A FEASIBILITY STUDY OF THE LARPBS OPTICAL BUS MODEL

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THESIS

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Abstract

Parallel processing systems require interconnections capable of handling high data rates in order to satisfy the communication demands of applications. The data rates that electrical data buses can handle may not be sufficient for some types of data interactive applications. Optical technologies have been proposed to address this limitation of electrical bus systems. During the past decade, several optical bus parallel models have been proposed. This thesis evaluates the practical nature of such optical bus models. Specifically, this thesis reports on optical power and signal loss in the Linear Array with a Reconfigurable Pipelined Bus System (LARPBS). A model that assists the calculation of signal losses in the LARPBS is presented together with four case studies. A straightforward implementation of the bus model suggests high losses that limit the number of processors supported. Nevertheless, this work also suggests that variations in the architecture may lead to more practical parallel systems.

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Chapter 1

Introduction

Parallel computing has emerged as a solution to the need of solving large computable problems in a shorter and more reasonable amount of time. Problems are divided into smaller parts which are expected to be easier to solve. These smaller parts are distributed among the various processing units within a parallel computing system. Each processor computes its part of the problem and communicates its corresponding partial result as needed. Hence, communication and computation are the two most important architectural factors in the performance of any parallel computing system.

Communication in parallel computing systems is achieved via the connections between the different processing units. These interconnection networks have a number of properties. Some of the most important properties are topology, diameter, size, and scale. Topology refers to the different formations an interconnection network may have where the interconnections are the edges and the processors are the nodes. For example, an interconnection network may be a linear array, a ring, a mesh, or a cube. The diameter is the longest of the minimum paths between processors. The size is measured by the number of processors in the system. The scale refers to the physical size of the system.

Traditionally, interconnection networks have used metal conductors that carry electrical signals. Some metals are better conductors than others. In semiconductor circuits for example, using copper instead of aluminum as metal interconnections increases the communication speed due to the lower resistivity of copper. However, one of the drawbacks is that, as both the size and processing speeds increase, such electrical interconnections limit the communication performance and bandwidth due to the inherent physical limitations of electrical signals in metal conductors [1]. One of the characteristics of electrical conductors that limit bandwidth is a phenomenon called skin effect. Skin effect produces distortion as the frequency of the electrical signal increases, in other words, the higher the frequency, the lower the bandwidth.

Optical interconnections have been proposed to address the drawbacks of and add enhancements over electrical interconnection networks. In addition, optical interconnections promise high bandwidth [1, 2]. Light possesses characteristics such as unidirectional propagation and predictable propagation delay per unit length [2, 3] which are convenient for a high performance communication. For example, for a signal in an optical fiber, very precise delays (in the order of picoseconds per millimeter) can be calculated. Optical interconnections can be one of two basic types: free space interconnects, or wave-guided interconnects. The former utilizes free space (e.g. air) as the transmission medium while the later uses waveguides (e.g. optical fibers) to constrain the path of the optical signal.

Optical interconnections have been significantly utilized in telecommunications [4], in Wide Area Networks (WAN) [5, 3], and in Metropolitan Area Networks (MAN) [5]. The majority of these systems are based on wave-guided interconnects. Also, some commercial standards have integrated optical interconnections in Local Area Networks (LAN) [5]. However, in parallel systems, the practical implementation of optical interconnections is more limited. One kind of optical interconnection that has gained acceptance for parallel models is the optical bus network. Several optical bus parallel

models have already been proposed. Most of the wave-guided optical bus models that have been proposed consist of linear or multidimensional arrays of processors; linear arrays appear to be the most common. There are a number of variations in these models, for example, the number of waveguides and the reconfigurability of the network. Reconfigurability refers to the property of partitioning a single global bus into sub-buses where each group of processors can use an independent bus system.

The optical bus model of interest in this thesis is the LARPBS (Linear Array with a Reconfigurable Pipelined Bus System), proposed in 1996 [6]. This is one of the most popular models in the literature. It is believed to be realizable with current technology [3]. However, this evaluation is based on a decade-old systems study. In this thesis, a study based on current optical technology is performed on the LARPBS model. In particular, an estimation of signal loss, power budget, and maximum number of processors is performed.

