A SAW Matched Filter Based Spread Spectrum Technique for Indoor Multiple Access Systems

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ABSTRACT

Surface Acoustic Wave (SAW) tapped delay lines and convolvers functioning as Matched Filters (MFs) are of superior advantages in broadband spread spectrum communication systems in comparison to digital signal processors. SAW MFs allow indoor systems to have a bandwidth larger than the coherence bandwidth of the indoor radio channel. A multiple access technique called Time Code Division Multiple Access (TCDMA) based on SAW MFs is proposed. Using Gold codes of length 128 as spreading codes, our uplink performance simulation results reveal the capacity of TCDMA in a typical indoor cell.

INTRODUCTION

Spread spectrum techniques used for multiple access systems play a more and more important role in commercial radio frequency (RF) communication systems [1]. Indoor environments for mobile radio communications provide special challenges due to the physical characteristics of the RF wave propagation. For indoor environments such as factory halls, office buildings and supermarkets, the coherence bandwidth is in the range of 30 ~ 40 MHz and the delay spread is small so that narrowband CDMA systems are not suitable. In Time Division Multiple Access (TDMA) systems for indoor applications such as DECT, to combat the frequency selective fading, the frequency synthesizers required for frequency hopping are complicated and reduce the system capacity.

To solve this dilemma, a new multiple access technique called TCDMA for indoor wireless communications was proposed based on SAW components as analog matched filters (MFs) in the receiver [2].

THE TCDMA SYSTEM

The TCDMA downlink scheme [3] is illustrated in Figure 1. The downlink and the uplink schemes are arranged in a time multiplex form. The users are divided into *1, 2, ..., i, ...,I* code groups. Users in each group have the same spreading code C_i, and within a group to each user its own timeslot is assigned not disturbing any other user in the same group.

In the downlink the synchronization channel is defined with C_s. Like the user channels, it is divided in J timeslots. Since TCDMA is a synchroneous spread spectrum system with a time multiplex schedule, it has in contrary to the asynchronous systems all advantages of a synchroneous CDMA system for data detection in the receiver. With a SAW MF and this time code schedule, the synchronization and tracking is kept simple and easy.

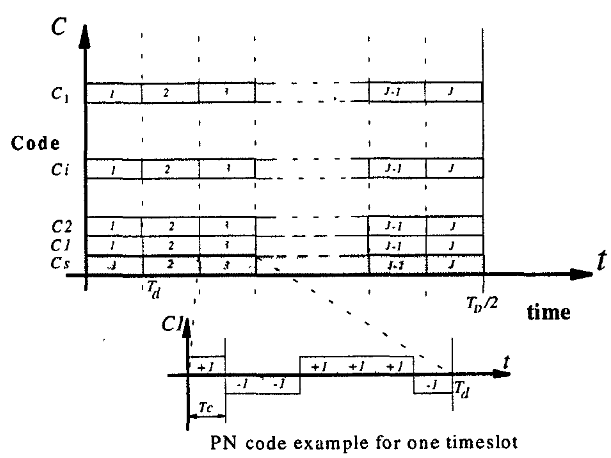

Figure 1. The TCDMA downlink schedule with the synchronization channel C_s

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THE SAW MATCHED FILTERS

SAW devices can have bandwidths of more than 500 MHz and delay times of up to some ten μs. Such a large time-bandwidth-product surpasses by far present digital signal processors. However, costs of SAW devices increase with third power of their length. So, for our system, we choose short SAW MFs (delays < 5 μs). For an inverse SAW filter [4], avoiding cross correlation peaks in a perfect synchronized system, much longer SAW substrates would be necessary. Since synchronization is achievable only for the downlink easily, for the diffusely timed uplink the advantage of an inverse filter, compared to the MF, vanishes.

