signalling channels are used for arbitrating access of WATM cells from different users on the shared channel according the multiple access protocol described in [9]. A traffic channel carries the actual information using a WATM cell format.

The CDMA channels allocated to a BS are each divided up into time-slots which are shared on a time division duplex (TDD) basis between transmissions from a base station (BS) to a mobile terminal (MT). Each channel also contains a number of so-called mini-slots which are used for the transmission of signalling information, i.e. requests and acknowledgements. We use either simple error detection or forward error correction (FEC) coding to protect mini-slots against errors depending on whether a delay-sensitive or loss-sensitive service is requested. On the other hand, to provide the reliability and throughput performance required for ATM services, we protect an ATM cell by combining FEC with a retransmission strategy establishing a hybrid ARQ protocol.

For the protection of ATM cells, we have designed an efficient coding scheme specifically for a WATM indoor environment [10]. The coding scheme is based on shortened BCH codes. The BCH code used for FEC adds 100 bits to each ATM cell. Results of throughput efficiency for hybrid Selective Repeat (SR) ARQ schemes on a channel with average bit error rate (BER) of $\bar{p}_b = 1\%$ are shown in Figure 2. As can be seen from the plots, a throughput of slightly less than $\eta = 80\%$ is obtained by introducing $m = 100$ parity bits used to correct up to $t = 10$ errors, where the number of information bytes can be chosen in the range of 50 to 70 bytes without significant impact on throughput.

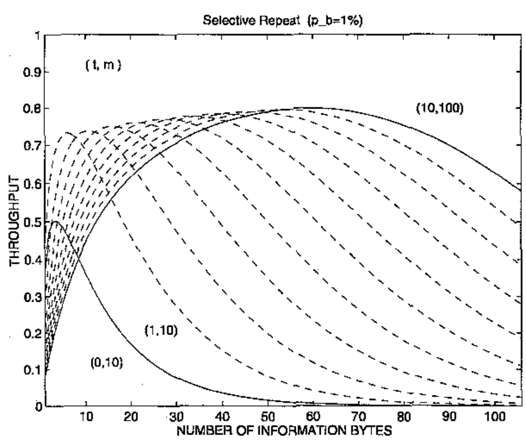

Figure 2: Throughput of a hybrid SR ARQ vs number of information bytes on a channel with bit error rate of 1% (t=error-correcting capability, m=number of parity bits)

Using an error-correcting capability of $t = 10$, we are able to correct the majority of those error events shown in the histogram of Figure 1. The corresponding histogram of errors in a WATM cell after decoding and summation over all 13 channels is depicted in Figure 3. Out of the 26000 transmitted WATM cells, the BCH decoder is able to decode 25830 WATM cells whereas 170 WATM cells have been detected as being corrupted by an uncorrectable error pattern. Further on, only a single WATM cell has been released erroneous with 19 bits in error and this gives a post-decoding BER of 1.4×10^{-6}. All of the other 25829 released WATM cells are error free. For all 13 channels, the total number of WATM cells which require a retransmission is in the order of 0.6%, ranging from 0% to 2.1%.

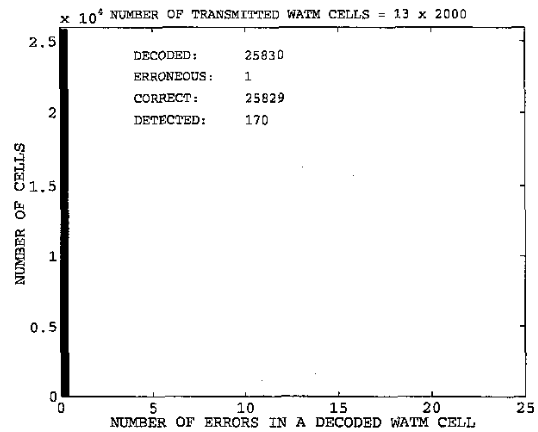

Figure 3: Histogram of the numbers of errors in a WATM cell after decoding for all 13 channels.

