Optical Fiber Technology 20 (2014) 228–234

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Wavelength assignment for locally twisted cube communication pattern on optical bus network-on-chip

Jing Zhang [a], Xiaofan Yang [a,b,*], Xianyong Li [a]

[a] College of Computer Science, Chongqing University, Chongqing 400044, PR China
[b] School of Electronic and Information Engineering, Southwest University, Chongqing 400715, PR China

ARTICLE INFO

Article history:
Received 13 November 2013
Revised 13 January 2014
Available online 1 March 2014

Keywords:
Optical network-on-chip
Locally twisted cube
Global bus
Routing and wavelength assignment
Congestion

ABSTRACT

Optical network-on-chip (NoC) is a new designing of Multi-Processor System-on-Chip (MPSoC). Global bus is the simplest logical topology of optical NoC. Static routing and wavelength assignment is one important communication mechanism of optical NoC. This paper addresses the routing and wavelength assignment (RWA) problem for locally twisted cube communication pattern on global bus optical NoC. For that purpose, a routing scheme, that is an embedding scheme, is proposed, and a wavelength assignment scheme under the embedding scheme is designed. The number of required wavelengths is shown to attain the minimum, guaranteeing the optimality of the proposed scheme.

1. Introduction

With the development of Multi-Processor System-on-Chip (MPSoC), current electronic network-on-chip (NoC) designs face serious challenges, such as bandwidth, latency and power consumption. Recently, optical network-on-chip (NoC) approach has been proposed as promising technique to overcome this bottleneck [2,11–13,19]. Selecting a logical network topology is very important in designing of optical NoC. Several topologies, such as bus, crossbar, butterfly and torus topologies, have been proposed [2]. In this paper, we address the wavelength assignment problem in optical NoC with bus topology. A global bus is perhaps the simplest of logical topology, and involves N terminals and an optical bus (see Fig. 1). One of the terminals arbitrates whether the optical bus is leisure so that it can communicate with other $N-1$ terminals. However, using the arbitral optical bus often limits the performance due to practical constraints on bus bandwidth and arbitration latency as the number of network terminals increases. Then wavelength division multiplexing (WDM) technique provides an approach to enhancing the performance of optical bus.

Wavelength division multiplexing technique divides the bandwidth of an optical fiber into multiple communication channels represented by their respective wavelengths. Then a multiplicity of different data streams can be transmitted simultaneously across a same optical fiber. Because the wavelength resource is restricted and the current WDM technology has already allowed about sixty wavelengths per fiber. The routing and wavelength assignment (RWA) problem is very important in optical NoC. In recent years, the RWA problem has been studied for various combinations of communication pattern and optical network [3–5,20,21]. This paper proposes a static routing and wavelength assignment scheme for locally twisted cube (LTQ) communication pattern on global bus optical NoC. In order to facilitate the research, the global bus can be expressed as a linear array graph (see Fig. 2). In the linear array, nodes and edges represent the processors and the shared bus respectively.

Mainly due to smaller diameter (nearly half that of hypercube of the same size), locally twisted cube has been studied by many researchers [7–10,14,15,17]. Indeed, quite a number of algorithms have been designed based on locally twisted cube [8,10,15,18]. To execute an algorithm developed for LTQ on linear array topology, it is crucial to solve the corresponding routing and wavelength assignment (RWA) problem, i.e., that of finding all source–destination paths in the LTQ and assigning appropriate wavelengths to these paths so that the total number of wavelengths is minimized. For this purpose, an embedding scheme having the minimum congestion called the optimal embedding scheme is proposed in this paper. The embedding scheme maps each node and edge of LTQ onto a node and path of linear array respectively. In order to gauge the congestion of an embedding scheme and prove the optimality, a maximum m-induced subgraph of LTQ will be proposed firstly. Based on this, an optimal wavelength assignment is proposed.

* Corresponding author at: College of Computer Science, Chongqing University, Chongqing 400044, PR China.
E-mail addresses: zhangjing455@163.com (J. Zhang), cqu2010lab@gmail.com (X. Yang).

http://dx.doi.org/10.1016/j.yofte.2014.02.002
1068-5200/© 2014 Elsevier Inc. All rights reserved.

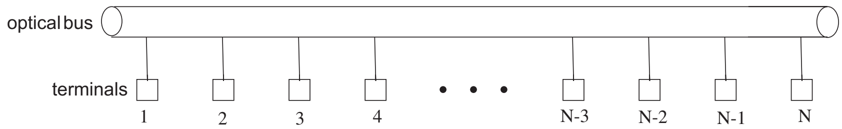

Fig. 1. The global bus with N terminals.

Fig. 2. Linear array with N nodes.

The remainder of this paper is organized in this fashion: Section 2 describes some terminologies and preliminaries. Section 3 determines the maximum m-induced subgraph of LTQ. Section 4 is devoted to the congestion of a LTQ embedding into linear array. In Section 5, the wavelength assignment schemes, together with their optimality proofs, are described. Finally, Section 6 summarizes this work.

2. Preliminary

2.1. Locally twisted cube

Let $\{0,1\}^n$ denote the set of all 0, 1 binary strings of length n. Let 0^n (resp. 1^n) denote a string consisting of n 0s (resp. n 1s). For two binary strings x and $y \in \{0,1\}^n$, let $x+y$ denote the (bitwise modulo 2) sum of x and y. For $x=(x_{n-1},x_{n-2},\dots,x_0)\in\{0,1\}^n, x_0$ is called the zero bit of x, x_1 is called the first bit, etc.

