Digital Signal Processing Optimization Algorithm for Terahertz Communication Based on Short Convolution Iterative Algorithm and Adaptive Blind Equalization Algorithm

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Abstract. This paper systematically studies the crosstalk problem caused by the low parallelization rate and tail-to-back tailing in the high-speed digital signal parallel processing in terahertz communication. First, in order to improve the parallelization rate in system application, a high-speed digital signal in the network is filtered in parallel based on a short convolution iterative algorithm for the input signal. Second, an adaptive blind equalization algorithm is proposed to solve the problem crosstalk is used to restore the original signal. Finally, the effectiveness of the equalization algorithm is verified by MATLAB, and the designed algorithm is implemented by Labview simulation software. The effectiveness of the designed algorithm is verified by simulation analysis. The high-speed signal after parallel filtering and equalization can restore the information of the original signal well.

1. Introduction
With the progress of science and technology and the acceleration of the pace of life, people’s demand for network communication speed is increasing day by day. Since the mid-1990s, wireless network applications began to develop rapidly in the world, and the transmission rate of megabits has been unable to meet the current actual communication needs. However, the high-speed communication of T-bit has been successfully realized in the laboratory with terahertz technology. The traditional hardware system is difficult to support such a high communication rate. Serial communication is the internal communication mode of the equipment, even if the auxiliary equipment such as antenna is added by external means, the internal communication is still the same. Increasing the sampling rate, bandwidth and modulation signal order is the main way to improve the communication rate in serial communication. Today, the demand is expanding rapidly, and the actual effect is not enough. In view of this, the industry urgently needs to find another way to achieve this goal from other perspectives[1-2].

In recent years, parallel signal processing technology has been widely used in various fields because of its advantages over the traditional serial method. Without changing the single channel capacity, the communication speed has been significantly improved. The United States and other developed countries started this research earlier, and China also paid enough attention to this technology. As early as the mid-1990s, NASA’s JPL laboratory has proposed a concept of parallel receiving device; until 2012, the high-speed parallel principle prototype based on high-frequency terahertz unit with communication rate up to 2 Gbps developed by China Academy of engineering physics finally came out[3-4].
2. Significance of developing terahertz communication

The electromagnetic wave whose frequency is between 100 GHz and 10 THz is called terahertz wave. Because of the particularity of this frequency band, the research on it is still in the primary stage in academic and engineering circles.

The development of new wireless communication frequency band has been more and more focused on solving the contradiction of spectrum resources. With the rapid development of wireless communication, there is an obvious trend of scarcity. The key to solve the problem is the terahertz frequency band, which is suitable for future wireless communication. Although the choice of technical route is diverse, wireless communication system is usually realized by solid-state electronic equipment, and the system can be integrated on chip in the future, which is very important for the commercialization of terahertz wireless communication system. The most significant advantage of using terahertz frequency for wireless communication is that terahertz frequency band has abundant bandwidth resources. On the ground, it is connected to the mobile communication base station through terahertz wireless connection, high-speed access to dense area, reverse data transmission, and finally connected to remote users to solve the "last kilometer" problem; in space, for high-capacity and high-speed wireless communication between satellites, it is called the best choice because of the characteristics of terahertz wave that is not easy to decay in vacuum. First of all, terahertz wave has unique advantages for carrying confidential information: because of its length and directionality, it is easier to achieve ultra-high communication bandwidth in this frequency band; secondly, in the battlefield and other harsh environments, the attenuation of terahertz wave is less than that of light wave attenuation, which is convenient for high-speed transmission. Therefore, terahertz communication technology not only has high academic value, but also has a good prospect in practical application.

3. Overview of mainstream parallel algorithms

3.1. Parallel filtering algorithm

In practical application, if the communication rate is not very high, then the parallel algorithm can be realized by adding sharing. It can run from 2 Gbps to 5 Gpbs and consume the least hardware resources. However, with the increase of communication speed and the number of parallel channels, the pure addition sharing method has lost its practical application value in some cases due to the factors of too high data dimension, too much computation overhead and low fault tolerance. As for parallel processing, fast finite impulse response algorithm (FFA) and iterative short convolution algorithm (ISCA) are two parallel filtering algorithms used in high-speed environment.

