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(54) DYNAMIC GRANULARITY IN DATA REPLICATION

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G06F 17/00 (2006.01)
G06F 11/14 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 11/1446*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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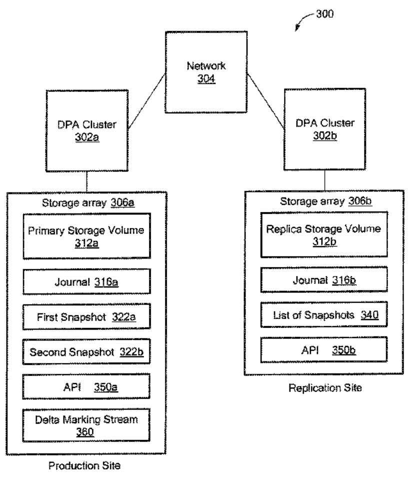
(57) **ABSTRACT**

In one aspect, a method includes sending a snapshot of a primary volume to a replica site, determining if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume and sending the changes from the primary volume if the bandwidth is available.

13 Claims, 10 Drawing Sheets



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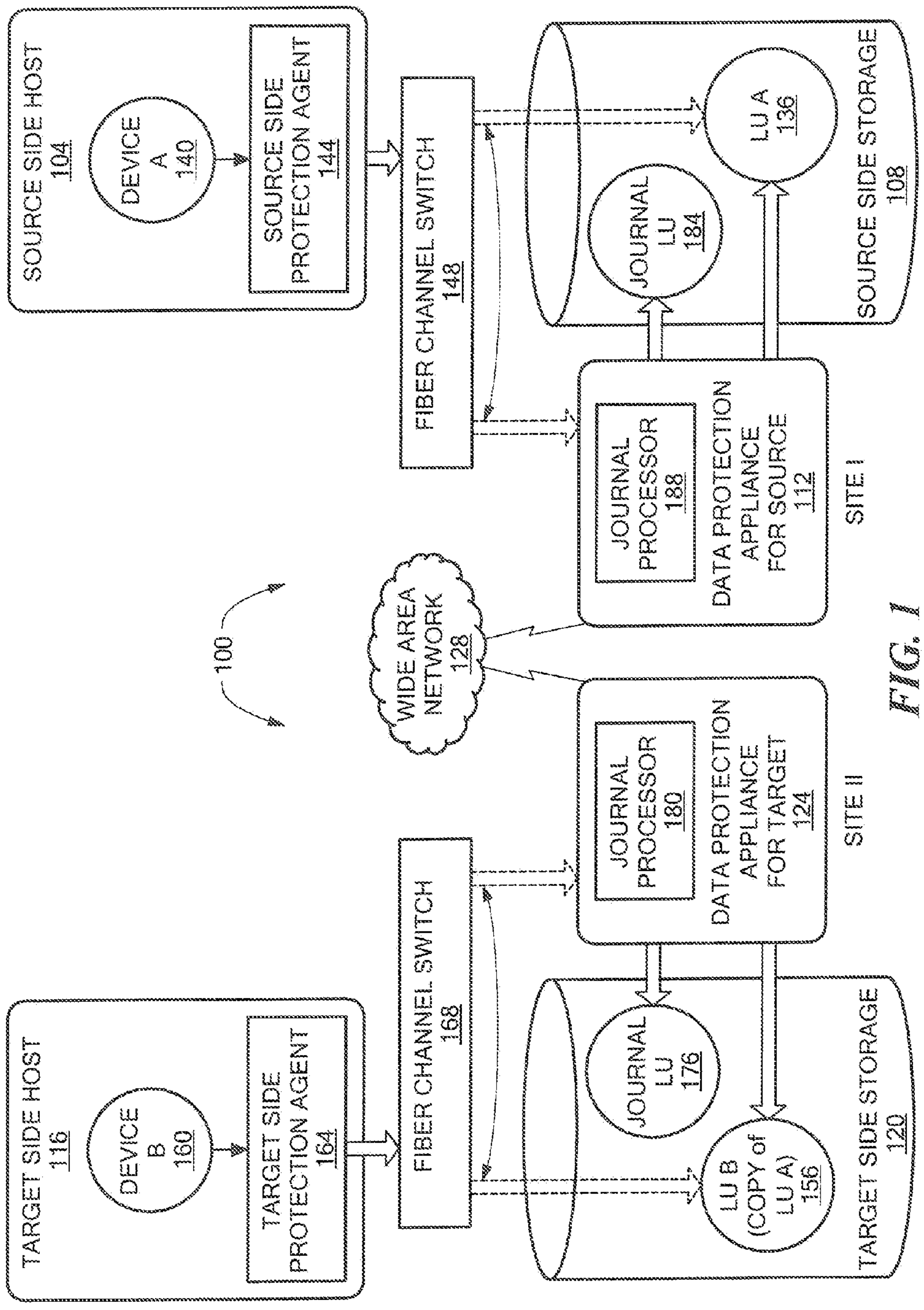

