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(54) **MANAGEMENT OF MULTIPLE NETWORK ROUTES**

(71) Applicant: **INTERMODAL DATA, INC.**, Sausalito, CA (US)

(72) Inventors: **Samuel A. Hopkins**, Foster City, CA (US); **Sherman J. Sanders**, Foster City, CA (US); **Steven E. Stallion**, Santa Clara, CA (US)

(73) Assignee: **INTERMODAL DATA, INC.**, Sausalito, CA (US)

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H04L 12/707	(2013.01)
H04L 29/08	(2006.01)
H04L 29/06	(2006.01)
H04L 12/729	(2013.01)
H04L 29/12	(2006.01)

(52) **U.S. Cl.**

CPC ***H04L 45/24*** (2013.01); ***H04L 67/1097*** (2013.01); ***H04L 69/14*** (2013.01); *H04L 45/125* (2013.01); *H04L 61/103* (2013.01)

(58) **Field of Classification Search**

USPC 370/229, 230, 235, 236, 252, 351, 359, 370/395.54, 419, 468

See application file for complete search history.

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Primary Examiner — Kwang B Yao

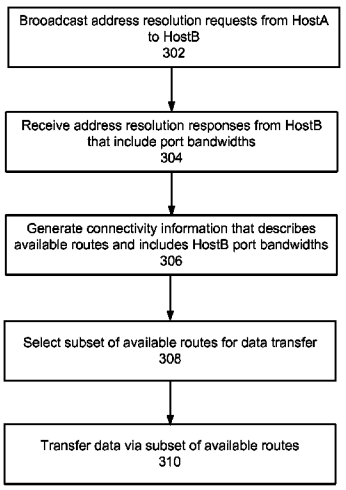
Assistant Examiner — Nguyen Ngo

(74) *Attorney, Agent, or Firm* — K&L Gates LLP

(57) **ABSTRACT**

Managing network communications between network hosts that have multiple physical network ports coupled to the network. A first host broadcasts address resolution requests from first physical network ports of the first host and receives responses to the address resolution requests from second physical network ports of a second host. The responses include respective connection bandwidths of the second physical network ports. The first host generates connectivity information describing a plurality of available communication routes in the network between first physical network ports of the first host and second physical network ports of the second host based on the responses, from which a subset of available communication routes can be selected for data transfer.

18 Claims, 5 Drawing Sheets



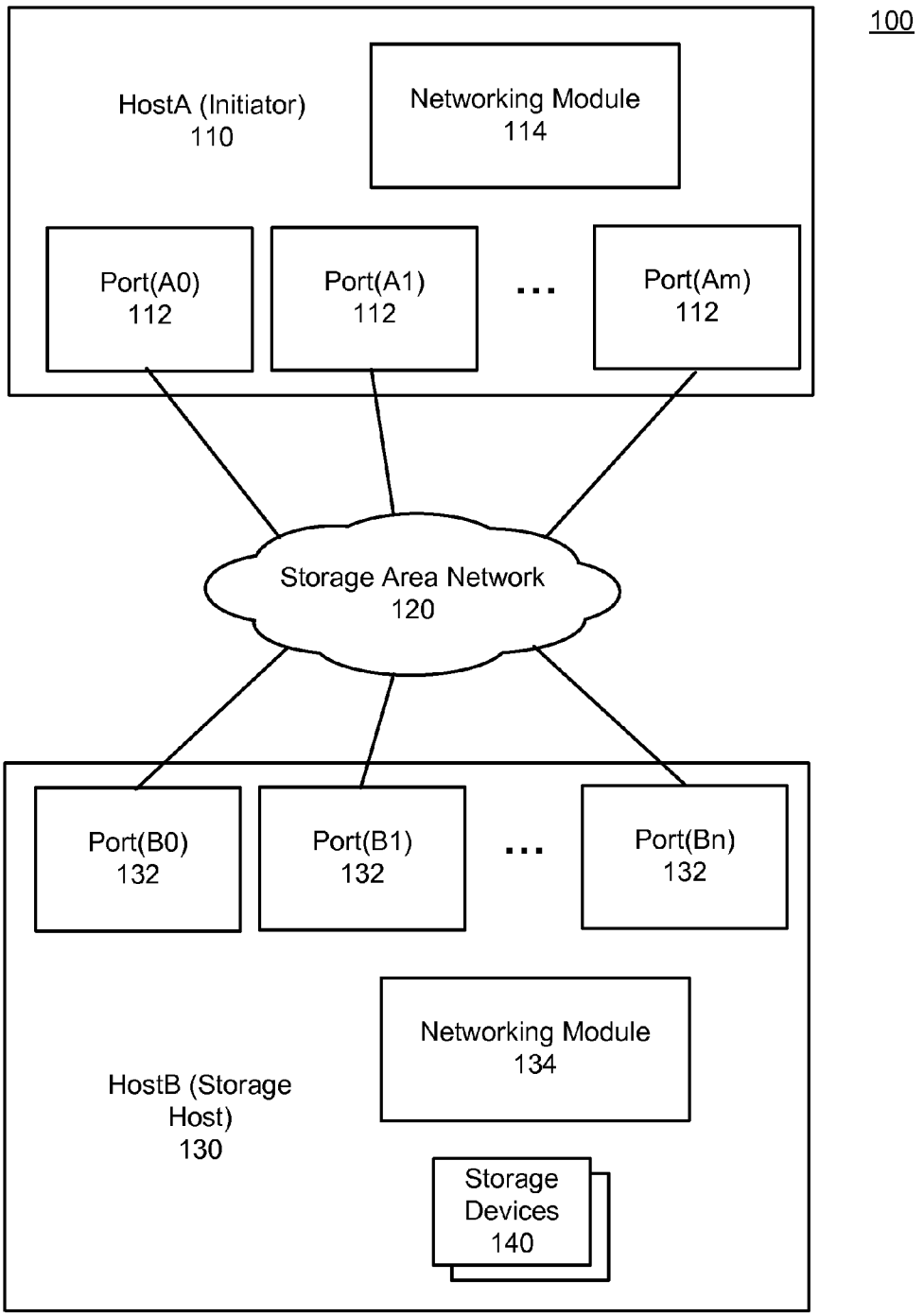

100
HostA (Initiator)
110
Networking Module
114
Port(A0)
112
Port(A1)
112
...
Port(Am)
112
Storage Area Network
120
Port(B0)
132
Port(B1)
132
...
Port(Bn)
132
Networking Module
134
HostB (Storage
Host)
130
Storage
Devices
140