Optical technology is in a rapid state of evolution. New technology and devices are being developed, the position in this thesis is to consider current technology that is suitable for optical buses, such as the LARPBS, and try to answer the question: is this system feasible using current technology?

1.1 Motivation

In the course of a literature research it was found that a large number of studies support the idea that eventually optical interconnections will replace their electrical counterparts. One reason found is that with the rapid increase in processing speeds, electrical interconnects are becoming insufficient to satisfy the required communication speeds.

Extensive theoretical studies, such as the design of algorithms and communication techniques, have been performed on the different models of optical buses that have

been proposed, under the assumption that these models will be a reality any time soon. For example, in [3], the authors claim: "we believe that the LARPBS model is implementable and practical using current optical technology". The motivation for this thesis is this statement, together with the lack of studies related to the feasibility of optical buses, specifically, the LARPBS model.

The previous statement on the LARPBS model and the general expectations on optical buses (high speed, low power consumption, and the potential for a large number of processors in the system [4]), suggest some questions:

- What kind of current optical technology, if any, is appropriate for the implementation of this model?
- How much power is required to drive a LARPBS optical bus system?
- How many processors could be accommodated?
- How fast the data transmission would be?

The goal of this thesis is to answer these questions and provide information that can lead to further studies of the practical implementation of the LARPBS and similar optical bus models.

1.2 Contributions of the Thesis

Fiber optics has a vast potential in the field of communications technology that has already been applied to systems of large scale, such as telecommunication networks, with outstanding results. The same potential is being focused with more occurrences on systems of small scale.

In an attempt to know whether the potential of fiber optics technology can be used in the implementation of the LARPBS model, this thesis makes the following contributions:

- A survey of current optical devices and technology.
- The identification and selection of optical devices suitable for the implementation of a LARPBS optical bus.
- A signal loss analysis on the LARPBS that provides a formula to calculate the total system loss;
- A model that supports the calculation of power budget, total system loss, optimum splitting ratio, and number of processors supported;
- Four case studies that help to understand how a LARPBS system behaves in terms of signal losses when different input powers are used.
- Estimation of the data rates for the LARPBS model.

1.3 Thesis Organization

Chapter 2 presents some wave-guided-based optical buses that have been proposed in the literature, the definition of the LARPBS model, and a previous work related to the feasibility of an optical bus. Chapter 3 describes fiber optics, optical devices available in the market, and optical technologies. Chapter 4 presents a feasibility study on the LARPBS optical bus model. Chapter 5 presents the conclusions.

Chapter 2

Optical Buses

The sections of this chapter include background information related to optical buses. First, a survey of different optical buses that have been proposed in the literature and their general characteristics is presented in Section 2.1. Next, a detailed description of the LARPBS is given in Section 2.2. Subsection 2.2.1 explains the Coincident Pulse Technique: this is the most common processor addressing technique applicable to different bus models of three waveguides. Particular emphasis is made on how it applies to the LARPBS. Section 2.3 discusses information on a previous study related to the feasibility of an optical bus.

Wave-guided optical buses use optical fibers instead of electrical wiring to connect the electronic processors in the system. They make use of two special characteristics of light: unidirectional propagation and predictable propagation delay per unit length [2, 3]. These two characteristics allow all the processors in the system to have a synchronized and concurrent access to the bus in a pipelined mode [4].

Many algorithms that perform basic and advanced operations on the different optical bus models have been proposed and studied [7, 8, 9, 10, 11, 12, 6, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25] and have shown that the time complexities of

some operations are smaller than those in electrical buses [2, 3, 26].

Optical buses may differ in the number of waveguides and their configuration. They differ also, in the way the processors access the waveguides for purposes of writing to and reading from. Some configurations consist of a linear array of processors connected by one or more waveguides. Multidimensional arrays can be formed as well. Reconfigurability is another characteristic of some of the proposed systems.

Some of the optical bus models that have been proposed in the literature are: array with pipelined buses(APPB and APPBS) [27], reconfigurable array with spanning optical buses(RASOB) [28], array with reconfigurable optical buses(AROB) [29], pipelined asynchronous time division multiplexing optical bus(POB) [30], array with pipelined optical bus(APOB) [31], array with synchronous optical switches(ASOS) [32], linear array with a reconfigurable pipelined bus system(LARPBS) [6], and linear pipelined bus(LPB) [33].