100
SOURCE SIDE HOST 104
DEVICE A 140
SOURCE SIDE PROTECTION AGENT 144
FIBER CHANNEL SWITCH 148
JOURNAL LU 184
LU A 136
SOURCE SIDE STORAGE 108
JOURNAL PROCESSOR 188
DATA PROTECTION APPLIANCE FOR SOURCE 112
SITE I
WIDE AREA NETWORK 128
JOURNAL PROCESSOR 180
DATA PROTECTION APPLIANCE FOR TARGET 124
SITE II
TARGET SIDE HOST 116
DEVICE B 160
TARGET SIDE PROTECTION AGENT 164
FIBER CHANNEL SWITCH 168
JOURNAL LU 176
LU B (COPY of LU A) 156
TARGET SIDE STORAGE 120

FIG. 1

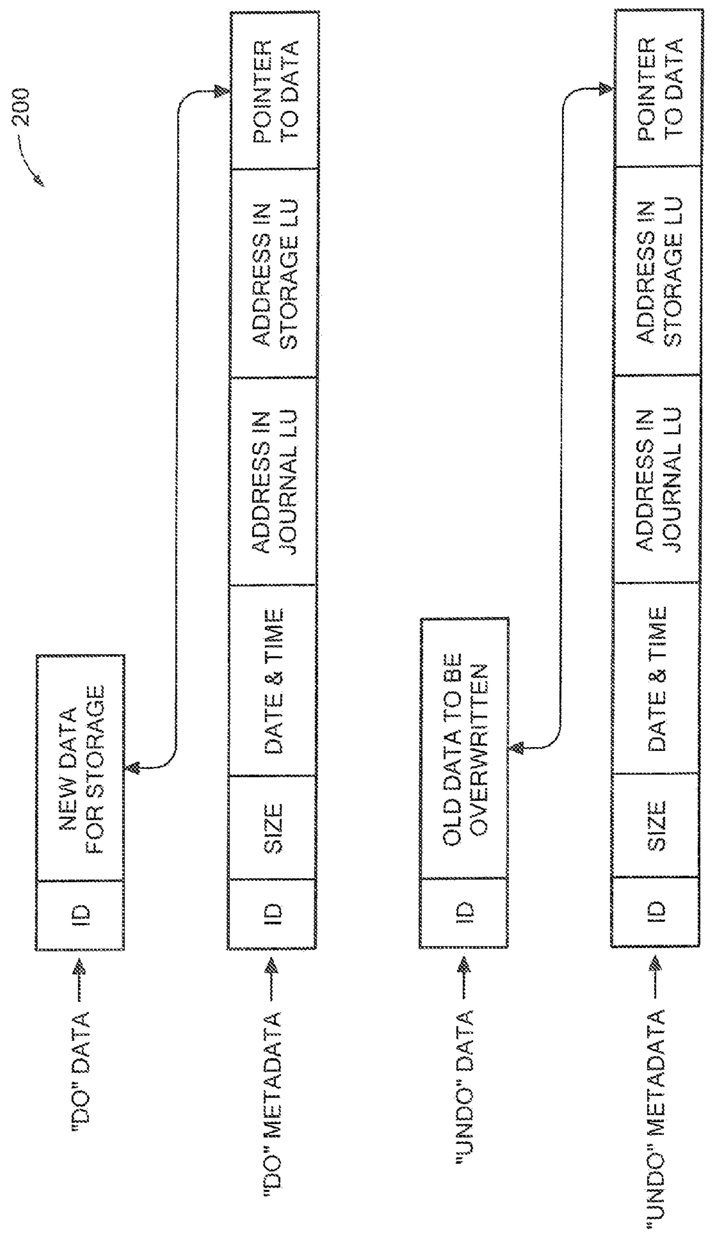

200
"DO" DATA
ID
NEW DATA FOR STORAGE
"DO" METADATA
ID
SIZE
DATE & TIME
ADDRESS IN JOURNAL LU
ADDRESS IN STORAGE LU
POINTER TO DATA
"UNDO" DATA
ID
OLD DATA TO BE OVERWRITTEN
"UNDO" METADATA
ID
SIZE
DATE & TIME
ADDRESS IN JOURNAL LU
ADDRESS IN STORAGE LU
POINTER TO DATA