FIG. 1

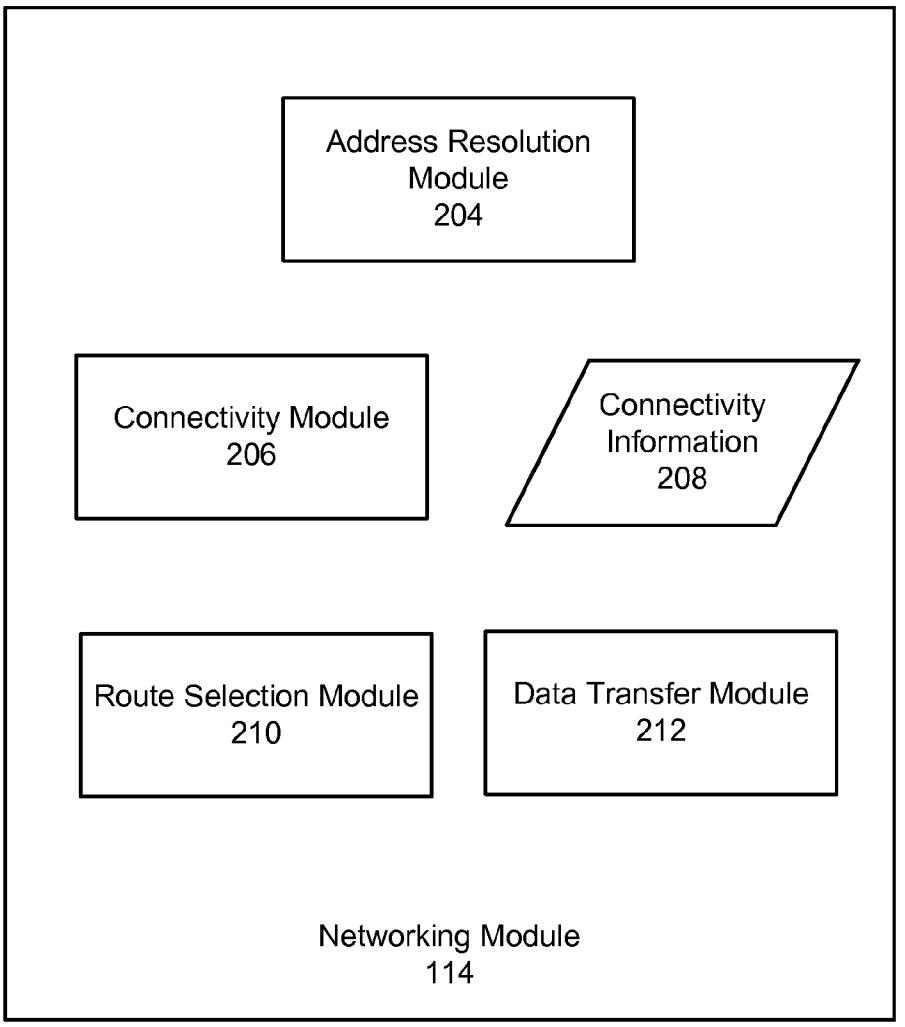

Address Resolution Module 204
Connectivity Module 206
Connectivity Information 208
Route Selection Module 210
Data Transfer Module 212
Networking Module 114

FIG. 2

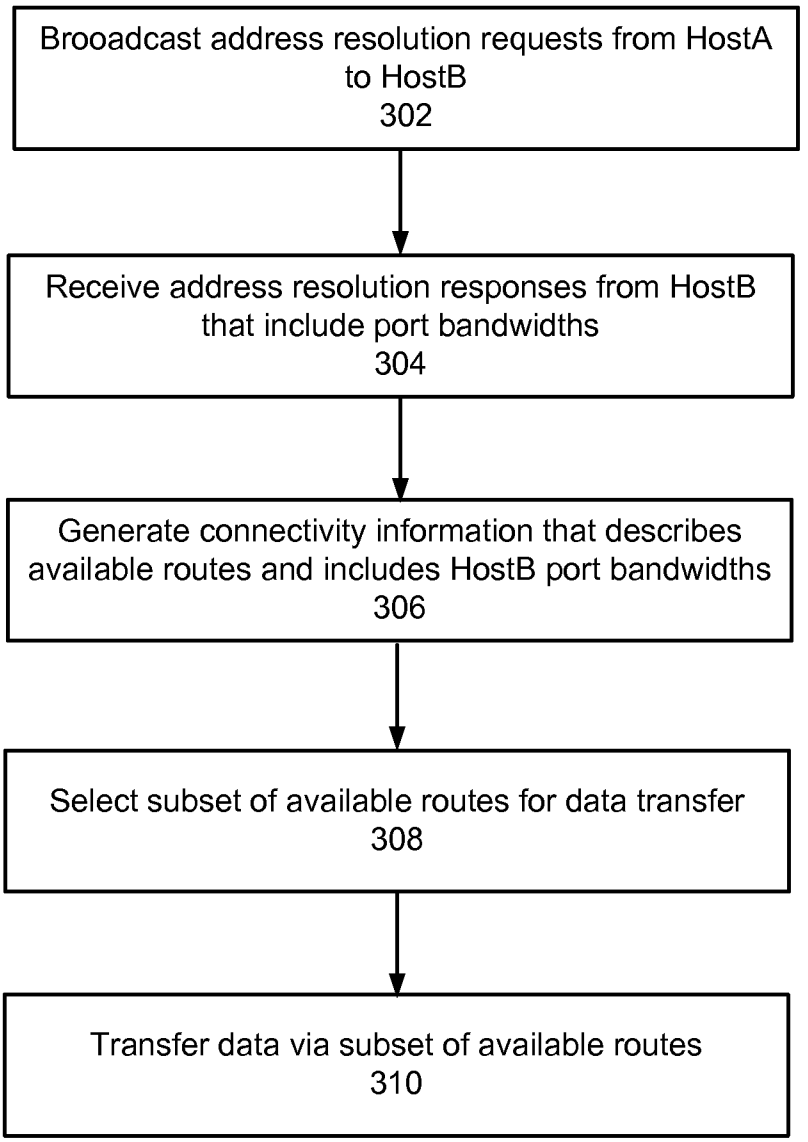

Brooadcast address resolution requests from HostA to HostB
302
Receive address resolution responses from HostB that include port bandwidths
304
Generate connectivity information that describes available routes and includes HostB port bandwidths
306
Select subset of available routes for data transfer
308
Transfer data via subset of available routes
310

