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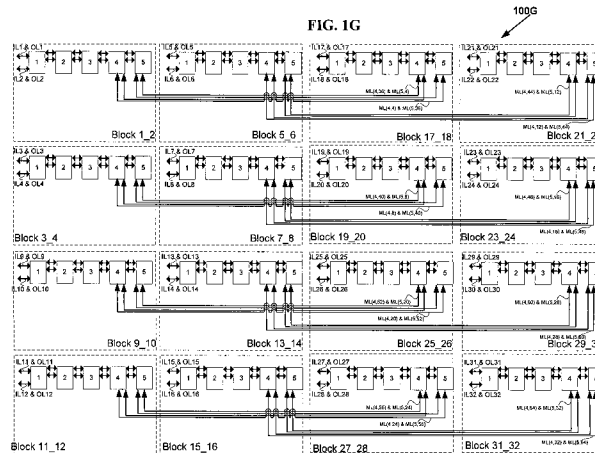
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(54) Title: VLSI LAYOUTS OF FULLY CONNECTED GENERALIZED NETWORKS



(57) Abstract: In accordance with the invention, VLSI layouts of generalized multi-stage networks for broadcast, unicast and multicast connections are presented using only horizontal and vertical links. The VLSI layouts employ shuffle exchange links where outlet links of cross links from switches in a stage in one sub-integrated circuit block are connected to inlet links of switches in the succeeding stage in another sub-integrated circuit block so that said cross links are either vertical links or horizontal and vice versa. In one embodiment the sub-integrated circuit blocks are arranged in a hypercube arrangement in a two-dimensional plane. The VLSI layouts exploit the benefits of significantly lower cross points, lower signal latency, lower power and full connectivity with significantly fast compilation.

WO 2008/147928 A1

VLSI LAYOUTS OF FULLY CONNECTED GENERALIZED NETWORKS

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5 CROSS REFERENCE TO RELATED APPLICATIONS

This application is Continuation In Part PCT Application to and incorporates by reference in its entirety the U.S. Provisional Patent Application Serial No. 60/940, 394 entitled "VLSI LAYOUTS OF FULLY CONNECTED GENERALIZED NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed May 25,
10 2007.

This application is related to and incorporates by reference in its entirety the PCT Application Serial No. PCT/US08/56064 entitled "FULLY CONNECTED GENERALIZED MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed March 6, 2008, the U.S. Provisional Patent
15 Application Serial No. 60/905,526 entitled "LARGE SCALE CROSSPOINT REDUCTION WITH NONBLOCKING UNICAST & MULTICAST IN ARBITRARILY LARGE MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed March 6, 2007, and the U.S. Provisional Patent Application Serial No. 60/940, 383 entitled "FULLY CONNECTED
20 GENERALIZED MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed May 25, 2007.

This application is related to and incorporates by reference in its entirety the PCT Application Docket No. S-0038PCT entitled "FULLY CONNECTED GENERALIZED BUTTERFLY FAT TREE NETWORKS" by Venkat Konda assigned to the same
25 assignee as the current application, filed concurrently, the U.S. Provisional Patent Application Serial No. 60/940, 387 entitled "FULLY CONNECTED GENERALIZED BUTTERFLY FAT TREE NETWORKS" by Venkat Konda assigned to the same

assignee as the current application, filed May 25, 2007, and the U.S. Provisional Patent Application Serial No. 60/940, 390 entitled "FULLY CONNECTED GENERALIZED MULTI-LINK BUTTERFLY FAT TREE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed May 25, 2007

5 This application is related to and incorporates by reference in its entirety the PCT Application Docket No. S-0039PCT entitled "FULLY CONNECTED GENERALIZED MULTI-LINK MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently, the U.S. Provisional Patent Application Serial No. 60/940, 389 entitled "FULLY CONNECTED GENERALIZED
10 REARRANGEABLY NONBLOCKING MULTI-LINK MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed May 25, 2007, the U.S. Provisional Patent Application Serial No. 60/940, 391 entitled "FULLY CONNECTED GENERALIZED FOLDED MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed May 25, 2007 and
15 the U.S. Provisional Patent Application Serial No. 60/940, 392 entitled "FULLY CONNECTED GENERALIZED STRICTLY NONBLOCKING MULTI-LINK MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed May 25, 2007.