FIG. 2

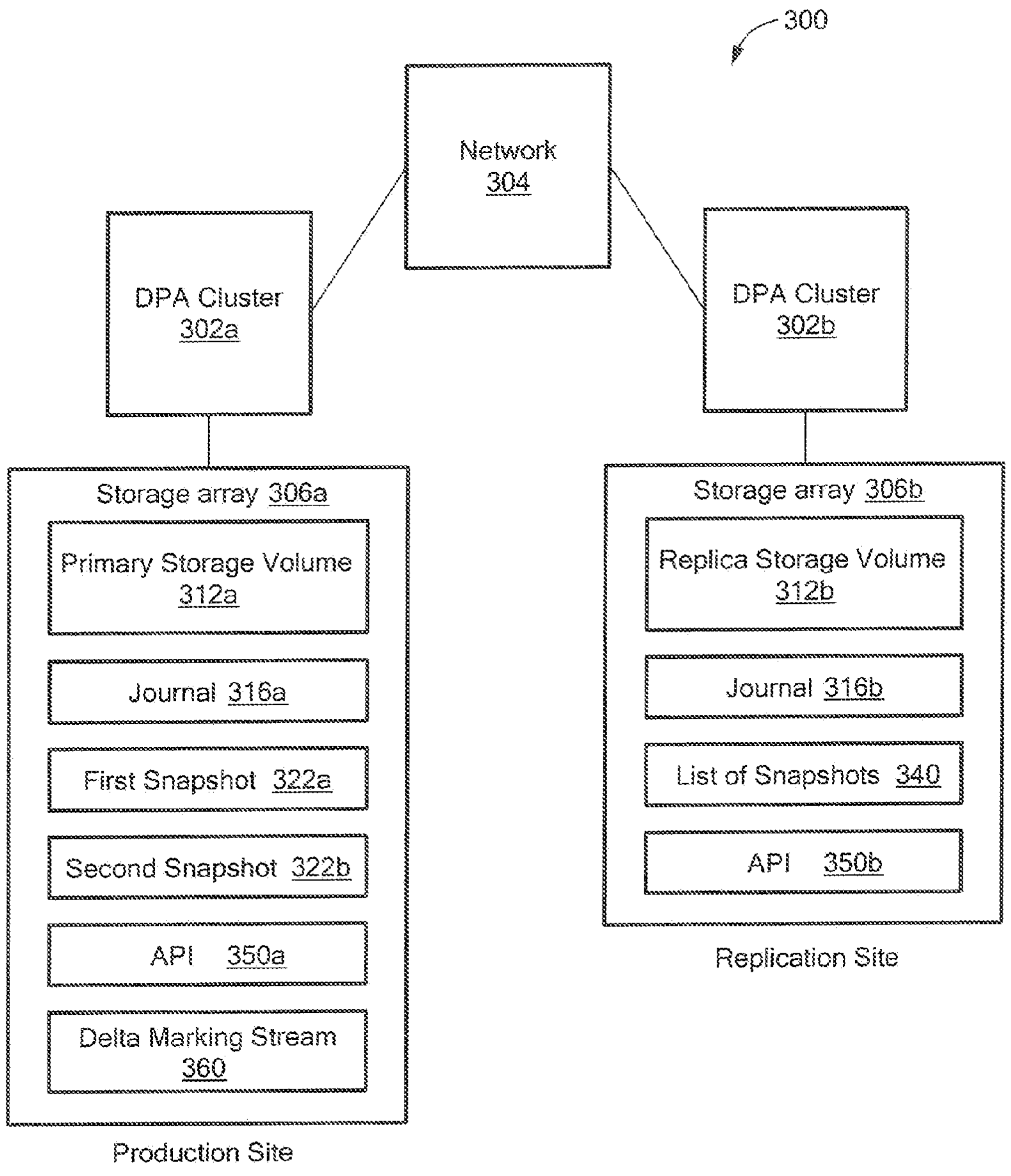

300
Network 304
DPA Cluster 302a
DPA Cluster 302b
Storage array 306a
Primary Storage Volume 312a
Journal 316a
First Snapshot 322a
Second Snapshot 322b
API 350a
Delta Marking Stream 360
Production Site
Storage array 306b
Replica Storage Volume 312b
Journal 316b
List of Snapshots 340
API 350b
Replication Site

FIG. 3

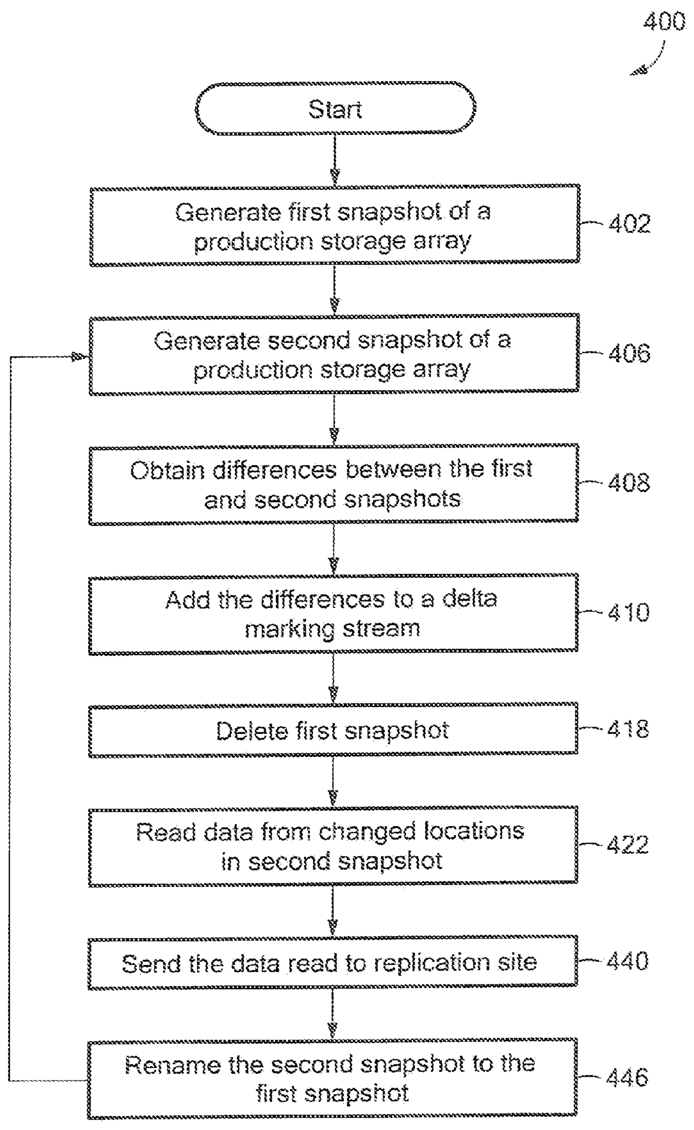

400
Start
Generate first snapshot of a production storage array
402
Generate second snapshot of a production storage array
406
Obtain differences between the first and second snapshots
408
Add the differences to a delta marking stream
410
Delete first snapshot
418
Read data from changed locations in second snapshot
422
Send the data read to replication site
440
Rename the second snapshot to the first snapshot
446

