Multi-carrier CDMA Communication System Design

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Abstract- Multi-carrier Code Division Multiple Access (MC-CDMA) technique which combines OFDM (Orthogonal Frequency Division Multiplexing) and CDMA (Code Division Multiple Access) is a novel digital modulation and multiplexing technique. It is very suitable for the future 3rd generation Universal Mobile Telecommunication System (UMTS) which demands a very wide range of bit rates for covering a wide range of applications such as voice, HDTV etc.. The MC-CDMA system is very suitable to be implemented by using embedded DSP processors. Ptolemy is a system level design tool which can map system level design to embedded DSP processors. This will short the system design and implementation time for embedded DSP design. In our project, we model the core of MC-CDMA communication system as a SDF (Synchronous Dataflow) model and implement the core of MC-CDMA communication system by using Ptolemy SDF domain.

I. Introduction

Recently, there has been considerable interest in applying direct sequence code division multiple access (DS-CDMA) technique to the mobile communications such as IS-95. This is partly due to its multiple access capability, robustness against multipath fading, and anti-interference capability. On the other hand, the multicarrier modulation scheme, often called orthogonal frequency-division multiplexing (OFDM), has drawn a lot of attention in the field of radio communications. This is primarily because of the need to transmit high data rate in a mobile hostile environment channel. To combat the problem, the OFDM seems to be a solution.

The combination of OFDM and CDMA which is so called Multi-carrier CDMA (MC-CDMA) is anticipated a good approach to the 3rd generation mobile communication system [5] where users will get access to an array of voice, data, and video communication services anywhere in the world at any time. All these date rates with different qualities of services will be variable and the data rate will be up to 2 Mbit/s for HDTV etc.

II. MC-CDMA system

The MC-CDMA transmitter for a single user is shown in figure 1. The binary data $a_m( )$ are first multiplied by the pseudo-noise (PN) binary sequence $s_m( )$ which is called spreading code. The bit duration T of the data is much longer than the PN sequence chip duration T_c. Normally $N = \frac{T}{T_c}$ may be equal to 32, 64, 128 or higher. After the necessary encoding, the sequence that corresponds to one data bit is modulated in the band of N modulators.

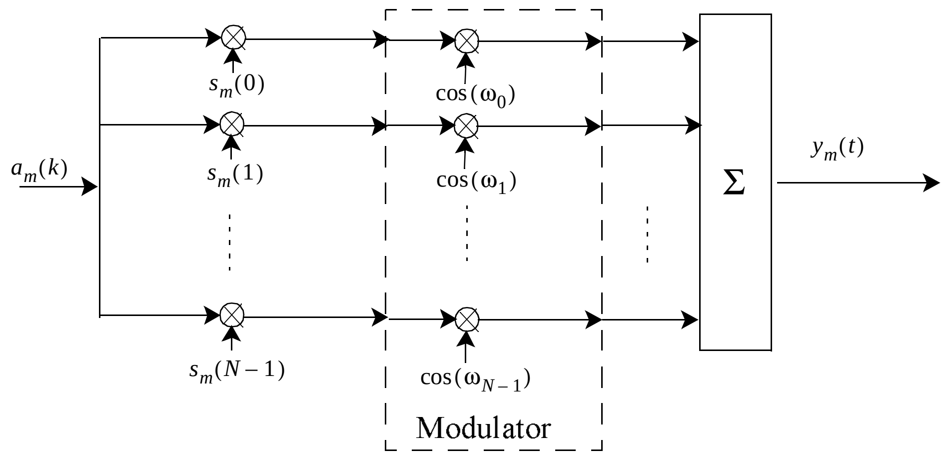
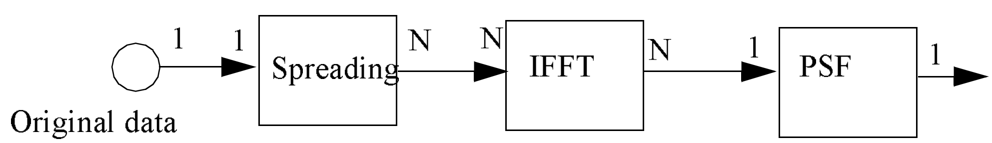