The essence of FFA algorithm is a finite impulse response filter. It inputs the original serial sequence into parallel input sequence after serial parallel conversion, and then decomposes the filter coefficients into similar parallel sequences similarly. After being decomposed into parallel sequences, parallelization is expressed in matrix form. This algorithm does not need to use the general overlap technique in the cyclic or aperiodic convolution based method. Can significantly reduce hardware performance requirements. Because of its excellent linear phase characteristics and unconditional stability, FFA algorithm is widely used in many fields such as video, image processing and wireless communication. In some applications, such as high-speed remote sensing satellite receiver, 4G communication system, their throughput requirements for FIR filter are also increased due to their high data transmission rate, such as cellular data communication and portable medical applications. On the other hand, in the field of equipment, there are strict requirements for the power consumption of FIR filter. Parallel technology can be used to improve the throughput of FIR filter and reduce the power consumption of FIR filter, which is its main advantage. But generally, the number of parallel structures increases significantly with the increase of parallel series, making it difficult to be applied in the system with high complexity. How to solve the complexity of parallel FIR filter has been an important topic in the past decade. However, in most designs of FIR filter, the parallel structure can not tolerate the hardware overhead. In addition to the FFA algorithm, there is still a more suitable...
algorithm - ISCA algorithm, which can obtain better hardware resource utilization efficiency than FFA algorithm, so as to improve the FFA algorithm is difficult to adapt to the problem of high complexity system. In this algorithm, parallel filtering is realized by fast short convolution. The fast short convolution algorithm was first proposed by achaji in 1989, and then improved by Cheng C and Cheng C, parhi K. Especially, when the length of FIR filter is very large, this kind of linear convolution structure based on ISC can save a lot of hardware cost.

3.2. Parallel equalization algorithm
With the increasing demand for high-speed data transmission, the existing digital modulation and demodulation technology has been stretched out, which is difficult to meet the high demand of the public. At this time, terahertz communication is in the public eye. At present, the research of terahertz communication mainly focuses on terahertz high-speed signal processing, but ignores the accuracy of signal transmission. At present, most of the academic literature does not consider equalizer, but in the actual communication, the problem of code crosstalk is widespread. There are many reasons for crosstalk, such as finite length truncation and sampling period deviation. In order to recover the original signal, equalization technology is needed to reduce or even eliminate the adverse effects of these inter code interference. However, due to the non-linear characteristics of the actual channel and devices, it is impossible to accurately observe the impact caused by them. At the same time, considering the magnitude time-varying characteristics of the channel itself, the equalization algorithm must have self adaptability. In this paper, the parallel adaptive blind equalization algorithm is selected.

4. Basic principle of algorithm

4.1. Iterative short convolution algorithm
In parallel filtering algorithm, the iterative short convolution algorithm (ISCA) is more efficient than FFA in hardware resource utilization. In this algorithm, some multiplication units are replaced by addition units and delay units, while fast convolution is used to reduce the number of sub filters, and the coefficient symmetry of sub filters is guaranteed as much as possible. The number of multipliers needs to be optimized by relying on coefficient symmetry. ISCA algorithm equation is as follows:

$$S_{2M-1} = A_{M \times m}(Q_m \otimes Q_n)H_{M \times mn}(P_m \otimes P_n)X_M$$  \hspace{1cm} (1)

On the basis of formula (1), the formula of multi-level iteration can be further derived, which is suitable for the case of high parallel series. The formula of multi-level iteration is as follows:

$$S_{2M-1} = A_{M \times mn}(A_{M \times mn} \otimes I_{(2k-1)(2k-1)})(Q_m \otimes (Q_m \otimes Q_n))H_{M \times mnk}(P_m \otimes (P_n \otimes P_k))X_N$$  \hspace{1cm} (2)

In formula (2):

$$\begin{cases}
N = Mk = mnk \\
H_{N \times mn} = \text{diag} [(P_m \otimes (P_n \otimes P_k))(h_0, h_1, \cdots, h_{N-1})^T]
\end{cases}$$  \hspace{1cm} (3)

4.2. Parallel adaptive blind equalization algorithm
Set the transmitted information symbol as $s(n) = a(n) + jb(n)$, the equalizer length as $N$, and the signal vector received by the equalizer as follows:

$$X(n) = [x_n, x_{n-1}, \cdots, x_{n-N+1}]$$  \hspace{1cm} (4)

The equalizer coefficient is:

$$W(n) = [w_0(n), w_1(n), \cdots, w_{N-1}(n)]^T$$  \hspace{1cm} (5)

The renewal equation of adaptive coefficient based on stochastic gradient method can be expressed as follows:

$$W(n + 1) = W(n) + \mu e(n)X^*(n)$$  \hspace{1cm} (6)

Where $\mu$ is the parameter of adaptive updating step size, and its error function is.
The formula of adaptive blind equalization algorithm is as follows:

\[ y(Lk + i) = W^T (Lk + i)X (LK + i) \]  