FIG. 4

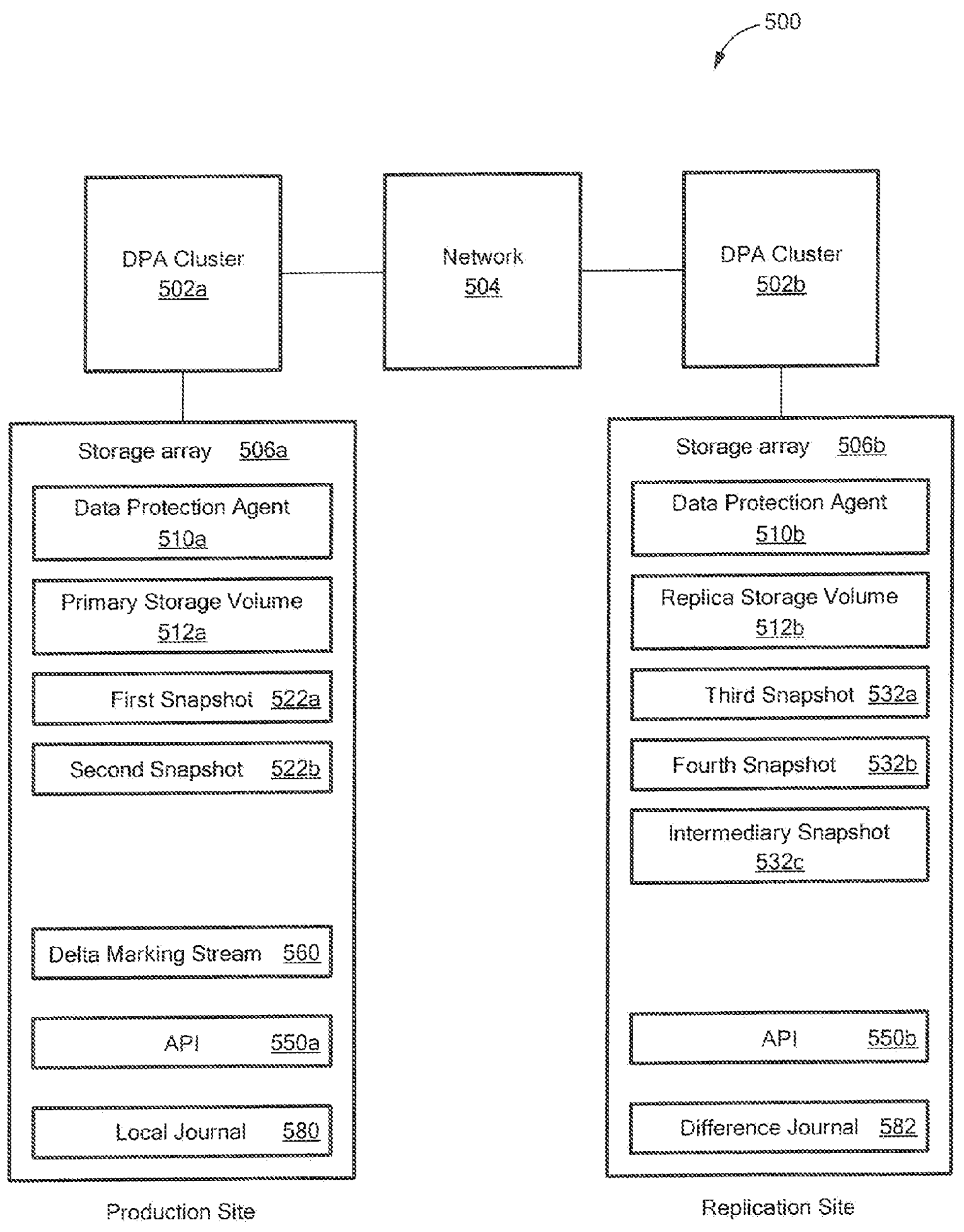
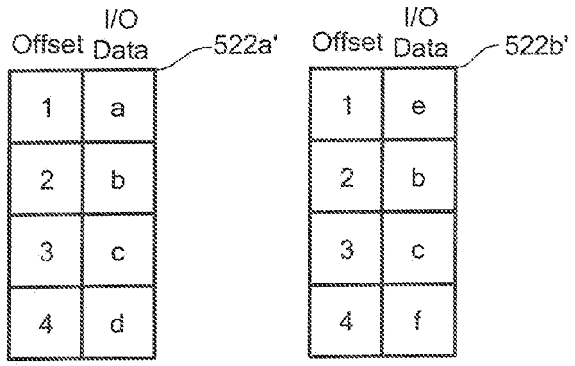