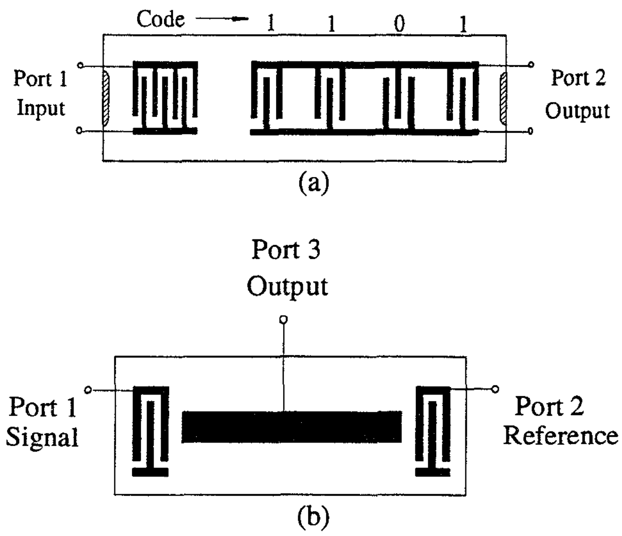


Figure 2. SAW MFs designed as the tapped delay line form (a) and in the convolver form (b)

In principle, two different SAW approaches as MF are feasible in the TCDMA receiver: the linear SAW tapped delay line and the SAW convolver, which are illustrated in Figure 2, respectively.

Using a SAW tapped delay line, a very simple passive correlation device can be realized with a fixed correlation function. The correlation gain obtainable depends on the chosen binary code. Using PN code sequences of length 128, the correlation gain will be about 21 dB. Additionally, weighting of the spectrum of the frequency response is possible. The tapped delay line is sufficient to be applied with a fixed code in the mobile stations (MSs) because it is not necessary for the MSs to know the spreading codes of other mobile users. But several switchable SAW MFs may be used in the MS and the base station (BS). Since the SAW convolver can easily be programmed without any change of its internal structure by simply matching the external refernce PN-code to the changing received signal [7], the TCDMA BS can use the SAW convolvers to detect the multiple active mobile user signals.

Mathematically, the matched filtering process taking place in the SAW tapped delay line or convolver, as indicated in Figure 3, can be described commonly by the correlation function

$$\psi(t) = \int_0^T r(\tau)\cdot m(t-\tau)d\tau\,, \qquad (1)$$

where $r(t)$ is the received signal as an input of the SAW MF, and $m(t)$ is the reference code sequence in the MF time-inversed to the signal code.