Some of these optical bus models are further discussed in Section 2.1 to provide a general idea of the different configurations that can be constructed. Only basic details on communication and processor addressing are given.

2.1 Survey of Wave-guided Optical Buses

2.1.1 Unidirectional Buses

A typical unidirectional optical bus system, as represented in Figure 2.1, is composed of a set of n processors, P_0 to P_{n-1}, an optical bus denoted by a horizontal arrow, and n readers/writers represented by the vertical lines. Communication between processors is carried out via messages that travel only in one direction on the bus; in this case, messages are sent from low numbered to high numbered processors. This means that, in unidirectional buses, communication is not possible from any processor

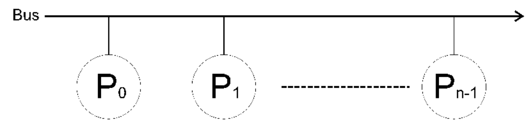

Figure 2.1: Unidirectional bus with one waveguide

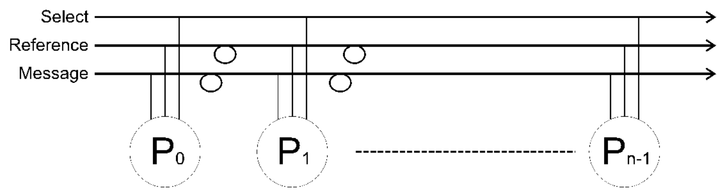

Figure 2.2: Unidirectional bus with three waveguides

on the right to any other processor on the left.

In an optical bus system, every processor is evenly distanced from the subsequent ones, and a transmitted signal takes a fixed time, t, to travel from one processor to the next one, this is, obeying the property of light of constant propagation time per unit length. Therefore, any signal traveling from P_0 to P_2 will take a time of $2t$, and a time of $3t$ if traveling from P_1 to P_4. A cycle time for a unidirectional bus system with n processors is then close to nt where each cycle is composed by n time slots of size t. For this model, it is assumed that every processor can write to only one slot in a cycle and can read from only one slot per cycle.

Another variation of unidirectional buses is the one represented in Figure 2.2 which makes use of three waveguides. One of them, called message waveguide, is used for message transmission and the other two, select and reference, are utilized for processor addressing. Two processor addressing techniques commonly used in algorithms for this type of buses are time division multiplexing [4] and the coincident pulse technique described in Section 2.2.1. The main drawback of unidirectional buses is the impossibility of a two-way communication among processors.

2.1.2 One-Dimensional Array with Pipelined Buses

A one dimensional array with pipelined buses also known as 1D APPB, allows communication between all the processors within the system due to the double bus configuration where each bus transmits messages in a different direction. This type of bus is depicted in Figure 2.3. The upper segment of the system transmits messages from lower numbered processors to the higher numbered ones, that is from left to right, while the lower segment transmits messages in the opposite direction, from higher numbered processors to lower numbered ones. This model has the advantage over the unidirectional buses, it allows a bi-directional communication among the processors. In this model, processors write to and read from both upper and lower segments. This characteristic is a relevant drawback for this model because two readers/writers are required per processor.

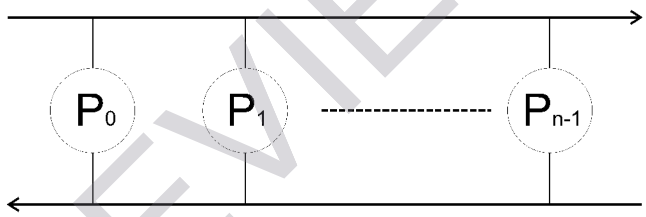

Figure 2.3: One Dimensional Array with Pipelined Buses (1D APPB)

2.1.3 A Folded One-Dimensional Array Bus

Another one-dimensional model is the folded one-dimensional bus, illustrated in Figure 2.4. This configuration allows intercommunication among all the processors in the system with a single waveguide. Processors write messages to the upper segment of the bus system and read them from the lower segment. Only one writer and one reader are required per processor, which is an advantage over the 1D APPB model