Figure 1: MC-CDMA transmitter of a single user

A very efficient way of realizing such a modulation scheme is the Inverse Fast Fourier Transform (IFFT) which is shown in figure 2. The distance between subcarriers is equal to the chip rate or its multiple. This modulation is called OFDM (Orthogonal Frequency Division Multiplex). The circular prefix or guard time should be introduced for each symbol in order to combat the transients and the intersymbol interference caused by the channel and filters in the system. The circular prefix consists of $\mu - 1$ repeated samples from the IFFT output where μ is the length of the channel impulse response or the delay spread measured in samples. At the output of IFFT the pulse shaping filter followed by a modulator which shifts the whole spectrum to the desirable frequency band can be applied. Another solution is to apply the offset IFFT that eliminates the necessity of the above mentioned frequency shift.



PSF-pulse shaping filter

The number in the arcs is the tokens produces and consumes

Figure 2: MC-CDMA transmitter using IFFT no circular perfix

In MC-CDMA system, sub-carrier frequencies are usually chosen to be orthogonal to each other, i.e., sub-carrier frequencies satisfy the following condition:

$$\int_{o}^{T_C} \cos \qquad dt = 0 \;\; V \;\; i \neq j \;\; i, j \in N \qquad (1)$$

where Tc is the chip duration; ω_i and ω_j are the i-th and j-th carrier frequencies. The spectrum of MC-CDMA signal is shown in figure 3.

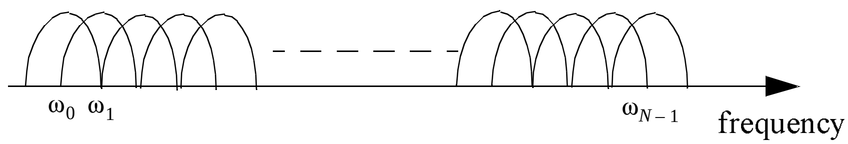
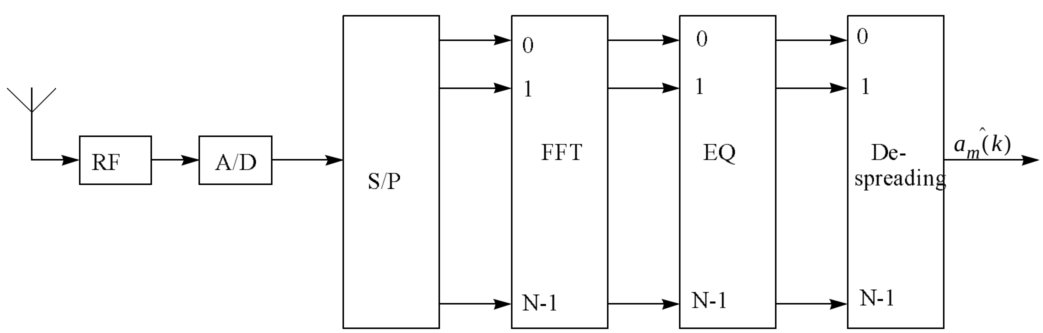


Figure 3: Spectrum of MC-CDMA signal

The basic structure of the MC-CDMA mobile station receiver is presented in figure 4. The



RF: receive filter;
EQ means equalization

Figure 4: MC-CDMA receiver for a mobile station

receiver of the basestation consists of the same blocks as those in figure 4, however the output of FFT are fed to x branches (one branch for each user). An N equalizer and despreading block are applied in every branch to equalize the user's individual channel and multiply the received signal by the user's unique PN code.

The equalization usually uses adaptive equalizer or adaptive discrete matched filter (ADMF) at the receiver input. Its coefficients are calculated adaptively according to the adequate algorithm like LMS algorithm. For the correct operation of the applied adaptive filter we assume the channel characteristic remains unchanged during the duration of the block of N samples. The changes of channel characteristics depend primarily on the vehicle's speed. Thus, the duration of a single block must be much smaller than the inverse of the maximum Doppler frequency. Hence, the upper limit for the IFFT order applied in the transmitter is specified by Equation (2).

$$N \ll \frac{f_c}{f_D} \tag{2}$$

where f_c is the chip rate and f_D is the maximum Doppler frequency.