 This application is related to and incorporates by reference in its entirety the U.S.
20 Provisional Patent Application Serial No. 60/984, 724 entitled "VLSI LAYOUTS OF FULLY CONNECTED NETWORKS WITH LOCALITY EXPLOITATION" by Venkat Konda assigned to the same assignee as the current application, filed November 2, 2007.

 This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Serial No. 61/018, 494 entitled "VLSI LAYOUTS OF
25 FULLY CONNECTED GENERALIZED AND PYRAMID NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed January 1, 2008.

BACKGROUND OF INVENTION

Multi-stage interconnection networks such as Benes networks and butterfly fat tree networks are widely useful in telecommunications, parallel and distributed computing. However VLSI layouts, known in the prior art, of these interconnection
5 networks in an integrated circuit are inefficient and complicated.

Other multi-stage interconnection networks including butterfly fat tree networks, Banyan networks, Batcher-Banyan networks, Baseline networks, Delta networks, Omega networks and Flip networks have been widely studied particularly for self routing packet switching applications. Also Benes Networks with radix of two have been widely studied
10 and it is known that Benes Networks of radix two are shown to be built with back to back baseline networks which are rearrangeably nonblocking for unicast connections.

The most commonly used VLSI layout in an integrated circuit is based on a two-dimensional grid model comprising only horizontal and vertical tracks. An intuitive interconnection network that utilizes two-dimensional grid model is 2D Mesh Network
15 and its variations such as segmented mesh networks. Hence routing networks used in VLSI layouts are typically 2D mesh networks and its variations. However Mesh Networks require large scale cross points typically with a growth rate of $O(N^2)$ where N is the number of computing elements, ports, or logic elements depending on the application.

20 Multi-stage interconnection with a growth rate of $O(N \times \log N)$ requires significantly small number of cross points. U.S. Patent 6,185,220 entitled "Grid Layouts of Switching and Sorting Networks" granted to Muthukrishnan et al. describes a VLSI layout using existing VLSI grid model for Benes and Butterfly networks. U.S. Patent 6,940,308 entitled "Interconnection Network for a Field Programmable Gate Array"
25 granted to Wong describes a VLSI layout where switches belonging to lower stage of Benes Network are layed out close to the logic cells and switches belonging to higher stages are layed out towards the center of the layout.

Due to the inefficient and in some cases impractical VLSI layout of Benes and butterfly fat tree networks on a semiconductor chip, today mesh networks and segmented mesh networks are widely used in the practical applications such as field programmable gate arrays (FPGAs), programmable logic devices (PLDs), and parallel computing interconnects. The prior art VLSI layouts of Benes and butterfly fat tree networks and VLSI layouts of mesh networks and segmented mesh networks require large area to implement the switches on the chip, large number of wires, longer wires, with increased power consumption, increased latency of the signals which effect the maximum clock speed of operation. Some networks may not even be implemented practically on a chip due to the lack of efficient layouts.

SUMMARY OF INVENTION

When large scale sub-integrated circuit blocks with inlet and outlet links are layed out in an integrated circuit device in a two-dimensional grid arrangement, (for example in an FPGA where the sub-integrated circuit blocks are Lookup Tables) the most intuitive routing network is a network that uses horizontal and vertical links only (the most often used such a network is one of the variations of a 2D Mesh network). A direct embedding of a generalized multi-stage network on to a 2D Mesh network is neither simple nor efficient.

In accordance with the invention, VLSI layouts of generalized multi-stage networks for broadcast, unicast and multicast connections are presented using only horizontal and vertical links. The VLSI layouts employ shuffle exchange links where outlet links of cross links from switches in a stage in one sub-integrated circuit block are connected to inlet links of switches in the succeeding stage in another sub-integrated circuit block so that said cross links are either vertical links or horizontal and vice versa. In one embodiment the sub-integrated circuit blocks are arranged in a hypercube arrangement in a two-dimensional plane. The VLSI layouts exploit the benefits of significantly lower cross points, lower signal latency, lower power and full connectivity with significantly fast compilation.

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