An essential component of the hybrid ARQ scheme is the acknowledgement of received information. When an MT receives a cell from the base station BS, it sends an acknowledgement (ACK) back to the BS in a dedicated uplink mini-slot. The positive or negative ACK from the MT informs the BS whether a retransmission is required. The exact retransmission procedure is determined by the BS. Some FEC coding is used for the protection of the ACK to provide a reliable ACK mechanism. A similar ACK mechanism is used by the BS to acknowledge the reception of ATM cells from a MT. Because of the throughput characteristics shown in Figure 2, we can consider to include some signalling information into an WATM header for downlink communication, i.e. from BS to MS

The high priority request mini-slots and acknowledgement mini-slots each carry one bit of information. To protect the one information bit in these cases, we use a (7,1) repetition code. Because repetition codes of odd length are members of the class of perfect codes, we are able to avoid the event of detecting an uncorrectable error by simply using the full error-correcting capability of $t = 3$ provided by the employed (7,1) code. Simultaneously, an acceptable probability of erroneous decoding of approximately 10^{-5} can be maintained for a BER even in the order of 10^{-2}, as illustrated in Figure 4. This provides for a very reliable mechanism for the communication of high priority requests, ensuring that the delay variation for real-time services is maintained at an acceptably low level.

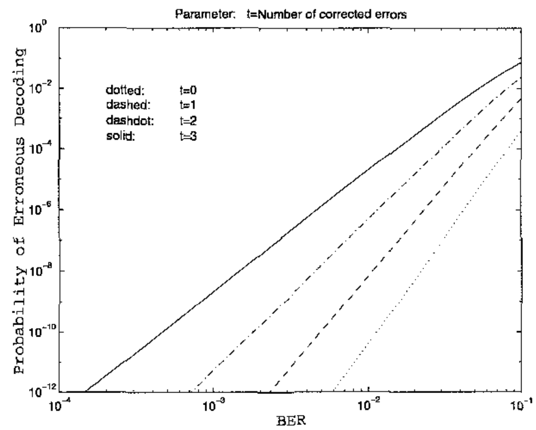

Figure 4: Performance of a (7,1) repetition code used to protect a single high priority request mini-slot or acknowledgement mini-slot

On the other hand, the low priority request mini-slots carry five bits of information representing the MT's ID number. To protect these five information bits, we use a (15,5) BCH code which is capable of correcting up to $t = 3$ errors. Because of the low priority of these requests, we do not use the full error-correcting capability of the (15,5) BCH code so as to maintain an acceptable probability of erroneous decoding of approximately 10^{-5} for a BER in the order of 10^{-2}. That is, we correct up to two bit errors and rely on requests with more than two bit errors to be retransmitted. The performance of the (15,5) BCH code is shown in Figure 5.

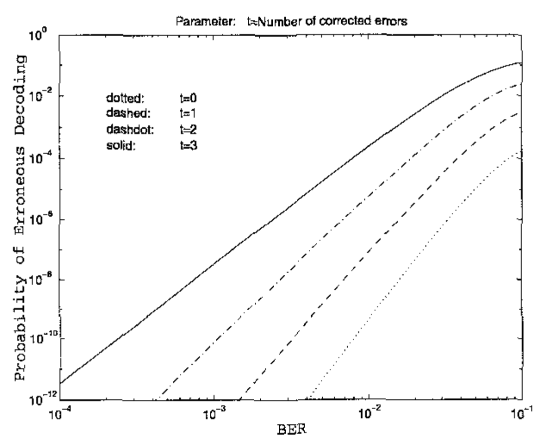

Figure 5: Performance of a (15,5) BCH code used to protect a single low priority request mini-slot

V. CONCLUSIONS

In this paper we presented the simulation results for the 13 channel DS CDMA WATM LAN utilising optimized complex spreading signatures based on Walsh-Rademacher functions. The results are very promising, and indicate that with the application of a hybrid ARQ scheme, capable of correcting 10 errors [9],[10], the number of WATM cells which would require retransmission is in the order of 0.6%. Further research investigating the behaviour of the system without the perfect power control and incorporating the realistic indoor channel model is required.

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