The benefit when we use MC-CDMA modulation scheme for 3rd generation mobile communications is that the spreading code chip rate is the same as the original data rate. It is unlike the DS-CDMA scheme the spreading code chip rate is the original data rate times the length of spreading code. For example for HDTV case data rate will be up to 2Mbits/s. If the length of spreading code is 32, in DS-CDMA case the spreading code chip rate will be 32x2Mbits/s=64Mbits/s. This spreading code chip rate is too high to receiver synchronize and track the spreading code. On the other hand, MC-CDMA the spreading code rate is still 2Mbits/s. It will make the receiver easy to synchronize and track.

III. Model of computation to implement MC-CDMA system

Dataflow is a natural representation for signal processing algorithms. Applications are specified by a dataflow graph in which the nodes represent computations, and data tokens flow between them along the arcs of the graph.

Synchronous data flow (SDF) is a special case of dataflow model. In SDF model the number of tokens produced or consumed in one firing of a node is constant. This property makes it possible to determine execution order and memory requirements at compile time. Thus these systems do not have the overhead of run-time scheduling, and have very predictable run-time behavior.

Figure 5 shows a simple SDF graph. In this graph, node A produces two tokens and node B consumes three tokens for each firing. In a periodic SDF schedule, the first-in/first-out (FIFO) buffer on each arc returns to its initial state after one schedule period. For each node x in a properly constructed SDF graph, there exists a positive integer q(x) such that node x must be invoked at least q(x) times in a each period of a periodic schedule. For the example in figure 5, q(A)=3 and q(B)=2.

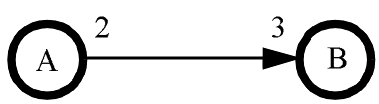


Figure 5: A simple SDF graph

The transmitter of MC-CDMA system described in figure 2 contains the original data stream node, spreading node, IFFT node, and pulse shaping filter node. All of these nodes consume and produce constant number of tokens. For example the original data stream node produces one token for each firing. The spreading node consumes one token and produces N token for each firing. The IFFT node consumes and produces N tokens for each firing where N is the length of the IFFT algorithm and also the length of the spreading code. So the transmitter can be modeled by SDF model very perfectly.

The receiver of MC-CDMA system described in figure 4 contains FFT node, Equalizer node, and despreading node. These nodes are also produce and consume constant number of tokens for each firing. Therefore the receiver can also be modeled by SDF model.

IV. Ptolemy

The Ptolemy is a freely distributable, extensible block diagram environment for specifying, simulation, and generating code for signal processing and communications systems. Which is developed by the University of California at berkeley.

The Ptolemy kernel does not define any model of computation. The semantics of a domain are defined by classes that manage the execution of a specification. These classes could invoke a simulator, or could generate code, or could invoke a sophisticated compiler.

The domain which the Ptolemy kernel can support is shown is figure 6:

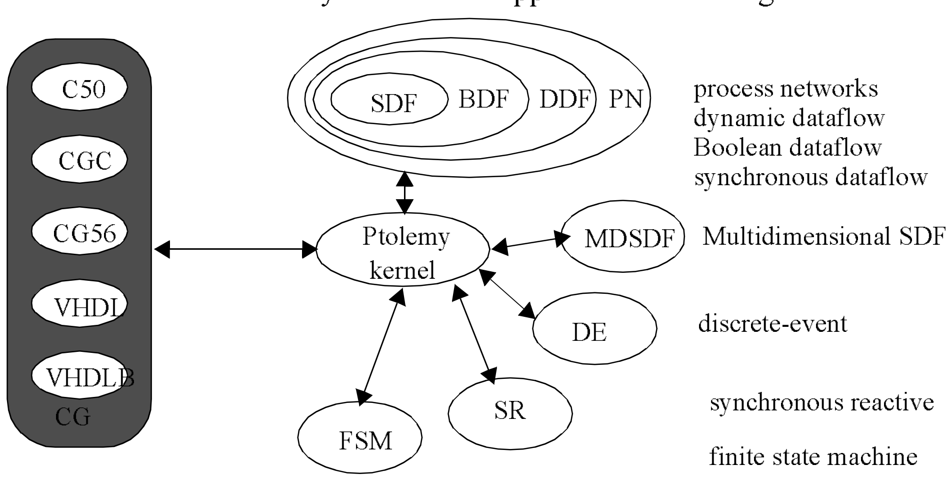


Fig.ure 6: Domains available with Ptolemy 0.7

In Ptolemy the function blocks can be hierarchical, the lowest level of the hierarchy is star. A hierarchical block is a Galaxy, and a top-level system representation is a Universe. The function blocks can be also mixing domains.