FIG. 3

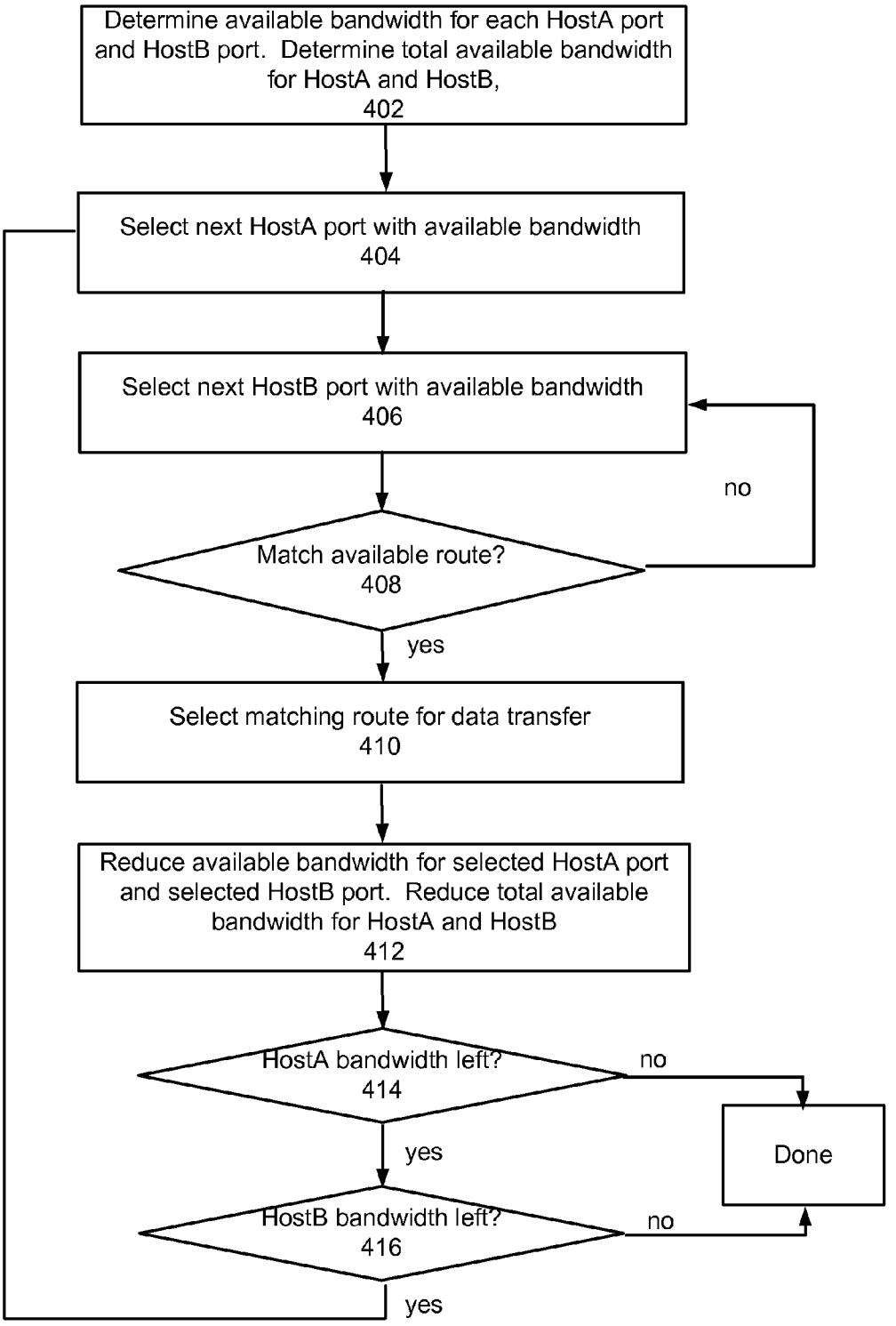

Determine available bandwidth for each HostA port and HostB port. Determine total available bandwidth for HostA and HostB,
402
Select next HostA port with available bandwidth
404
Select next HostB port with available bandwidth
406
no
Match available route?
408
yes
Select matching route for data transfer
410
Reduce available bandwidth for selected HostA port and selected HostB port. Reduce total available bandwidth for HostA and HostB
412
HostA bandwidth left?
414
no
yes
Done
HostB bandwidth left?
416
no
yes

