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A CDMA-based Network on Chip dedicated to data-dominated streaming applications

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Abstract

In this paper an analysis of the CDMA-based transmission in Network on Chip (NoC) is presented. In order to realize CDMA transmission scheme between IP cores in the NoC, dedicated encoders and decoders using Walsh codes are proposed. To check the possibility of implementing CDMA NoC, a parametrization stage of audio analysis system was adapted to the NoC structure as a set of 14 independent blocks. The system was implemented with use of the ImpulseC hardware description language on an FPGA platform (Xilinx Virtex-5). The obtained results and the requirements needed to realize the CDMA scheme in the hardware show that a higher number of transmitted bits does not lead to any benefits over bus-based transmission.

Keywords: CDMA, Network on Chip, ImpulseC.

Sieć wewnątrzukładowa wykorzystująca transmisję rozpraszania kodowego CDMA przeznaczona do zastosowań przetwarzania strumieni danych

Streszczenie

W pracy została przedstawiona analiza wykorzystania transmisja strumieni danych między blokami IP w strukturze sieci wewnątrzukładowej (NoC) z użyciem rozpraszania kodowego CDMA. Ponieważ typowe rozwiązania łączenia bloków w systemach MPSoCs oparte o sieci wewnątrzukładowe wykorzystują routing typu wormhole, często pojawia się problem związany z dostępem do wspólnych zasobów. W artykule podjęto próbę zmiany mechanizmu transmisyjnego w celu określenia możliwości poprawy takiej sytuacji. Proponowane podejście wykorzystuje transmisję CDMA z zastosowaniem kodów Walsha. W celu relizacji zadań transmisyjnych opracowane zostały dedykowane układy kodera i dekodera CDMA wykorzystywane do komunikacji między blokami przetwarzającymi. Do oceny i weryfikacji proponowanego rozwiązania zdecydowano się na użycie modułu parametryzacji sygnałów akustycznych (rys. 2), pracującego na strumieniach danych. Blok ten przetwarza strumień akustyczny dzieląc go na równej długości ramki i dla każdej z nich wyznacza ponad 100 deskryptorów. Zaproponowane rozwiązanie zostało zaimplementowane w układzie FPGA z rodziny Virtex 5 wykorzystując język opisu sprzętu ImpulseC. W wyniku przeprowadzonej analizy wydajności transmisyjnej i narzutu spowodowanego specyfiką rozpraszania kodowego uzyskano wyniki gorsze niż w przypadku tradycyjnej transmisji wykorzystującej magistrale. Ponadto, konieczność stosowania globalnej synchronizacji oraz w wielu sytuacjach również globalnego routingu powoduje, że transmisja CDMA w sieciach NoC nie stanowi konkurencji do rozwiązań magistralowych dedykowanych przetwarzaniu danych strumieniowych.

Słowa kluczowe: CDMA, sieci wewnątrzukładowe, ImpulseC.

1. Introduction

Due to the growing volumes of multimedia streams used in contemporary computer applications, their effective processing requires utilization of parallel computation at every possible level. Such parallelism can be offered by dedicated hardware structures. However, the majority of referred hardware-software co-designed solutions rather rarely benefit from the state-of-the art multiprocessor System on Chips (MPSoCs) connected with Network on Chips (NoCs) modelled at the transaction level (TLM).

One of the reasons for such a situation is the fact that despite offering high throughput, meticulous flow control mechanisms have to be applied to eliminate problems with common resource accesses [1]. According to [2] and [3], other techniques known from off-chip data transmission, such as TDMA or CDMA, can offer better transmission properties than wormhole switching, which is typical for NoCs, for some specific applications. Unfortunately, the authors of these papers present only introductory experiments confirming this claim. In this paper, we present our experiments using an audio feature extraction module in order to verify the applicability of CDMA transmission in NoCs.

2. CDMA NoC transmission principles

In CDMA, multiple senders can share the same communication channel since their output values are encoded with an appropriate orthogonal spreading code. Thanks to the codes' orthogonality the transmitted values do not interfere each other. For the orthogonal codes the following equations, using autocorrelation $R_{xx}(\tau)$ and cross-correlation $R_{xy}(\tau)$ functions, should be satisfied:

$$\begin{cases} \bigwedge\limits_{\tau\in\{0,N,2N,\dots\}} R_{xx}(\tau) = \frac{1}{N}\sum\limits_{n=0}^{N-1} x(n)x(n+\tau) = 1 \\ \bigwedge\limits_{\tau\in\{0,1,2,\dots\}} R_{xy}(\tau) = \frac{1}{N}\sum\limits_{n=0}^{N-1} x(n)y(n+\tau) = 0 \end{cases}$$

where: τ is the time lag and N denotes the period of the spreading code. Consequently, it is enough to multiply the received signal by the appropriate code, used for encoding, to obtain the proper input value [4].

In digital CDMA encoding and decoding schemes, described in details in [2], data bits from various cores are sent to an encoder serially. Each bit is spread by the encoder into a certain number of bits using an exclusive or operation with an appropriate bit of the chosen code. The encoded bits are added (arithmetically) to the common communication channel.