V. Implementing MC-CDMA system with Ptolemy

As mentioned, the MC-CDMA system can be modeled by SDF model. The SDF domain is one of the most mature in Ptolemy, having a large library of stars and demo programs. It is a simulation domain, but the model of computation is the same as that used in most of the code generation domains. A number of different schedulers, including parallel schedulers, have been developed for this model of computation.

We use hierarchical design methodology. The transmitter galaxy is shown in figure 7. It contains spreading block and IFFT block. The length of spreading code can be set by changing the spreading galaxy parameter. The length of IFFT can also be set by changing the IFFT galaxy parameter. The receiver galaxy contains FFT and despreading block. The spreading and despreading blocks are also galaxies which contain several stars or galaxies. Figure 7 shows the implementation of transmitter and figure 8 the implementation of receiver.

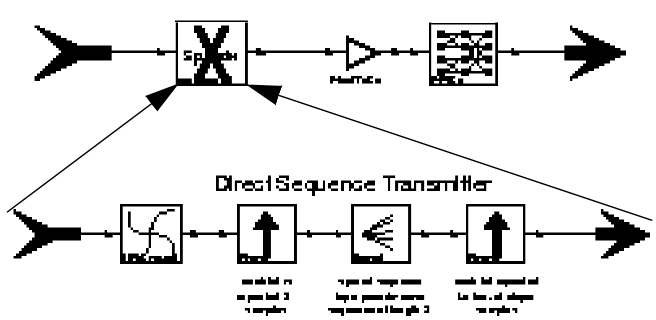


Figure 7 the implementation of MC-CDMA transmitter in Ptolemy

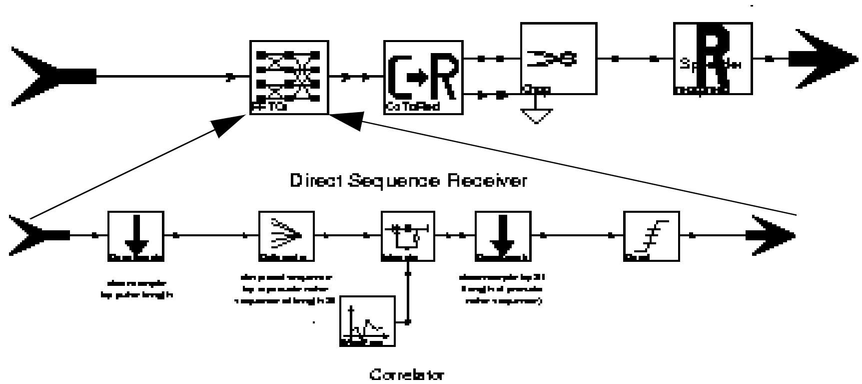


Figure 8: the implementation of MC-CDMA receiver in Ptolemy

To verify the transmitter and the receiver is working properly. We use the MC-CDMA transmitter and receiver galaxy to form a universe and also the Gausian white noise is added to transmission signal. The universe of MC-CDMA is shown in figure 9.

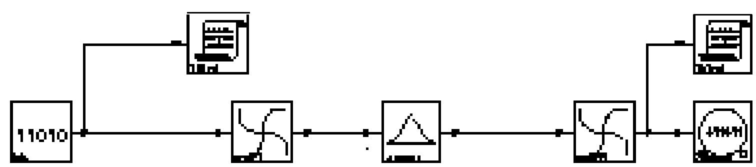


Figure 9: Universe of MC-CDMA

VI. Conclusion

In this project, we use SDF domain to model the core of MC-CDMA system. Ptolemy is used to verify our modeling. The result shows SDF model can sufficiently model the core of MC-CDMA system. In reality, to design a practical MC-CDMA technology based 3rd generation mobile communication system, we must also design a signaling system which can naturally be modeled by Finite State Machine (FSM). The core of MC-CDMA which is SDF domain will be a child domain of FSM domain. So we need mixing domain design tool like Ptolemy.

VII. Reference

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