500
DPA Cluster 502a
Network 504
DPA Cluster 502b
Storage array 506a
Data Protection Agent 510a
Primary Storage Volume 512a
First Snapshot 522a
Second Snapshot 522b
Delta Marking Stream 560
API 550a
Local Journal 580
Production Site
Storage array 506b
Data Protection Agent 510b
Replica Storage Volume 512b
Third Snapshot 532a
Fourth Snapshot 532b
Intermediary Snapshot 532c
API 550b
Difference Journal 582
Replication Site

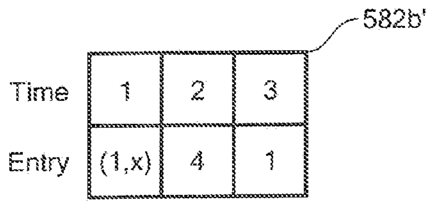
FIG. 5



Offset	I/O Data
1	a
2	b
3	c
4	d

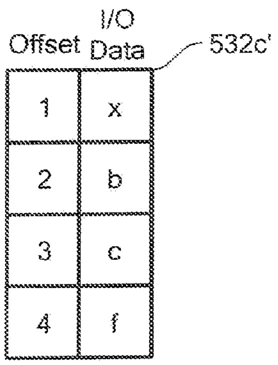
Offset	I/O Data
1	e
2	b
3	c
4	f

FIG. 6A



Time	1	2	3
Entry	(1,x)	4	1

FIG. 6B



Offset	I/O Data
1	x
2	b
3	c
4	f

FIG. 6C

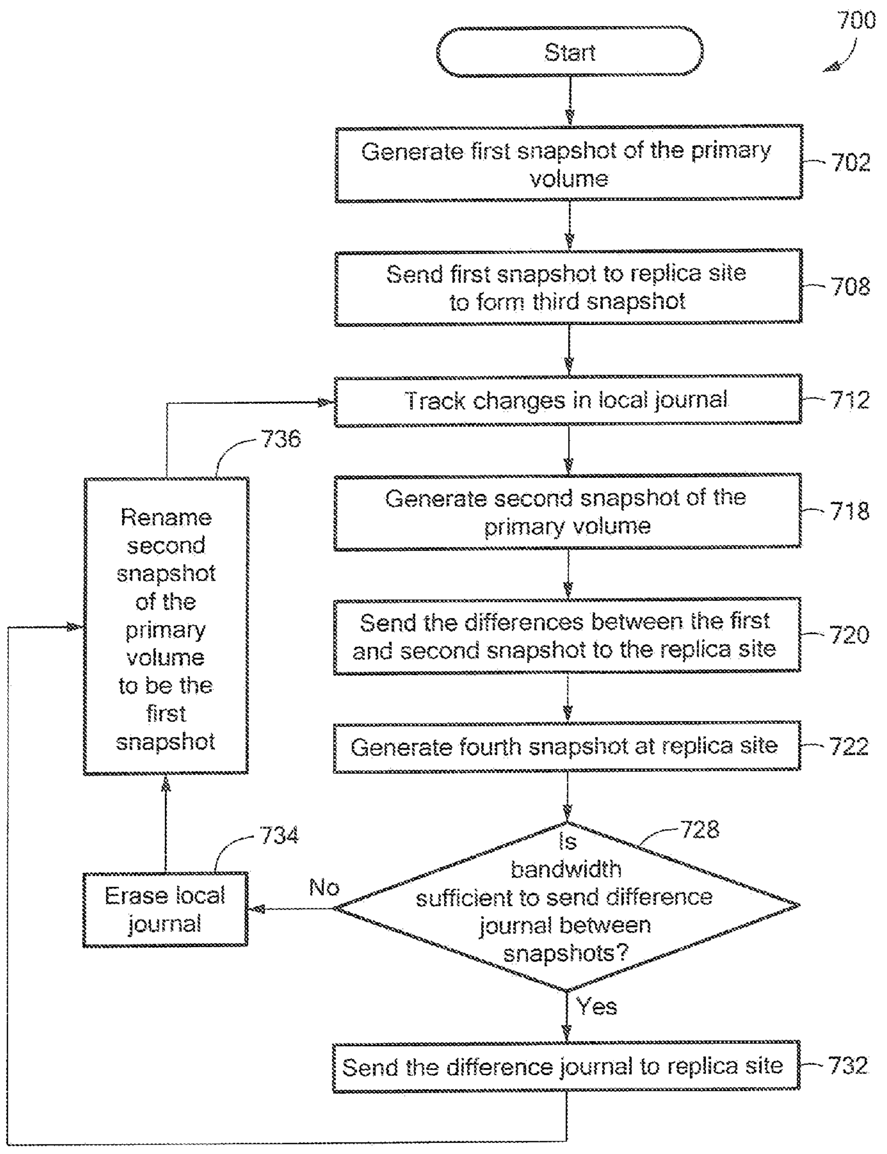

700
Start
Generate first snapshot of the primary volume
702
Send first snapshot to replica site to form third snapshot
708
Track changes in local journal
712
Generate second snapshot of the primary volume
718
Send the differences between the first and second snapshot to the replica site
720
Generate fourth snapshot at replica site
722
Is bandwidth sufficient to send difference journal between snapshots?
728
No
Yes
Send the difference journal to replica site
732
Erase local journal
734
Rename second snapshot of the primary volume to be the first snapshot
736