The receiving IP core decoder is connected with the common communication channel. To extract its portion of information, it has to use an appropriate code for decoding. We decided to use the technique described in [2]. After obtaining the bit, it is multiplied by its weight and, depending on the value of the appropriate bit of the code, added either to the first accumulator if the code bit is equal to zero, or to the second accumulator otherwise. After receiving the whole portion of the spread bit, the values stored in the two accumulators are compared and, if in the first accumulator it is higher than in the second one, the output value is 0, and 1 otherwise. To use this encoding scheme, the code has to be not only orthogonal, but also balanced, i.e., the number of 0s and 1s in each code word should be equal. One of the codes satisfying both these conditions is the Walsh code. Its consecutive values are generated from the consecutive rows of the Walsh matrix [4].

The lowest order Walsh matrix is of the following form:

$$\mathrm{W}(2^1) = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}.$$

To generate a Walsh matrix of a larger size, we have to use the Kronecker product in the following way:

$$\mathrm{W}(2^k) = \mathrm{W}(2^1) \otimes \mathrm{W}(2^{k-1}),$$

where $k \in N$ and $k \geq 2$.

As the first row of the $\mathrm{W}(2^k)$ matrix is to be skipped (it contains only 1s and thus is not balanced), using $n \times n$ matrix we can address n-1 cores in a NoC sending values at the same time. To connect two cores in a NoC, using a centralized router is suggested in [2].

The length of the spreading code S is a function of a number of sources, n, capable of sending streams independently in the following way $S = 2^k$, where $k = \lceil log_2(n+1) \rceil$. This relationship is presented in Fig. 1.

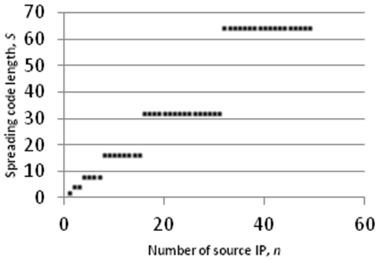

Fig. 1. Length of the spreading code for a given number of source IPs
Rys. 1. Rozmiar kodu rozpraszającego dla określonej liczby bloków IP

3. Implementation and experiments

We implemented the basic transmission blocks, namely the CDMA encoder and decoder in the ImpulseC hardware description language [5]. It is an extension of ANSI C with new data types, aimed at hardware synthesis, and new functions and directives for steering the hardware implementation. The code is executed in the so-called processes, which communicate with other processes using streams, signals, shared memory and semaphores. As the processes are to be realized in hardware, they may benefit from various ImpulseC optimization techniques, such as loop unrolling or pipelining. According to the ImpulseC code generator, an implementation of the encoder requires two 32-bit adders and one 2-bit comparator, whereas the decoder needs four 32-bit adders, one 2-bit and one 32-bit comparators. Due to this rather limited requirements we envisaged low resource utilization in the final implementation.

To check the possibility of implementing the CDMA NoC we decided to use the audio feature extraction case study, presented schematically in Fig. 2 and described in [6]. The feature extraction module contains a set of low-level audio features exploited in many audio analyses and processing tasks at the parametrization stage. The descriptors are extracted from time and frequency domains as single features and derived from filter banks.

In the CDMA NoC implementation, one of the most important parameters is the number of senders that transmit data concurrently. In the considered system, as many as 14 IP nodes are to send the data concurrently. To simplify the calculation below, we assume a non-realistic sample length equal to one byte. Planning to assign a separate orthogonal code to each sender, we would need the codes of 32 bits each.

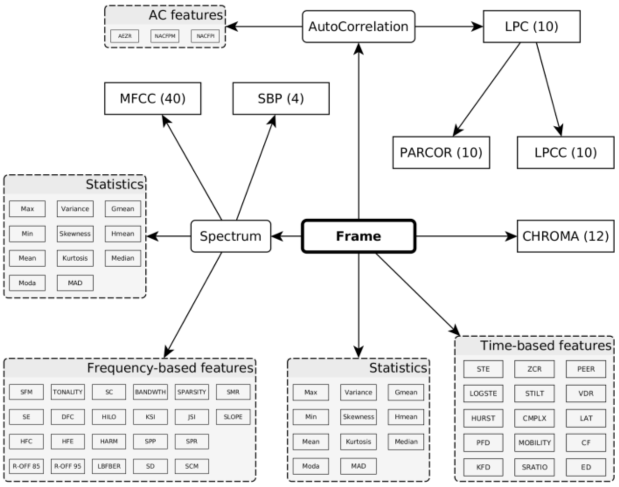

Fig. 2. Diagram of low-level audio features dependencies
Rys. 2. Diagram zależności między niskopoziomowymi cechami akustycznymi

However, the amount of sent data varies from the number of bytes equal to the frame length (e.g., 1024 bytes) to 3 bytes generated by AC Features block. Thus it would be a waste of bandwidth to assign the same throughput to each core. Moreover, since all the transfers are known a priori, we can assign the appropriate time slices statically and not use the centralized router, as suggested in [2]. This way we decrease the number of the required codes to 3. (Notice, that in other cases it may be even beneficial to assign two orthogonal codes to senders generating particular large amount of data.) Since all but Frame and AutoCorrelation blocks generate 626 bytes together, they can share the same code and transmit in different time slots (but even in this situation we waste 13% of the total link bandwidths). The additional requirement that the cores have to determine the time they are allowed to transmit possess almost no additional overhead, as strict synchronisation is a key property of CDMA in general.

