

**FULLY CONNECTED GENERALIZED BUTTERFLY FAT TREE NETWORKS**

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5 CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Docket No. M-0037US entitled "FULLY CONNECTED GENERALIZED MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently.

10 This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Docket No. M-0039US entitled "FULLY CONNECTED GENERALIZED REARRANGEABLY NONBLOCKING MULTI-LINK MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently.

15 This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Docket No. M-0040US entitled "FULLY CONNECTED GENERALIZED MULTI-LINK BUTTERFLY FAT TREE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently.

20 This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Docket No. M-0041US entitled "FULLY CONNECTED GENERALIZED FOLDED MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently.

25 This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Docket No. M-0042US entitled "FULLY CONNECTED GENERALIZED STRICTLY NONBLOCKING MULTI-LINK MULTI-STAGE NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently.

This application is related to and incorporates by reference in its entirety the U.S. Provisional Patent Application Docket No. M-0045US entitled "VLSI LAYOUTS OF FULLY CONNECTED GENERALIZED NETWORKS" by Venkat Konda assigned to the same assignee as the current application, filed concurrently.

5 BRIEF DESCRIPTION OF DRAWINGS

FIG. 1A is a diagram 100A of an exemplary Symmetrical Butterfly fat tree network  $V_{bft}(N, d, s)$  having inverse Benes connection topology of three stages with  $N = 8$ ,  $d = 2$  and  $s=2$  with exemplary multicast connections, strictly nonblocking network for unicast connections and rearrangeably nonblocking network for arbitrary fan-out  
10 multicast connections, in accordance with the invention.

FIG. 1B is a diagram 100B of a general symmetrical Butterfly fat tree network  $V_{bft}(N, d, s)$  with  $(\log_d N)$  stages strictly nonblocking network for unicast connections and rearrangeably nonblocking network for arbitrary fan-out multicast connections in accordance with the invention.

15 FIG. 1C is a diagram 100C of an exemplary Asymmetrical Butterfly fat tree network  $V_{bft}(N_1, N_2, d, 2)$  having inverse Benes connection topology of three stages with  $N_1 = 8$ ,  $N_2 = p * N_1 = 24$  where  $p = 3$ , and  $d = 2$  with exemplary multicast connections, strictly nonblocking network for unicast connections and rearrangeably nonblocking network for arbitrary fan-out multicast connections, in accordance with the invention.

20 FIG. 1D is a diagram 100D of a general asymmetrical Butterfly fat tree network  $V_{bft}(N_1, N_2, d, 2)$  with  $N_2 = p * N_1$  and with  $(\log_d N)$  stages strictly nonblocking network for unicast connections and rearrangeably nonblocking network for arbitrary fan-out multicast connections in accordance with the invention.

FIG. 1E is a diagram 100E of an exemplary Asymmetrical Butterfly fat tree  
25 network  $V_{bft}(N_1, N_2, d, 2)$  having inverse Benes connection topology of three stages with  $N_2 = 8$ ,  $N_1 = p * N_2 = 24$ , where  $p = 3$ , and  $d = 2$  with exemplary multicast connections,

strictly nonblocking network for unicast connections and rearrangeably nonblocking network for arbitrary fan-out multicast connections, in accordance with the invention.

FIG. 1F is a diagram 100F of a general asymmetrical Butterfly fat tree network  $V_{bft}(N_1, N_2, d, 2)$  with  $N_1 = p * N_2$  and with  $(\log_d N)$  stages strictly nonblocking network  
5 for unicast connections and rearrangeably nonblocking network for arbitrary fan-out multicast connections in accordance with the invention.

FIG. 2A is a diagram 200A of an exemplary Symmetrical Butterfly fat tree network  $V_{bft}(N, d, s)$  having inverse Benes connection topology of three stages with  $N = 8$ ,  $d = 2$  and  $s=1$  with exemplary unicast connections rearrangeably nonblocking network  
10 for unicast connections, in accordance with the invention.

FIG. 2B is a diagram 200B of a general symmetrical Butterfly fat tree network  $V_{bft}(N, d, s)$  with  $(\log_d N)$  stages and  $s=1$ , rearrangeably nonblocking network for unicast connections in accordance with the invention.