If the above formula is transformed in advance and the equilibrium coefficient at the current time is replaced by that at the next time, it can be obtained:

\[ y(Lk + i) \approx W^T (Lk)X (Lk + i) \]  

This transformation method can simplify the calculation of the iterative process, and will not have a significant impact on the performance of the algorithm. Where \( k \) is the time index corresponding to \( n \) under \( L \)-channel parallelism. By expanding the above formula (10), we can get:

\[ W[L(k + 1)] \approx W(Lk) + \mu \frac{L}{L_A} \sum_{m=0}^{L_A-1} e(Lk + m)X^*(Lk + m) \]  

Pipeline delay is unavoidable in the hardware implementation phase of the algorithm, so it must be considered in the modeling process. In this system, the pipeline delay of the error feedback loop is defined as \( D_1 \). Since the converged coefficients are stable and slow in the adaptive updating, formula (10) can be approximately expressed as follows:

\[ W[L(k + 1)] \approx W(Lk) + \mu \frac{L}{L_A} \sum_{m=0}^{L_A-1} e(Lk + m - D_1)X^*(Lk + m - D_1) \]  

Combining short convolution to update coefficients adaptively can realize parallelization, and the hardware cost is low. Take \( L=8, L_A=2 \). As shown in Figure 1, the overall implementation structure is obtained, and the flow of parallel adaptive blind equalization algorithm based on short convolution is described.

Through the matrix \( Q^T \) and matrix \( A^T \) preprocessing, \( d_1-d_6 \) is the pipeline delay, through \( X_q(n) = X_p(n)H(n) \) filtering and the matrix \( P^T \) data combination processing can get the final equalization results. Here we need to limit the pipeline delay conditions:

\[ D_1 = d_1 + d_2 + d_3 + d_4 \]  

5. Algorithm simulation

The effectiveness and performance of the designed algorithm need to be verified by simulation. For the verification platform of the adaptive blind equalization algorithm, MATLAB is selected. The simulation results of the algorithm are shown in Figure 2. As can be seen from the figure, the result of the equalization is ideal, and the virtual devices used in the simulation process are low-performance hardware, and can still achieve fast equalization.
We adopt Labview simulates the entire process of transmitting signal filtering and equalization algorithms, and uses 5Gbps 16QAM signals to simulate input signals. Select the modulation phase filter for parallelization and select 32-channel parallel simulation. First, the modulation data is parallelized on four channels through polyphase decomposition. Each of the four channels uses the ISCA algorithm for eight channels in parallel, so that the total number of parallel channels eventually becomes 32. Signal reduction is performed by a parallel equalization algorithm. Figure 3 shows the frequency spectrum of the output data. It can be seen from the parallel output data spectrum in Figure 3 that the parallel signal spectrum is highly similar to the general serial transmission spectrum. And the signal bandwidth does not change after parallelization. The transmission speed of the parallel signals meets the requirements, and the amplitude within the bandwidth is stable, indicating that the data equalization processing effect is better.

In summary, the effectiveness of the filtering and equalization algorithms described in this article can be verified by simulation. Provide a solution for parallel processing of high-speed digital signals in terahertz communication in hardware systems in the future.

6. Conclusion
Intelligent mobile devices, big data, the Internet of Things, and artificial intelligence services continue to penetrate all aspects of human life, so terahertz communication needs sufficient rates to support high-speed wireless communications. Terahertz science and technology has achieved success in many key areas over the past two decades: spectroscopy, communications, radar, astronomy, meteorology, petroleum, chemistry, military security, and breakthrough breakthroughs, especially in the fields of
defense and aerospace. Research on terahertz science and technology still has a long way to go, and the development of terahertz communication is highly expected. Improving communication speed, from component integration to system integration, and short-range high-speed terahertz secure wireless communication are the major development trends of terahertz communication research.

At the same time, with the advent of the 5G era and the introduction of efficient and secure new communication technologies, the digital media industry will also face new technological innovations. With the gradual popularization of 5G, the communication industry and the digital media industry will also have explosive growth, which will greatly reduce the arrival time of the next technology bottleneck period. Terahertz technology is leading the frontier of today’s communication neighborhood with its superior communication speed and security. The research of high-speed signal processing technology in terahertz communication can not only serve the public at the moment, but also serve as a technological precipitation, which is more conducive to the research of next-generation technology. With the vigorous development of terahertz technology today, the focus on hardware development has been recognized by the industry, but good software algorithms cannot be ignored. After the hardware system is determined, the algorithm needs to be continuously improved to improve performance and system stability. In the future work, we will continue to conduct in-depth research on signal processing algorithms in terahertz communication.

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