FIG. 4

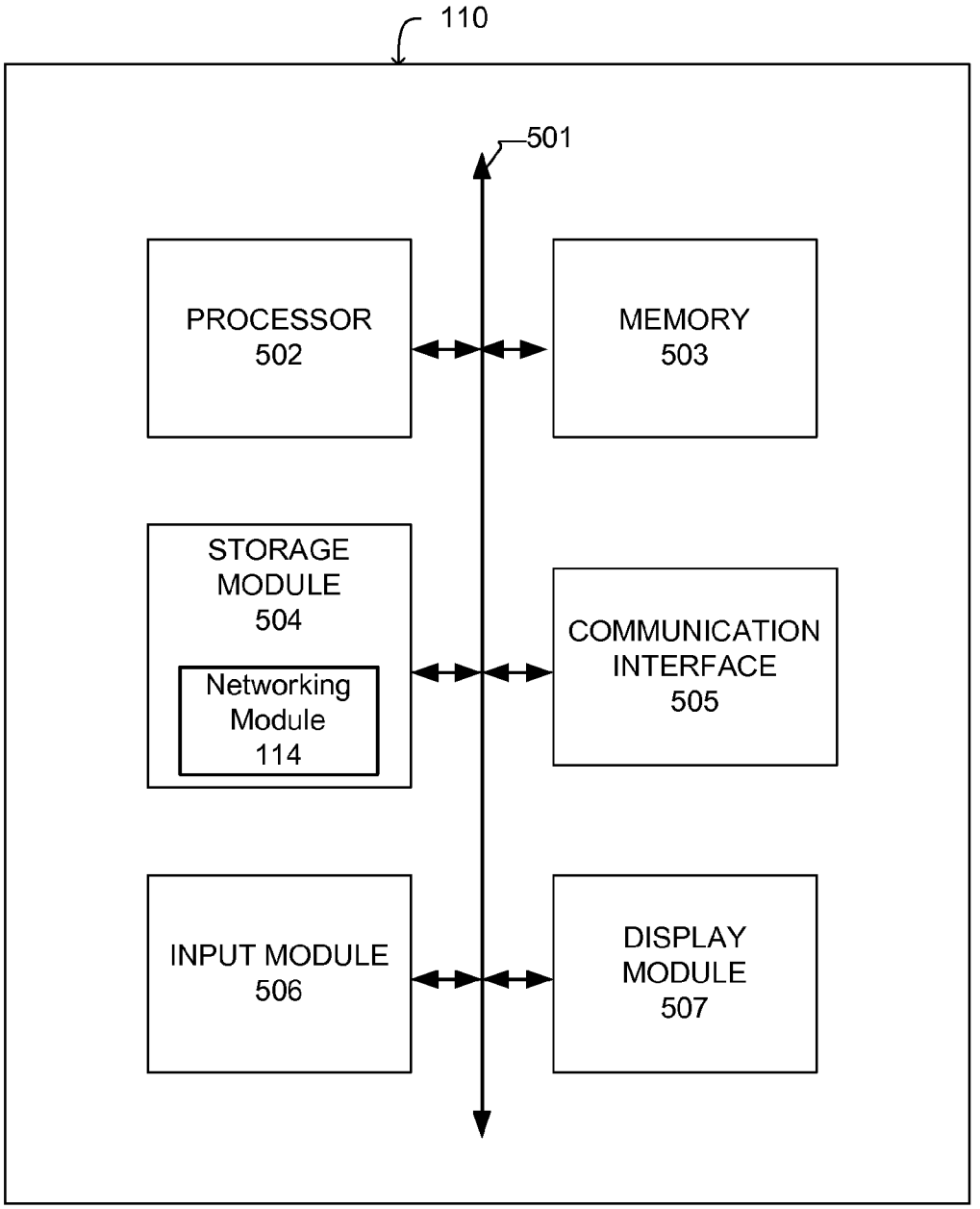

110
501
PROCESSOR
502
MEMORY
503
STORAGE
MODULE
504
Networking
Module
114
COMMUNICATION
INTERFACE
505
INPUT MODULE
506
DISPLAY
MODULE
507

FIG. 5

MANAGEMENT OF MULTIPLE NETWORK ROUTES

BACKGROUND

1. Field of the Disclosure

This disclosure pertains in general to network communication, and in particular to managing network communications between network hosts that have multiple physical network ports coupled to a network.

2. Description of the Related Art

Hosts systems in a networked environment, such as a storage area network (SAN), can each have multiple physical network ports that couple the host to the network. This creates multiple routes in the network through which the hosts can communicate with each other. The ports can be also configured with mismatched connection bandwidths (e.g. 100 Mb/s, 1 Gb/s). Due to the large number of available routes and potential configurations of the ports, it is difficult for the host systems to automatically identify an optimal subset of the routes that uses the routes efficiently.

SUMMARY

Embodiments of the present disclosure are related to managing network communications between network hosts that have multiple physical network ports coupled to the network. In one embodiment, a method of operations is performed in a first host that communicates with a second host through a network. The first host includes a plurality of first physical network ports and the second host includes a plurality of physical network ports that are coupled to the network.

The first host broadcasts address resolution requests from the first physical network ports of the first host to the second physical network ports of the second host. The first host then receives responses to the address resolution requests from the second physical network ports of the second host. The responses to the address resolution requests include respective connection bandwidths for the second physical network ports. Using the responses, the first host generates connectivity information describing a plurality of available communication routes in the network between a plurality of first physical network ports of the first host and a plurality of second physical network ports of the second host. The connectivity information can also describe the respective connection bandwidths of the second physical network ports.

Once the connectivity information is generated, the first host selects a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports. The first host then transfers data with the second host via the subset of the available communication routes. By selecting communication routes in this manner, the first host can automatically select a subset of routes that result in efficient use of network bandwidth. Additionally, the selected subset of routes can be a minimum subset of the available communication routes that fully utilizes all available bandwidth of at least one of the first physical network ports or the second physical network ports.

BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the embodiments disclosed herein can be readily understood by considering the following detailed description in conjunction with the accompanying drawings.

FIG. **1** is a high-level block diagram of a computing environment for network communication across a storage area network, according to one embodiment.

FIG. **2** is a detailed view of a networking module of FIG. **1**, according to one embodiment.

FIG. **3** is a flowchart illustrating a process of network communications performed by the networking module of FIG. **1** according to one embodiment.

FIG. **4** is a flowchart illustrating a more detailed view for the step of selecting a subset of routes from FIG. **3**, according to one embodiment.

FIG. **5** is a hardware architecture of Network HostA from FIG. **1**, according to one embodiment.

DETAILED DESCRIPTION

The Figures (FIG.) and the following description relate to various embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles discussed herein.

Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict various embodiments for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

Embodiments disclosed herein describe a system and process for route management in a network environment when there are multiple hosts connected to the network, each of which has multiple physical network ports. The hosts automatically discover each other during address resolution and provide information about the connection bandwidths of their ports to the other hosts. Each host generates connectivity information describing all of the available routes for communicating with another host and which can also describe the connection bandwidths of the ports of the other host. From the connectivity information a subset of the available routes is selected for transferring data between the hosts.

FIG. **1** is a high-level block diagram of a computing environment **100** for network communication across a storage area network (SAN) **120**, according to one embodiment. The computing environment **100** includes a network host A **110** (HostA) and a network host B **130** (HostB) connected to a SAN **120**. In one embodiment, the computing environment **100** may exist within a datacenter. Only two hosts **110** and **130** are shown in FIG. **1** to simplify and clarify the description. In other embodiments the computing environment **100** can have a larger number of hosts **110** and **130**.

SAN **120** is a dedicated network that provides access to consolidated, block level data storage. The SAN **120** may include communication links using technologies such as Ethernet. In other embodiments the communication links can use other technologies such as Fibre Channels or the like. HostA **110** and HostB **130** can communicate over the SAN **120** using a communication protocol such as ATA over Ethernet (AoE), Fiber Channel Protocol (FCP), Fiber Channel over Ethernet (FCoE), or other appropriate communication protocol. The SAN **120** can be located in one physical location or can span multiple physical locations. The SAN **120** may include one or

more network switches (not shown) that route communications in the SAN **120** between HostA **110** and HostB **130**.