FIG. 2C is a diagram 200C of an exemplary Asymmetrical Butterfly fat tree  
15 network  $V_{bft}(N_1, N_2, d, 1)$  having inverse Benes connection topology of three stages with  $N_1 = 8$ ,  $N_2 = p * N_1 = 24$  where  $p = 3$ , and  $d = 2$  with exemplary unicast connections rearrangeably nonblocking network for unicast connections, in accordance with the invention.

FIG. 2D is a diagram 200D of a general asymmetrical Butterfly fat tree network  
20  $V_{bft}(N_1, N_2, d, 1)$  with  $N_2 = p * N_1$  and with  $(\log_d N)$  stages rearrangeably nonblocking network for unicast connections in accordance with the invention.

FIG. 2E is a diagram 200E of an exemplary Asymmetrical Butterfly fat tree  
25 network  $V_{bft}(N_1, N_2, d, 1)$  having inverse Benes connection topology of three stages with  $N_2 = 8$ ,  $N_1 = p * N_2 = 24$ , where  $p = 3$ , and  $d = 2$  with exemplary unicast connections rearrangeably nonblocking network for unicast connections, in accordance with the invention.

FIG. 2F is a diagram 200F of a general asymmetrical Butterfly fat tree network  $V_{bf}(N_1, N_2, d, 1)$  with  $N_1 = p * N_2$  and with  $(\log_d N)$  stages rearrangeably nonblocking network for unicast connections in accordance with the invention.

FIG. 3A is high-level flowchart of a scheduling method according to the invention, used to set up the multicast connections in all the networks disclosed in this invention.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention is concerned with the design and operation of large scale crosspoint reduction using arbitrarily large Butterfly fat tree networks for broadcast, unicast and multicast connections. Particularly Butterfly fat tree networks with stages more than or equal to three and radices greater than or equal to two offer large scale crosspoint reduction when configured with optimal links as disclosed in this invention.

When a transmitting device simultaneously sends information to more than one receiving device, the one-to-many connection required between the transmitting device and the receiving devices is called a multicast connection. A set of multicast connections is referred to as a multicast assignment. When a transmitting device sends information to one receiving device, the one-to-one connection required between the transmitting device and the receiving device is called unicast connection. When a transmitting device simultaneously sends information to all the available receiving devices, the one-to-all connection required between the transmitting device and the receiving devices is called a broadcast connection.

In general, a multicast connection is meant to be one-to-many connection, which includes unicast and broadcast connections. A multicast assignment in a switching network is nonblocking if any of the available inlet links can always be connected to any of the available outlet links.

In certain Butterfly fat tree networks of the type described herein, any connection request of arbitrary fan-out, i.e. from an inlet link to an outlet link or to a set of outlet

links of the network, can be satisfied without blocking if necessary by rearranging some of the previous connection requests. In certain other Butterfly fat tree networks of the type described herein, any connection request of arbitrary fan-out, i.e. from an inlet link to an outlet link or to a set of outlet links of the network, can be satisfied without  
 5 blocking with never needing to rearrange any of the previous connection requests.

In certain Butterfly fat tree networks of the type described herein, any connection request of unicast from an inlet link to an outlet link of the network, can be satisfied without blocking if necessary by rearranging some of the previous connection requests. In certain other Butterfly fat tree networks of the type described herein, any connection  
 10 request of unicast from an inlet link to an outlet link of the network, can be satisfied without blocking with never needing to rearrange any of the previous connection requests.

Nonblocking configurations for other types of networks with numerous connection topologies and scheduling methods are disclosed as follows:

15 1) Strictly and rearrangeably nonblocking for arbitrary fan-out multicast and unicast for generalized multi-stage networks  $V(N_1, N_2, d, s)$  with numerous connection topologies and the scheduling methods are described in detail in U.S. Provisional Patent Application, Attorney Docket No. M-0037 US that is incorporated by reference above.

20 2) Rearrangeably nonblocking for arbitrary fan-out multicast and unicast, and strictly nonblocking for unicast for generalized multi-link multi-stage networks  $V_{mlink}(N_1, N_2, d, s)$  and generalized folded multi-link multi-stage networks  $V_{fold-mlink}(N_1, N_2, d, s)$  with numerous connection topologies and the scheduling methods are described in detail in U.S. Provisional Patent Application, Attorney Docket No. M-0039 US that is incorporated by reference above.

25 3) Strictly and rearrangeably nonblocking for arbitrary fan-out multicast and unicast for generalized multi-link butterfly fat tree networks  $V_{mlink-bft}(N_1, N_2, d, s)$  with numerous connection topologies and the scheduling methods are described in detail in

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