FIG. 7

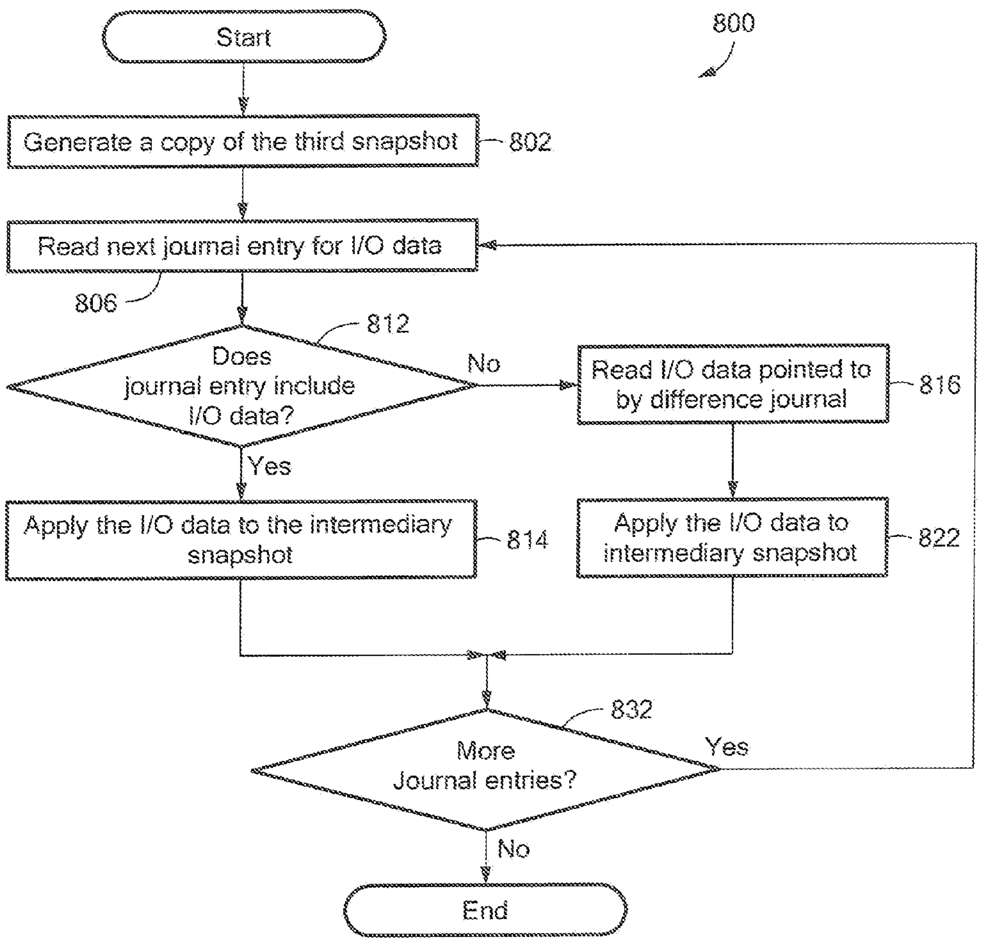

800
Start
Generate a copy of the third snapshot
802
Read next journal entry for I/O data
806
Does journal entry include I/O data?
812
No
Yes
Read I/O data pointed to by difference journal
816
Apply the I/O data to the intermediary snapshot
814
Apply the I/O data to intermediary snapshot
822
More Journal entries?
832
Yes
No
End