HostA **110** and HostB **130** are both computing devices, such as server class computers. HostA **110**, also known as an initiator host, initiates data transfer with HostB **130** across the SAN **120**. HostB **130**, also known as a storage host, provides storage services to HostA **110** through the SAN **120**. HostB **130** includes several storage devices **140**, such as magnetic disk drives, solid state drives, etc. HostB **130** forms the storage devices **140** into logical unit numbers (LUNs) which are assigned to HostA **110**, accessed by HostA **110** via the SAN **120** and appear as local storage to HostA **110**. In some embodiments a LUN may be shared among multiple network hosts.

Both HostA **110** and Host B **130** include several physical network ports **112** and **132**, respectively, that are coupled to the SAN **120**. HostA **110** includes ports **112**, and HostB **130** includes ports **132**. A physical network port is piece of hardware that provides physical access to the SAN **120** through a wired (or wireless) connection. An example of a physical network port is an Ethernet card. When connected to the SAN **120**, each port negotiates a network connection bandwidth (e.g. 100 Mb/s, 1 Gb/s) with the SAN **120**. The network connection bandwidth of a port defines the rate at which data is transferred with the SAN **120** through the port. In some instances the negotiated network connection bandwidth of a port may be lower than the maximum bandwidth of a port due to the limitations of the SAN **120**. Some of the physical network ports may have different network connection bandwidths. For example port A0 **112** may operate at 100 Mb/s while port A1 **112** and port B0 **132** operate at 1 Gb/s.

Each port has a unique physical address that can be used by other hosts to communicate with the port. The physical address may be hardwired into the port such that it is not modifiable. For example, an Ethernet based port may have a unique media access control (MAC) address. Each host (e.g. HostA **110** and HostB **130**) has a different network address that is typically unique across the SAN **120**. A network address is used as a higher order identifier for a host that is independent of the physical addresses. An example of a network address in the AoE protocol is a major.minor address. Another example of a network address is an internet protocol (IP) address or similar type of address. Each network host thus has multiple physical addresses and a single network address that spans the physical addresses.

HostA **110** and HostB **130** include respective networking modules **114** and **134**. For ease of understanding only the networking module **114** of HostA **110** will be described herein. However, it is understood that the description of networking module **114** can also apply to networking module **134**.

Networking module **114** communicates with HostB **130** to discover available communication routes in the SAN **120** between HostA **110** and Host B **130**. Because HostA **110** has (m) number of ports **112** and network host B **130** has (n) number of ports **132**, there are a total of (m×n) available communication routes between HostA **110** and HostB **130**.

When HostA **110** is first attached to the SAN **120**, the available communication routes are unknown to HostA **110**. To discover the available communication routes, networking module **114** broadcasts address resolution request packets to network host B **130** by transmitting address resolution request packets through the SAN **120**. Address resolution is a phase of network communications during which a host resolves network addresses of other hosts to physical addresses of the other hosts. The result of address resolution is that the mappings between network addresses and physical addresses are known. Address resolution is implemented in many different network standards, such as in IP communications and others.

A different address resolution request packet is broadcast from each HostA port **112**. The HostB ports **132** receive the address resolution request packets and respond by providing address resolution response packets to the HostA ports **112**. The address resolution response packets also include information about the connection bandwidths of the remote HostB ports **132**. The networking module **114** processes the address resolution response packets to generate connectivity information, which describes all of the available communication routes between HostA **110** and HostB **130** and the connection bandwidths of the HostB ports **132**.

Once the connectivity information is generated, the networking module **114** uses the connectivity information to select a subset of the communication routes for data transfer with HostB **130**. The subset of communication routes is selected in a manner that optimizes data transfer between HostA **110** and HostB **130**, even if one host has a different number of ports and/or ports with different connection bandwidths than the other host. The selection can be performed in an automatic manner at HostA **110** without the need for user intervention because the available routes and connection bandwidths of the HostB ports **132** are known to HostA **110**. Further, obtaining connection bandwidth information during address resolution provides a simple and easy to implement technique for obtaining information about the capabilities of the HostB ports **130** that requires only minor modifications to existing address resolution mechanisms.

In other embodiments, the SAN **120** can be replaced with a generic network that represents the communication pathways between the HostA **110** and HostB **130**. The network can be an internal network or the Internet. In one embodiment, the network uses standard communications technologies and/or protocols. Thus, the network can include links using technologies such as Ethernet, 802.11, integrated services digital network (ISDN), digital subscriber line (DSL), asynchronous transfer mode (ATM), etc. Similarly, the networking protocols used on the network can include the transmission control protocol/Internet protocol (TCP/IP), the hypertext transport protocol (HTTP), the simple mail transfer protocol (SMTP), the file transfer protocol (FTP), etc. The data exchanged over the network **120** can be represented using technologies and/or formats including the hypertext markup language (HTML), the extensible markup language (XML), etc. In addition, all or some of the links can be encrypted using conventional encryption technologies such as the secure sockets layer (SSL), Secure HTTP and/or virtual private networks (VPNs).

FIG. **2** is a detailed view of a networking module **114** of FIG. **1**, according to one embodiment. Networking module **114** includes an address resolution module **204**, a connectivity module **206**, connectivity information **208**, a route selection module **210** and a data transfer module **212**. In other embodiments there may be a different number of modules and the functionality described as being in one module may be implemented in a different module.

The address resolution module **204** generates address resolution request packets and broadcasts the address resolution request packets from the HostA ports **112** across the SAN **120**. A different address resolution request packet is broadcast from each HostA port **112**. For example, one address resolution request packet is broadcast from port(A0) **112** and another address resolution request packet is broadcast from port(A1) **112**. An address resolution request packet broadcast from a given HostA port **112** can include the following fields, among others: the physical address of the HostA port **112**, the

network address of the HostA port **112**, and the network address of HostB **130**. In some embodiments the address resolution request packet can include the connection bandwidth of the HostA port **112**. The following is an example of fields in an address resolution request packet sent by HostA **110**:

HostA port physical address	00-B0-D0-86-BB-F7
HostA network address	63.197.333.225
HostB network address	63.197.333.222