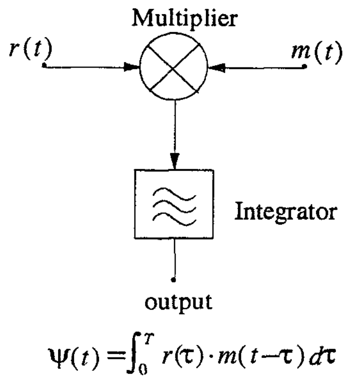


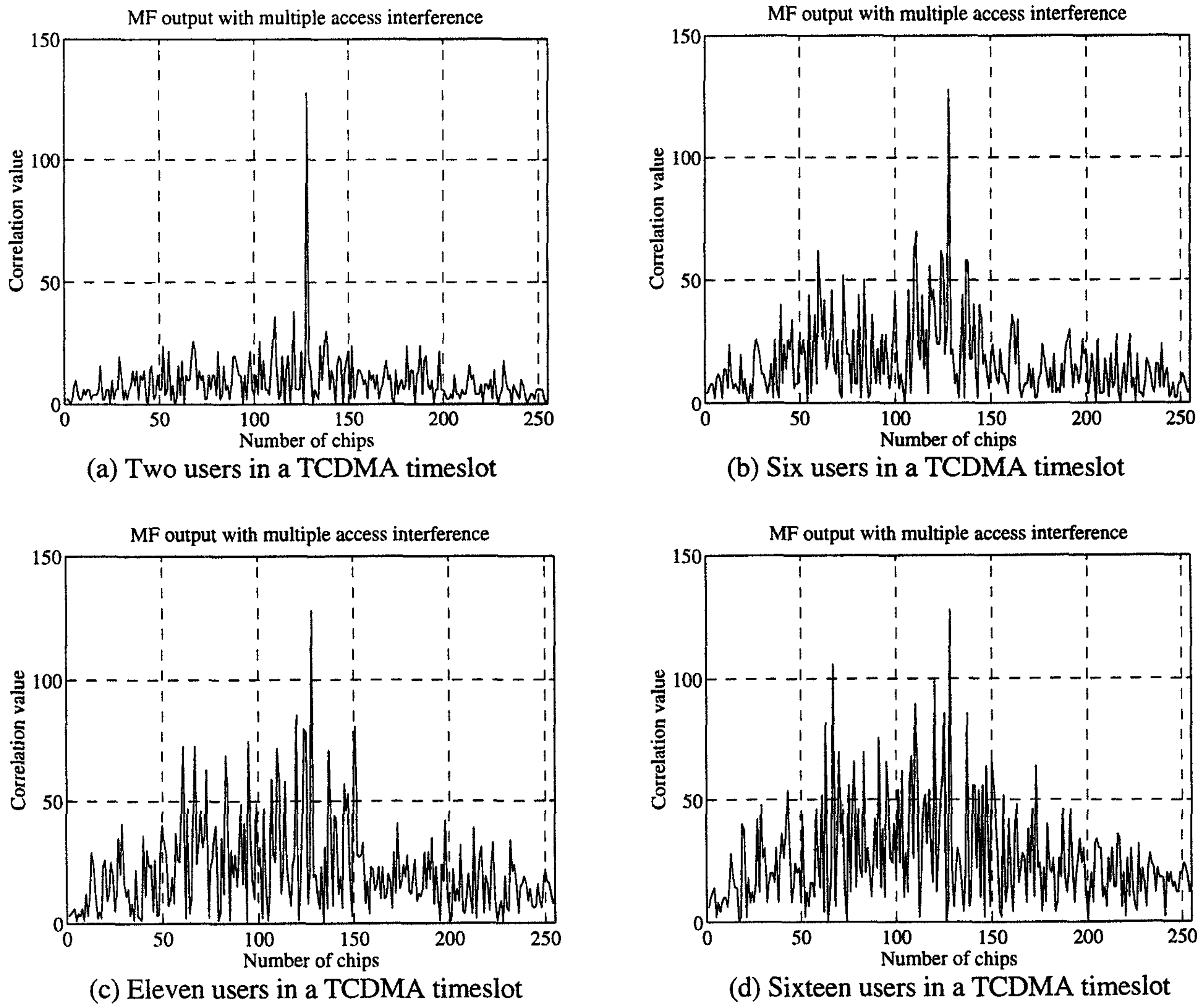
Figure 3. SAW Matched Filter model

SAW MF OUTPUT SIGNAL FOR MULTIPLE ACCESS USERS

Assuming linearity of the transmission of a TCDMA system, computer simulation for SAW MF with multiple access users can be carried out in the baseband. With a transmitted signal $s_{i,j}(t)$ by the MS using the i th code in the j th timeslot, the received signal in the uplink in the BS is expressed as

$$r(t) = \sum_{i=1}^{I}\sum_{j=1}^{J}\int_{-\infty}^{+\infty} s_{i,j}(\tau)h_{i,j}(t-\tau)d\tau + n(t)\,. \qquad (2)$$

$h_{i,j}(t)$ is the indoor radio channel impulse response. The multiple access interference occurs only for users in the same timeslot. We take Gold codes of length 128 for spreading the user signal. The correlation process taking place in the SAW MF produces the ouput signal of Eq. (1) depicted in Figure 4 for four different numbers of users in the same timeslot. The more users, the larger the multiple access interference will be. The side peaks are very large in Figure 4 (d) with 16 active users.