FIG. 8

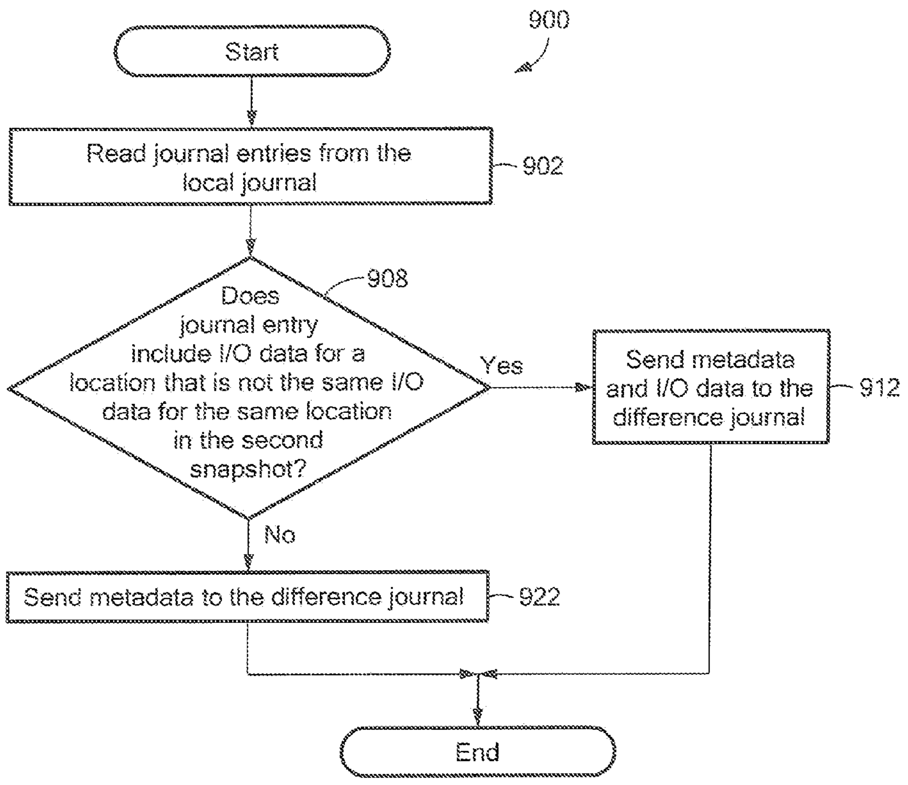

900
Start
Read journal entries from the local journal
902
908
Does journal entry include I/O data for a location that is not the same I/O data for the same location in the second snapshot?
Yes
Send metadata and I/O data to the difference journal
912
No
Send metadata to the difference journal
922
End

FIG. 9

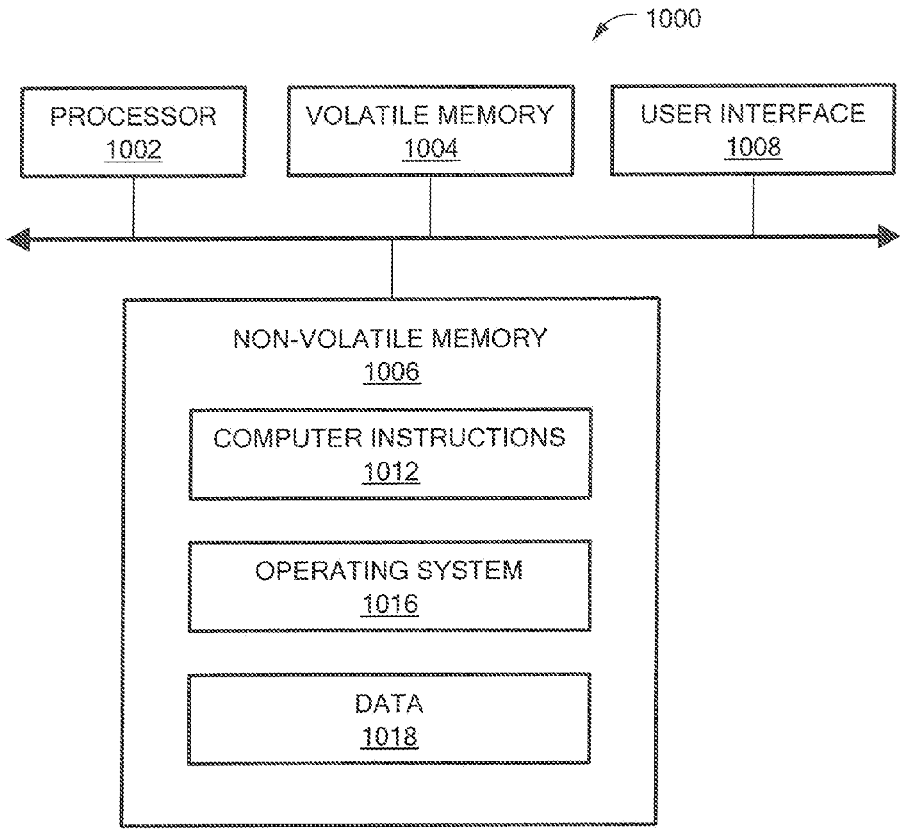

1000
PROCESSOR
1002
VOLATILE MEMORY
1004
USER INTERFACE
1008
NON-VOLATILE MEMORY
1006
COMPUTER INSTRUCTIONS
1012
OPERATING SYSTEM
1016
DATA
1018

FIG. 10

DYNAMIC GRANULARITY IN DATA REPLICATION

BACKGROUND

Computer data is vital to today's organizations and a significant part of protection against disasters is focused on data protection. As solid-state memory has advanced to the point where cost of memory has become a relatively insignificant factor, organizations can afford to operate with systems that store and process terabytes of data.

Conventional data protection systems include tape backup drives, for storing organizational production site data on a periodic basis. Another conventional data protection system uses data replication, by creating a copy of production site data of an organization on a secondary backup storage system, and updating the backup with changes. The backup storage system may be situated in the same physical location as the production storage system, or in a physically remote location. Data replication systems generally operate either at the application level, at the file system level, or at the data block level.

SUMMARY

In one aspect, a method includes sending a snapshot of a primary volume to a replica site, determining if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume and sending the changes from the primary volume if the bandwidth is available.

In another aspect, an apparatus includes electronic hardware circuitry configured to send a snapshot of a primary volume to a replica site, determine if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume and send the changes from the primary volume if the bandwidth is available.

In a further aspect, an article includes a non-transitory computer-readable medium that stores computer-executable instructions. The instructions cause a machine to send a snapshot of a primary volume to a replica site, determine if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume and send the changes from the primary volume if the bandwidth is available.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an example of a data protection system used with a continuous replication mode.

FIG. **2** is an illustration of an example of a journal history of write transactions for a storage system.