Definition 2.1 [17]. For $n \geqslant 2$, an n-dimensional locally twisted cube, LTQ_n, is defined recursively as follows:

(1) LTQ_2 is a graph consisting of four nodes labeled with 00, 01, 10, and 11, respectively, connected by four edges {00, 01}, {01, 11}, {11, 10}, and {10, 00}.
(2) For $n \geqslant 3$, LTQ_n is built from two disjoint copies of LTQ_{n-1} according to the following steps: Let LTQ^0_{n-1} denote the graph obtained from one copy of LTQ_{n-1} by prefixing the label of each node with 0. Let LTQ^1_{n-1} denote the graph obtained from the other copy of LTQ_{n-1} by prefixing the label of each node with 1. Connect each node $(0,x_{n-2},x_{n-3},\dots,x_0)$ of LTQ^0_{n-1} to the node $(1,x_{n-2}+x_0,x_{n-3},\dots,x_0)$ of LTQ^1_{n-1} with an edge.

Fig. 3 shows two examples of locally twisted cubes.

Lemma 2.1 [17]. *Two nodes $x=(x_{n-1},x_{n-2},\dots,x_0)$ and $y=(y_{n-1},y_{n-2},\dots,y_0)$ of LTQ_n are adjacent if and only if either (a) $x_k=\overline{y_k}$ and $x_{k-1}=y_{k-1}+x_0$ for some $3\leqslant k\leqslant n-1$, and $x_r=y_r$ for all the remaining bits or (b) $x_k=\overline{y_k}$ for some $k\in\{0,1\}$, and $x_r=y_r$ for all the remaining bits.*

LTQ_n is obviously an n-regular graph, and the labels of any two adjacent nodes of LTQ_n differ in at most two successive bits.

A *d-dimensional* edge, or simply d-edge, of LTQ_n is an edge (u,v) such that the labels of u and v are repugnant at bit d but are unanimous at all previous bits. In this case, v is called the *d-neighbor* of u, denoted $v=N_d(u)$. Let DIM_d denote the set of all d-edges of LTQ_n. Then, $E(LTQ_n)=\bigcup_{d=0}^{n-1}DIM_d$.

2.2. Induced subgraph

In this paper, we use $V(G)$ and $E(G)$ to denote the node set and edge set of graph G, respectively. For a node subset S, the subgraph of G induced by S, denoted by $G[S]$, is a graph with node set S and all the edges of G with both nodes in S. Let $\xi(S)$ denote the number of edges of $G[S]$. For a pair of disjoint node subset S_1 and S_2 of graph G, let $\xi(S_1,S_2)$ denote the number of edges with one node in S_1 and the other node in S_2.

Definition 2.2. An m-induced subgraph of a graph is one that is induced by m nodes. A maximum m-induced subgraph of a graph is one that has the maximum number of edges. Let $max\_\xi_G(m)$ denote the maximum number of edges in an m-induced subgraph of graph G. Then $max\_\xi_G(m)=\max_{S\subseteq V(G),|S|=m}\xi(S)$.

For the purpose of calculating the $max\_\xi_G(m)$, the following definition is most useful. Any nonnegative integer m can be uniquely written as $m=\sum_{i=0}^{r}2^{p_i}$, where $p_0>p_1>p_2>\dots>p_r\geqslant 0$. Abdel-Ghaffar [1] defined a function

$$f(m)=\sum_{i=0}^{r}\left(\frac{p_i}{2}+i\right)2^{p_i},$$

and proved that this function satisfies the following properties.

For a given positive integer m, we define $k=\lfloor log_2 m\rfloor$ and $m'=m-2^k$. Obviously, $2^k\leqslant m<2^{k+1}$ and $0\leqslant m'<m/2$.

Proposition 2.1 [1]. *Let m be a positive integer. Then,*

$$f(m)=k2^{k-1}+f(m')+m'=f(2^k)+f(m')+m'.$$

Proposition 2.2 [1]. *For any positive integers m_1 and m_2, we have*

$$f(m_1+m_2)\geqslant f(m_1)+f(m_2)+min\{m_1,m_2\}.$$

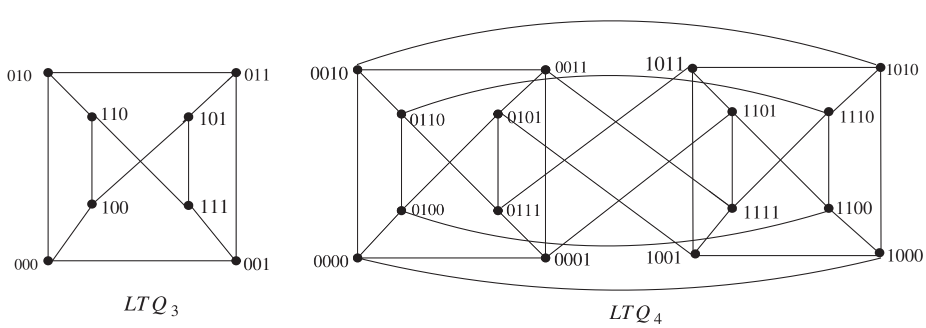

Fig. 3. LTQ_3 and LTQ_4.