The address resolution request packet is received at the HostB ports **132**, which respond by providing responses to the address resolution request packet. Each HostB port **132** provides its own response to the address resolution request packet in the form of an address resolution response packet. For example, port(B0) **132** returns an address resolution response packet to port(A0) **112** and port(B1) **132** also returns an address resolution response packet to port(A0) **112**. The address resolution response packet from a HostB port **132** can include the following fields: the physical address of the HostB Port **132**, a connection bandwidth of the HostB Port **132**, the network address of HostB **130**, the physical address of a HostA Port **112** and the network address of HostA **112**. The following is an example of fields in an address resolution response packet sent by HostB:

HostB port physical address	1A-23-55-CE-15-F7
HostB port bandwidth	1 Gb/s
HostB network address	63.197.333.222
HostA port physical address	00-B0-D0-86-BB-F7
HostA network address	63.197.333.225

Notably, the address resolution response packets include a field for the bandwidth of the HostB Port **132**. Conventional address resolution packets do not have a field for port bandwidth, so this bandwidth information may be transmitted in an optional extension field of an address resolution response packet. For backwards compatibility, the optional extension field may be ignored by hosts that do not support the optional extension field. The address resolution module **204** then receives and decodes the address resolution response packets.

The connectivity module **206** processes the address resolution response packets and generates connectivity information **208** describing available communication routes between HostA **110** and HostB **130** as well as the connection bandwidths of the HostB ports **132**. The available routes can be determined from the address resolution response packets. Each time an address resolution response packet is received at a HostA Port from a HostB Port, the connectivity module **206** assumes an available communication route exists between the HostA Port and the HostB Port and adds the route to the connectivity information **208**.

In one embodiment, the connectivity information **208** includes data that represents a connectivity matrix or connectivity map of the available communication routes. The connectivity information **208** can be stored in a computer-readable medium for later access, such as in a random access memory, solid state memory, etc. The connectivity information **208** includes a list of route entries for the available communication routes. Each route entry can include fields for: a timestamp of when the route entry was created or last updated, the physical address of a HostA port **112**, the HostA port bandwidth, the network address of HostB **130**, the physical address of a HostB port **132**, and the HostB port bandwidth. Most of the fields can be determined from the address resolution response packets, while the HostA port bandwidth can be determined locally by the connectivity module **206**. The following is an example of a route entry for a single route:

Timestamp	1:30 PM, Jul. 15, 2013
HostA port physical address	00-B0-D0-86-BB-F7
HostA port bandwidth	100 Mb/s
HostB port physical address	1A-23-55-CE-15-F7
HostB port bandwidth	1 Gb/s
HostB network address	63.197.333.222

A route entry thus defines a communication route between a single HostA port **112** and a single HostB port **132**. Collectively, the route entries represent all of the available communication routes through the SAN **120** between HostA **110** and HostB **130**.

To keep the connectivity information **208** up to date, the address resolution module **204** periodically broadcasts new address resolution request packets from the HostA ports **112**. The connectivity module **206** can cull stale entries from the connectivity information **208** to account for changes in the SAN **120** if no responses to the address resolution request packets are received. The culling can occur at periodic intervals, such as 2.5 times the broadcast time of address resolution request packets. For example, if the periodic broadcast time is 3 seconds, route entries may be invalidated if they are 7.5 seconds old. The address resolution module **204** and connectivity module **206** thus work together to generate and continuously update the connectivity information **208**.

The route selection module **210** selects a subset of the communication routes from the connectivity information **208** for data communications with remote HostB **110**. The route selection module **210** attempts to select a minimum number of routes that still consumes all of the available bandwidth for the HostA ports **112** or the HostB ports **132**. The exact communication routes that are selected depend on several factors, such as the number of HostA ports **112**, the number of HostB ports **132**, the bandwidths of the HostA ports **112**, and the bandwidths of the HostB ports **132**. Route selection can also re-occur periodically as the connectivity information **208** is updated. Route selection will be described in greater detail by reference to FIG. **4**.

The data transfer module **212** transfers data with HostB **130** via the subset of communication routes selected by the route selection module **210**. Data transfer can include either receiving data from HostB **130** or transmitting data to HostB **130** for storage into the storage devices **140**. The data is divided amongst the selected communication routes in order to make full use of the available bandwidth between HostA **110** and HostB **130**.

FIG. **3** is a flowchart illustrating a process of network communications performed by the networking module **114** of FIG. **1**, according to one embodiment. In step **302**, address resolution request packets are broadcast from HostA **110** to HostB **130**. Separate address resolution request packets are broadcast from each HostA port **112**. In step **304**, address resolution response packets are received from the HostB ports **132** that describe the connection bandwidths of the HostB ports **132**. In step **306**, the address resolution response packets are used to generate connectivity information **208** that describes available communication routes between HostA **110** and HostB **130**. The connectivity information also describes the connectivity bandwidths of the HostB ports **132**. In step **308**, using the connectivity information, a subset of the communication routes are selected for data transfer

with HostB **130**. In step **310**, data is transferred with HostB **130** via the selected subset of communication routes.

FIG. **4** is a flowchart illustrating a more detailed view for the step **308** of selecting a subset of routes from FIG. **3**, according to one embodiment. In step **402**, the available bandwidth for each HostA port **112** and each HostB port **132** is determined. Initially the available bandwidth for each port is equal to the connection bandwidth for the port as indicated in the connectivity information **208**. The total available bandwidth for HostA **110** is determined by combining the individual bandwidths of the HostA ports **112**. The total available bandwidth for HostB **130** is also determined by combining the individual bandwidths of the HostB ports **132**.

In step **404**, the next hostA port with available bandwidth is selected. In step **404**, the next HostB port **132** with available bandwidth is selected. In step **408** the selected HostA port **112** and the selected HostB port **132** are compared to the connectivity information **208** to determine if the HostA port **112** and HostB port **132** match an available route through the SAN **120**. If there is a match, the communication route is selected for data transfer in step **410**. For example, the selected communication route can be added to a table of selected communication routes. If there is not a match, the route selection process returns to step **406** to select the next HostB port **132** with available bandwidth.

In step **412**, the available bandwidth for the selected HostA port **112** and the available bandwidth for the selected HostB port **132** are reduced, which indicates that some or all of the bandwidth of the ports has been allocated to a selected route. The amount of the reduction is equal to the smaller of the available bandwidth of the HostA port **112** and the HostB port **132**. For example, if the available bandwidth for a HostA port is 1 Gb/s and the available bandwidth for a HostB port **132** is 100 Mb/s, both ports would have their available bandwidth reduced by 100 Mb/s. The total available bandwidth for both HostA **110** and HostB **112** are also reduced in the same manner.

