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Performance analysis of efficient multipath crossbars

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Abstract

This paper presents a comprehensive analysis of high-performance crossbars where crossbars can be asymmetrical in size, buffered at all crosspoints, and capable of multipath routing. A crossbar, as a building block of switching networks, with the mentioned features in its structure can demonstrate fault-tolerant property. This property is a major factor for crossbars to play the role of high-performance entity in modern computer and communication systems. A generic condition of $n \times k$ crossbar with n inputs (rows), k columns, and n outputs (rows) under which a crossbar becomes multipath is examined. In a multipath crossbar a packet can be routed through k different paths to an output. The multipath feature ensures the property of fault-tolerance and provides a faster congestion resolution especially under the multicast traffic. This paper describes a two-dimensional Markov chain associated with the queueing model, and presents the performance evaluation of crossbars.

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1. Introduction

As the high-speed networks are destined to play an increasingly important role in the new communication networking, there is a growing concern in identifying suitable switching architectures capable of handling high-rate traffic. The capability of multicasting traffic [9] is a fundamental factor for example. Switching systems must be able to multicast a message to many users and even route many messages to one user. In the multimedia environment, traditional networks are subject to severe blocking since they are not typically designed for high bandwidth communications. Under this condition, the performance of switching networks closely relies on the network architecture. The efficiency also depends on how fast networks can transfer the traffic. The inclusion of all of the new features into modern switching systems requires considerable sophistication in the architecture. Simplistic approaches can fail to meet required performance or cost objectives.

Crossbars are the building blocks of switching systems [2,6]. Conventional unipath and symmetrical crossbars are vulnerable to faults. There have been a number of papers in the literature [1,9,13] analyzing modern networks taking into account the efficiency of crossbar switches. There are also several papers [7] that compare the switching systems from different perspectives, providing a comprehensive survey of different systems. A number of different factors can be used to characterize switching systems, including buffering, capability of multipoint connections, speed, performance, cost, reliability, fault-tolerance, and scalability. The growing demand for large-scale switching networks and the increase of traffic volume call for reliable, high-speed, and low-cost fabrics. The performance of switching networks closely relies on the crossbar efficiency and fault-tolerance. This paper evaluates the performance of crossbar switches when they are multipath, fault-tolerance, non-symmetrical in dimension, multicast, and buffered.

This paper is organized as follows. In Section 2, the crossbar structure and routing and multicast techniques are introduced. Section 3 presents an analytical queueing model and uses it to evaluate the performance of the network. In this section, the results of performance evaluation are also presented and discussed.

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2. Multipath structure of crossbars

A fault-tolerant multipath crossbar is considered in this paper to reduce the probability of disconnection due to faults between each pair of input/output ports. With the increased interest in finding high-performance switches among switch manufacturer, the use of multichip module (MCM), system-on-chip (SoC), or other similar technologies are drawing special attention. The presented crossbar architecture in this paper aims satisfaction of such industry need. In general, conventional $n \times n$ crossbars are vulnerable to faults. The multipath crossbar network is a crossbar with n rows and k columns. Each row contains an input bus and an output bus. A packet being transferred from an input i to an output j is sent by input port processor i on input bus i to one of the k columns. It then passes along this column to the output bus in row j . The crosspoints that make up the multipath crossbar network include mechanisms that allow the inputs to contend for access to the different columns. The crosspoint buffers in one row act as a distributed output buffer for the corresponding output port. As shown in Fig. 1, in every crosspoint there are two different switches and a buffer.

Unlike a conventional crossbar, there are k different paths in the MC network to establish a connection between a particular pair of input and output ports. The network also has the capability to connect any input i to all or any subset of outputs. Now, consider a case of point-to-point connection between input i_1 to output a_1 . The packet is first randomly sent to a crosspoint at one of the k shared data buses, say column $(j - 2)$. In case the crosspoint on this bus is not available for any reason, another crosspoint selected at random is examined and so on. The reason for randomizing the initial location is to distribute the traffic as evenly as possible. When a functioning crosspoint (crosspoint 3) at column j is selected, the packet can be sent to a second

crosspoint (crosspoint 4) at this column, unless the selected crosspoint is found to be faulty or its buffer is full. The packet is buffered in crosspoint 4 and can be sent out after a contention resolution process in its row. In the case of multicast connections, as will be described later, the packet recycling technique [11] in which a multicast connection is converted to several *bicast* connections implemented one at a time within the network is used. Assume a packet at input i_1 is to be copied to a set of two outputs $p = \{a_1, a_2\}$ (Fig. 1). A bicast connection is treated as two independent point-to-point connections. In other words, sequential transmission of two packets is carried out recursively and independently. Since a selected crosspoint is not always available, any unfinished connection may be completed on another randomly selected column such as $(j + 1)$.

The availability of each crosspoint at a given node (i, j) is dynamically reported to the input ports by a flag. If more than one input port requests a given column, based on a contention resolution process, only one of them can use the column. Packets in the other input ports receive higher priorities to examine other columns. Obviously, the more the packet receives priority increments, the sooner it is granted one free column that it selects randomly. Once the packet gets accepted by one of the β buffers of a second crosspoint, it contends to get access to its corresponding output. The losers of the contention resolution get higher priorities for the next contention cycle until they are successfully transmitted. In Fig. 1, the connections $i_1 \rightarrow a_1$ and $i_1 \rightarrow a_2$ are made possible through nodes $\{2,4\}$ and nodes $\{3,6\}$, respectively.

2.1. Fault-tolerance

The structure of the network allows the induction of a simple bypassing method for the faulty crosspoints. With the mentioned system configuration, faulty modules do not

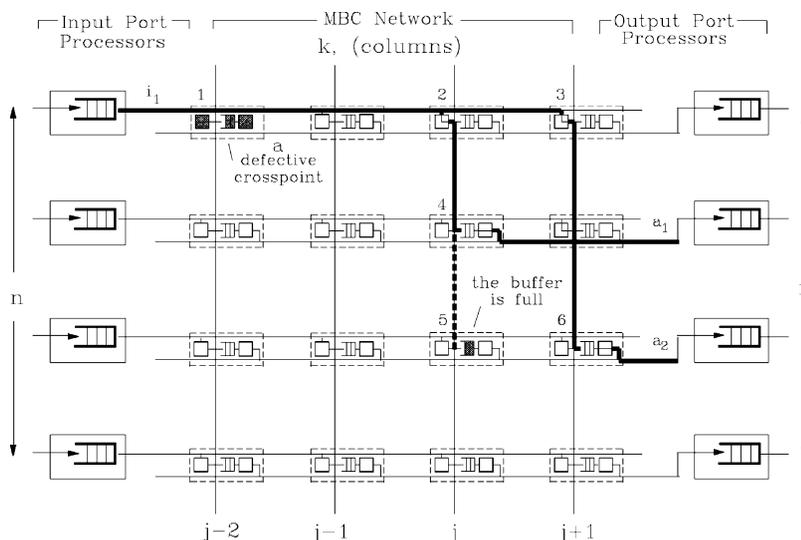


Fig. 1. A multipath crossbar ($n = k = 4$) and its routing.

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