Having assigned the codes to the sending cores, we used Xilinx ISE to perform an implementation of the coders and decoders in Virtex5 FPGA device (XC5VSX50T, Virtex 5 ML506 Evaluation Platform). Consistent with our expectations, the resource utilization, presented in Tab. 1, is rather low.

Tab. 1. Resource requirements of basic CDMA transmission blocks
Tab. 1. Zasoby wykorzystywane przez podstawowe bloki transmisji CDMA

Block	FF Used	LUT Used
Encoder	53	85
Decoder	73	105

The CDMA transmission in the proposed form is also quite fast. Despite a number of trials, we measured no difference in speed between the bit transmission with and without CDMA coding.

Having said this, the usage of CDMA in NoC is questionable. In [2, 8], a number of advantages (and drawbacks) in comparison with a typical wormhole-based NoC has been enumerated. In our view, however, these differences stem mainly with the simple fact of using common media. To make a fair comparison, it is necessary to show differences with a typical bus. We decided to make a brief comparison. There is no (small) resource usage overhead connected with encoding and decoding and the bit transmission time is in both situations the same. The amount of bits to be transmitted is different. Due to the properties of the spreading code, we need 131072 bits to transmit for the frame length of 1024 bytes and 262144 for two times longer frame, whereas these values equal 8192 and 16384 bits for a regular bus.

Even if we assume the maximal utilization of such NoC CDMA link bandwidth and multiplex at no additional cost data from 4 different sources, we still obtain 65536 bits per source (for 1024 bytes frame length), which is still 8 times worse than the most typical bus connection.

In both cases a global clock is needed, and some central routing or (in our case) statically assigned time slots is required. An alternative using micropipelines for introducing asynchrony from [2] is known to be costly in terms of required synchronization logic [7]. The main benefit of CDMA used in, e.g., cellular phones, namely, sharing the same frequencies for independent communication channels [9], is not applicable in wired digital transmission. Summarizing, despite the low cost of implementing CDMA in the NoC, the authors did not observe any benefit over traditional, bus-based transmission.

4. Conclusions

The CDMA is a channel multiplexing technique which does not require bandwidth allocation. It allows us to send a number of independent data through a common media without interfering by using orthogonal codes. What is beneficial in wireless transmission is rather not useful in wired NoC transmission. The (measured) low area overhead and higher number of transmitted bits do not seem to lead to any benefits over traditional, bus-based transmission. The global synchrony requirement and, in some cases, global routing, can be viewed as leading to the problem with the scalability. The CDMA-based NoCs, in the form described in this paper and in the cited literature, is in the view of the authors not beneficial enough to be further analysed. Thus in our future work we do not plan to investigate it any more, and continue our earlier work with wormhole-switched NoCs.

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5. References

[1] Bjerregaard T., Mahadevan S.: A survey of research and practices of Network-on-chip, ACM Computing Surveys (CSUR) archive, Vol. 38, Issue 1, 2006.

[2] Wang X., Ahonen T. and Nurmi J.: Applying CDMA Technique to Network-on-Chip, IEEE Transactions On Very Large Scale Integration (VLSI) Systems, Vol 15,No.10,Oct 2007, pp.1091-1100.

[3] Kim D., Kim M. and Sobelman G. E.: CDMA-Based Network-on-Chip Architecture, IEEE Asia Pacific Conference on Circuits and Systems, pp. 137-140, 2004.

[4] Viterbi A. J.: CDMA - Principles of Spread Spectrum Communication, Addison-Wesley Publishing Company, 1995.

[5] Impulse Accelerated Technologies, Accelerating HPC and HPEC Applications Using Impulse C, Reconfigurable Systems Summer Institute (RSSI), Urbana, IL, July 17-20, 2007.

[6] Maka T., Dziurzanski P.: Parallel Audio Features Extraction for Sound Indexing and Retrieval Systems, ELMAR, 2013 55th International Symposium, pp. 185-189, 25-27 September 2013.

[7] Sutherland I. E.: Micropipelines, Communications of the ACM, v.32 n.6, p.720-738, June 1989.

[8] Kim M., Kim D. and Sobelman G.E.: MPEG-4 Performance Analysis for a CDMA Network-on-Chip, International Conference on Communications, Circuits and Systems (ICCCAS'2005), 27-30 May, 2005.

[9] Ipatov V. P.: Spread Spectrum and CDMA - Principles and Applications, John Wiley & Sons, Ltd., 2005.

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