In step **414** it is determined if HostA **110** has any available bandwidth remaining. If so, in step **416** it is determined if HostB **130** has any available bandwidth remaining. If either HostA **110** or HostB **130** has no remaining bandwidth, the route selection process is completed because all of the available bandwidth has been consumed and there is no more bandwidth to be allocated.

If both HostA **110** and HostB **130** have remaining bandwidth, the process returns to step **404** and selects the next HostA port **112** with available bandwidth instead of selecting the same HostA port **112** from the previous iteration of the route selection process. For example, if HostA port(A0) was selected in one iteration of the route selection process, the next iteration will select HostA port(A1) for route selection. As a result, the HostA ports **112** are selected in a round-robin manner (A0→A1→A2→A0→A1→A2) that balances data transmission across the ports of HostA. Similarly, in step **406** the next HostB port **132** with available bandwidth is selected instead of selecting the same HostB port **132** from the previous iteration of the route selection process. This also balances data transmission across the HostB ports **132**. The process repeats until all available bandwidth for the HostA ports **113** or the HostB ports **132** is consumed.

The following examples illustrate route selections that are performed by the route selection process in FIG. **4**.

Example 1

HostA **110** has four 10 Gb/s ports **112** and HostB **130** also has four 10 Gb/s ports **132**. HostA's ports **112** are labeled A0, A1, A2 and A3. HostB's ports **132** are labeled B0, B1, B2 and B3. The full connectivity matrix of routes between HostA **110** and HostB **130** can be visually represented in Table 1A as follows:

TABLE 1A

	B0 (10 Gb/s)	B1 (10 Gb/s)	B2 (10 Gb/s)	B3 (10 Gb/s)
A0 (10 Gb/s)	Available	Available	Available	Available
A1 (10 Gb/s)	Available	Available	Available	Available
A2 (10 Gb/s)	Available	Available	Available	Available
A3 (10 Gb/s)	Available	Available	Available	Available

In Table 1A, there are 16 available communication routes between HostA **110** and HostB **130**. HostA **110** could use every available route in transferring data with HostB **130**. However, this is unnecessary. Instead, the networking module **114** selects a subset of the routes for data transfer, so that from the available routes, the selected subset of routes would be as follows:

TABLE 1B

	B0 (10 Gb/s)	B1 (10 Gb/s)	B2 (10 Gb/s)	B3 (10 Gb/s)
A0 (10 Gb/s)	Selected			
A1 (10 Gb/s)		Selected		
A2 (10 Gb/s)			Selected	
A3 (10 Gb/s)				Selected

In Table 1B, the four selected routes represent the minimum subset of the available routes that still consumes all of the available bandwidth (40 Gb/s) between HostA **110** and HostB **130**.

Example 2

HostA **110** has four 1 Gb/s Ports **112** and HostB **130** also has two 10 Gb/s Ports **132**. HostA ports **112** are labeled A0, A1, A2 and A3. HostB ports **132** are labeled B0 and B1. The full connectivity matrix of routes between HostA **110** and HostB **130** can be visually represented in Table 2A as follows:

TABLE 2A

	B0 (10 Gb/s)	B1 (10 Gb/s)
A0 (1 Gb/s)	Available	Available
A1 (1 Gb/s)	Available	Available
A2 (1 Gb/s)	Available	Available
A3 (1 Gb/s)	Available	Available

In Table 2A, there are 8 available communication routes between HostA **110** and HostB **130**. Route selection selects a subset of the routes for data transfer. Due to imbalance or mismatch between the bandwidths of the HostA ports **112** and the HostB ports **132**, the selected subset of routes would be as follows:

TABLE 2B

	B0 (10 Gb/s)	B1 (10 Gb/s)
A0 (1 Gb/s)	Selected	
A1 (1 Gb/s)		Selected
A2 (1 Gb/s)	Selected	
A3 (1 Gb/s)		Selected

In Table 2B, the routes are selected such that HostB port B0 is matched with HostA ports A0 and A2. HostB port B1 is

matched with HostA ports A1 and A3. The total bandwidth between HostA **110** and HostB **130** is 4 Gb/s, which is limited by the bandwidth of the HostA ports **112**. The 4 Gb/s bandwidth is split between the HostB ports **132** to balance data traffic amongst the HostB ports **132**.

Additionally, the routes are selected in a manner that can match ports with different connection bandwidths to each other. For example, HostB port B0 has 10 Gb/s bandwidth but is still matched against HostA port A0, which only has 1 Gb/s bandwidth.

Example 3

HostA **110** has four 10 Gb/s Ports **112** and HostB **130** also has two 10 Gb/s Ports **132**. HostA ports **112** are labeled A0, A1, A2 and A3. HostB ports **132** are labeled B0 and B1. The full connectivity matrix of routes between HostA **110** and HostB **130** can be visually represented in Table 3A as follows:

TABLE 3A

	B0 (10 Gb/s)	B1 (10 Gb/s)
A0 (10 Gb/s)	Available	Available
A1 (10 Gb/s)	Available	Available
A2 (10 Gb/s)	Available	Available
A3 (10 Gb/s)	Available	Available

In Table 3A, there are 8 available communication routes between HostA **110** and HostB **130**. Route selection selects a subset of the routes for data transfer. Due to imbalance between the number of HostA ports **112** and the number of HostB ports **132**, the selected subset of routes would be as follows:

TABLE 3B

	B0 (10 Gb/s)	B1 (10 Gb/s)
A0 (10 Gb/s)	Selected	
A1 (10 Gb/s)		Selected
A2 (10 Gb/s)		
A3 (10 Gb/s)		

In table 3B, two of the routes (A0-B0 and A1-B1) are selected for data transfer. The HostA ports A2 and A3 are not useful for data transfer as the total bandwidth is limited by the HostB ports **132** to 20 Gb/s. Additionally, using additional routes actually creates a "Y" configuration whereby HostA **110** can create unnecessary network congestion by attempting to send 40 Gb/s of data when HostB **130** can only sustain 20 Gb/s of data. The two selected routes thus represent the minimum subset of available routes that still consume all of the available bandwidth (20 Gb/s) between HostA **110** and HostB **130**.