(a) Two users in a TCDMA timeslot

(b) Six users in a TCDMA timeslot

(c) Eleven users in a TCDMA timeslot

(d) Sixteen users in a TCDMA timeslot

Figure 4. Multiple user interference in the same TCDMA timeslot

INDOOR CHANNEL MODELING

The indoor radio channel can be described by its time-invariant channel impulse response

$$h(t) = \sum_{k=1}^{K} a_k \cdot \delta(t - t_k) \cdot e^{j\theta_k} \qquad (3)$$

with relative amplitudes $\{a_k\}$ assumed to be log-normal distributed according to e.g. Hashemi [5] and Rappaport [6]. The excess time delays $\{t_k\}$ are calculated as per a modified exponential function by using a compare-rejection method, and the random phases $\{\theta_k\}$ are generated by a uniform distribution function in $[0,2\pi)$ combined with an increment method. Locations with line of sight (LOS) connection and with no line of sight (NLOS) connection are assumed to be equiprobable for the MSs. A bandwidth of 50 MHz is taken to combat the indoor multipath fading.

THE UPLINK PERFORMANCE WITH VOICE ACTIVITY DETECTION

Since in the TCDMA uplink the signal of each mobile user experiences an individual radio channel impulse response, the system performance degrades more severely than in the downlink. Assuming again linearity of the transmission, the transmitted signal can be expressed by

$$s_{i,j}(t) = v_{i,j} \operatorname{Re}\left\{\sqrt{2 \cdot P_b} \cdot d_{i,j}(t) \cdot C_{i,j}(t) \cdot \exp(j\omega_c t)\right\} \quad (4)$$

with the index of codes i, and the timeslot number j. The data bit energy $E_b = P_b \cdot T_b$ is normalized to unity for the simulation so that the data bits $d_{i,j}(t) \in \{0,1\}$ and spreading codes $C_{i,j}(t) \in \{-1,+1\}$ will be used directly in the baseband simulation due to the assumed linear transimission. $n(t)$ is the additive white Gaussian noise (AWGN).

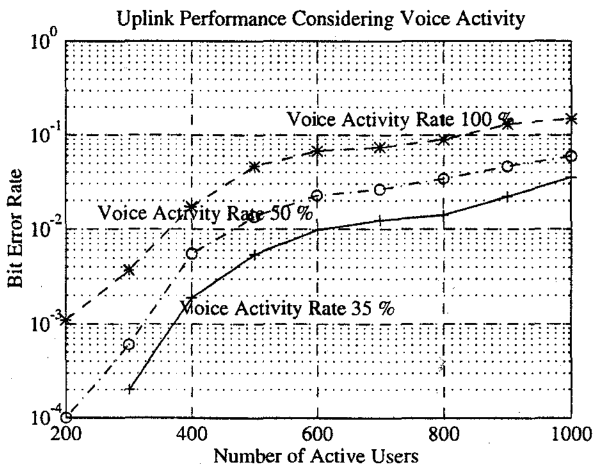


Figure 5. The TCDMA uplink performance with voice activity detection. The multipath diversity method - the hard integration method - is used. SNR=10 dB.

The voice activity factor $v_{i,j}$ is considered for phone calls. In reality, the rate of voice activity can be assumed to be equal to 35%. The voice activity detection is an advantage to decrease the mulitple access interference for TCDMA users in the same timeslot. Simulation results with $v_{i,j}$ = 35%, 50%, 100% show large improvements in performance and capacty of a TCDMA indoor system. A multipath diversity method - the hard integration method -, combined with a time window technique for the SAW MF output as is suggested in [2] is used for data decision.

CONCLUSION

SAW devices as MFs are of advantages when applied to the indoor TCDMA system due to the powerful capability of correlation calculations. With voice activity detection in the uplink, about 600 ~ 800 voice channels in a distance of up to 20 m can operate simultaneously with bit error rates in the order of 10^{-2} without considering any interleaving, error correction channel coding methods, sectorizing, antenna diversity and so on. Applying any of these techniques to the TCDMA system would improve the system performance significantly. The TCDMA system using SAW MFs is a simple solution for applications such as PCN, cordless telephones and wireless LANs for future indoor communications.

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