Example Computer Architecture

FIG. **5** illustrates the hardware architecture of Network HostA **110** (or Network HostB **130**), according to one embodiment. In one embodiment, HostA is a server computer including components such as a processor **502**, a memory **503**, a storage module **504**, an input module (e.g., keyboard, mouse, and the like) **506**, a display module **507** and a communication interface **505**, exchanging data and control signals with one another through a bus **501**. The storage module **504** is implemented as one or more non-transitory computer readable storage media (e.g., hard disk drive, solid state memory, etc.), and stores software instructions that are executed by the processor **502** in conjunction with the memory **503** to implement the network communications described herein. For example, the storage module **504** may include instructions in the form of a networking module **114**. Operating system software and other application software may also be stored in the storage module **504** to run on the processor **502**.

As can be seen from the description above, the embodiments herein discover all available routes between hosts that have multiple physical network ports, as well as the connection bandwidths of the ports during address resolution. Using this information, a subset of routes can be selected for data transfer between the hosts. The routes are selected in a manner that fully utilizes the available bandwidth between the two hosts while also balancing data traffic across the ports of the hosts.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative designs for network communications between network hosts. Thus, while particular embodiments and applications of the present disclosure have been illustrated and described, it is to be understood that the embodiments are not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus of the present disclosure disclosed herein without departing from the spirit and scope of the disclosure as defined in the appended claims.

What is claimed is:

1. A computer implemented method of operations in a first host that communicates with a second host through a network, comprising:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein the respective port bandwidths for the second physical network ports are included in optional extension fields of the responses to the address resolution requests.

2. The method of claim **1**, wherein the connectivity information includes a plurality of entries for the available communication routes, an entry for a available communication route identifying a respective one of the first physical network ports, a respective one of the second physical network ports and a respective connection bandwidth for the respective one of the second physical network ports.

3. A computer implemented method of operations in a first host that communicates with a second host through a network, comprising:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein selecting the subset of the available communication routes for data transfer via the network between the first host and the second host comprises: selecting the subset of the available communication routes for data transfer via the network between the first host and the second host based on respective connection bandwidths of the first physical network ports and the respective connection bandwidths of the second physical network ports.

4. The method of claim **3**, wherein selecting the subset of the available communication routes comprises: selecting the subset of the available communication routes by allocating the respective connection bandwidths of the first physical network ports and the respective connection bandwidths of the second physical network ports until the respective connection bandwidths for either the first physical network ports or the second physical network ports are consumed.

5. The method of claim **3**, wherein the subset of available communication routes are selected to balance data transfer across at least one of the first physical network ports or the second physical network ports.

6. A computer implemented method of operations in a first host that communicates with a second host through a network, comprising:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein the subset of available communication routes is a minimum subset of the available communication routes that fully utilizes all available bandwidth of at least one of the first physical network ports or the second physical network ports.

7. The method of claim **6**, wherein a first communication route in the subset of communication routes is a communication route between a first physical network port and a second physical network port having different connection bandwidths.

8. A computer implemented method of operations in a first host that communicates with a second host through a network, comprising:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein the first physical ports have different physical addresses and a single network address.

9. The method of claim **8**, wherein the network is a storage area network (SAN), the first host is an initiator host and the second host is a storage host that provides storage services for the initiator host via the SAN through a SAN protocol, wherein generating connectivity information comprises:

generating connectivity information describing a plurality of available communication routes in the SAN between a plurality of first physical network ports of the initiator host and a plurality of second physical network ports of the storage host that provide storage services for the initiator host via the SAN.

10. A non-transitory computer readable medium storing processor executable instructions for network communications between a first host that communicates with a second host through a network, the instructions comprising instructions for:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein the connectivity information includes a plurality of entries for the available communication routes, an entry for a available communication route identifying a respective one of the first physical network ports, a respective one of the second physical network ports and a respective connection bandwidth for the respective one of the second physical network ports.

11. The computer readable medium of claim **10**, wherein the respective port bandwidths for the second physical network ports are included in optional extension fields of the responses to the address resolution requests.

12. The computer readable medium of claim **10**, wherein the subset of available communication routes are selected to balance data transfer across at least one of the first physical network ports or the second physical network ports.

13. A non-transitory computer readable medium storing processor executable instructions for network communications between a first host that communicates with a second host through a network, the instructions comprising instructions for:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein selecting the subset of the available communication routes for data transfer via the network between the first host and the second host comprises: selecting the subset of the available communication routes for data transfer via the network between the first host and the second host based on respective connection bandwidths of the first physical network ports and the respective connection bandwidths of the second physical network ports.

14. The computer readable medium of claim **13**, wherein selecting the subset of the available communication routes comprises: selecting the subset of the available communication routes by allocating the respective connection bandwidths of the first physical network ports and the respective connection bandwidths of the second physical network ports until the respective connection bandwidths for either the first physical network ports or the second physical network ports are consumed.

15. A non-transitory computer readable medium storing processor executable instructions for network communications between a first host that communicates with a second host through a network, the instructions comprising instructions for:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein the subset of available communication routes is a minimum subset of the available communication routes that fully utilizes all available bandwidth of at least one of the first physical network ports or the second physical network ports.

16. The computer readable medium of claim **15**, wherein a first communication route in the subset of communication routes is a communication route between a first physical network port and a second physical network port having different connection bandwidths.

17. A non-transitory computer readable medium storing processor executable instructions for network communications between a first host that communicates with a second host through a network, the instructions comprising instructions for:

broadcasting address resolution requests from a plurality of first physical network ports of the first host to a plurality of second physical network ports of the second host;

receiving responses to the address resolution requests from the second physical network ports of the second host, the responses to the address resolution requests including respective connection bandwidths of the second physical network ports;

generating connectivity information describing a plurality of available communication routes in the network between the plurality of first physical network ports of the first host and the plurality of second physical network ports of the second host based on the responses to the address resolution requests;

selecting a subset of the available communication routes for data transfer via the network between the first host and the second host based on the respective connection bandwidths of the second physical network ports; and

transferring data with the second host via the subset of the available communication routes,

wherein the network is a storage area network (SAN), the first host is an initiator host and the second host is a storage host that provides storage services for the initiator host via the SAN through a SAN protocol, wherein generating connectivity information comprises:

generating connectivity information describing a plurality of available communication routes in the SAN between

a plurality of first physical network ports of the initiator host and a plurality of second physical network ports of the storage host that provide storage services for the initiator host via the SAN.

18. The computer readable medium of claim **17**, wherein the first physical ports have different physical addresses and a single network address.

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