FIG. **3** is a block diagram of an example of a data protection system used with a snapshot shipping mode.

FIG. **4** is a flowchart of an example of a process to replicate data from a production site to a replication site using the snapshot shipping mode.

FIG. **5** is a block diagram of an example of a data protection system used with the continuous replication mode and the snapshot shipping mode.

FIG. **6**A are block diagrams of examples of snapshots.

FIG. **6**B is a block diagram of a difference journal.

FIG. **6**C is a block diagram of an intermediary snapshot.

FIG. **7** is a flowchart of an example of a process to send written changes to a volume between two snapshots.

FIG. **8** is a flowchart of an example of a process to access a point in time between two snapshots at the replica site.

FIG. **9** is a flowchart of an example of a process to populate a difference journal.

FIG. **10** is a computer on which any of the processes of FIGS. **7** to **9** may be implemented.

DETAILED DESCRIPTION

Described herein is an approach to allow for shipping a snapshot from a production site to a replica site and, depending if there is enough bandwidth, to allow for sending a journal of differences to the replica site to allow any point in time recovery.

The following definitions may be useful in understanding the specification and claims.

BACKUP SITE—a facility where replicated production site data is stored; the backup site may be located in a remote site or at the same location as the production site;

BOOKMARK—a bookmark is metadata information stored in a replication journal which indicates a point in time.

DATA PROTECTION APPLIANCE (DPA)—a computer or a cluster of computers responsible for data protection services including inter alia data replication of a storage system, and journaling of I/O requests issued by a host computer to the storage system;

HOST—at least one computer or networks of computers that runs at least one data processing application that issues I/O requests to one or more storage systems; a host is an initiator with a SAN;

HOST DEVICE—an internal interface in a host, to a logical storage unit;

IMAGE—a copy of a logical storage unit at a specific point in time;

INITIATOR—a node in a SAN that issues I/O requests;

I/O DATA—Data that will be or is written to a volume by, for example, an application, sometimes called write transaction data or write data;

I/O REQUEST—an input/output request (sometimes referred to as an I/O), which may be a read I/O request (sometimes referred to as a read request or a read) or a write I/O request (sometimes referred to as a write request or a write);

JOURNAL—a record of write transactions issued to a storage system; used to maintain a duplicate storage system, and to roll back the duplicate storage system to a previous point in time;

LOGICAL UNIT—a logical entity provided by a storage system for accessing data from the storage system. The logical disk may be a physical logical unit or a virtual logical unit;

LUN—a logical unit number for identifying a logical unit;

PHYSICAL LOGICAL UNIT—a physical entity, such as a disk or an array of disks, for storing data in storage locations that can be accessed by address;

PRODUCTION SITE—a facility where one or more host computers run data processing applications that write data to a storage system and read data from the storage system;

REMOTE ACKNOWLEDGEMENTS—an acknowledgement from remote DPA to the local DPA that data arrived at the remote DPA (either to the appliance or the journal)

SPLITTER ACKNOWLEDGEMENT—an acknowledgement from a DPA to the protection agent (splitter) that data has been received at the DPA; this may be achieved by an SCSI status command.

SAN—a storage area network of nodes that send and receive an I/O and other requests, each node in the network being an initiator or a target, or both an initiator and a target;

SOURCE SIDE—a transmitter of data within a data replication workflow, during normal operation a production site is the source side; and during data recovery a backup site is the source side, sometimes called a primary side;

STORAGE SYSTEM—a SAN entity that provides multiple logical units for access by multiple SAN initiators

TARGET—a node in a SAN that replies to I/O requests;

TARGET SIDE—a receiver of data within a data replication workflow; during normal operation a back site is the target side, and during data recovery a production site is the target side, sometimes called a secondary side;

VIRTUAL LOGICAL UNIT—a virtual storage entity which is treated as a logical unit by virtual machines;

WAN—a wide area network that connects local networks and enables them to communicate with one another, such as the Internet.

A description of journaling and some techniques associated with journaling may be described in the patent titled "METHODS AND APPARATUS FOR OPTIMAL JOURNALING FOR CONTINUOUS DATA REPLICATION" and with U.S. Pat. No. 7,516,287, which is hereby incorporated by reference.

An Example of a Replication System Used with a Continuous Replication Mode (FIGS. **1** and **2**)

Referring to FIG. **1**, a data protection system **100** includes two sites; Site I, which is a production site, and Site II, which is a backup site or replica site. Under normal operation the production site is the source side of system **100**, and the backup site is the target side of the system. The backup site is responsible for replicating production site data. Additionally, the backup site enables roll back of Site I data to an earlier pointing time, which may be used in the event of data corruption of a disaster, or alternatively in order to view or to access data from an earlier point in time.

FIG. **1** is an overview of a system for data replication of either physical or virtual logical units. Thus, one of ordinary skill in the art would appreciate that in a virtual environment a hypervisor, in one example, would consume logical units and generate a distributed file system on them such as VMFS creates files in the file system and expose the files as logical units to the virtual machines (each VMDK is seen as a SCSI device by virtual hosts). In another example, the hypervisor consumes a network based file system and exposes files in the NFS as SCSI devices to virtual hosts.

During normal operations, the direction of replicate data flow goes from source side to target side. It is possible, however, for a user to reverse the direction of replicate data flow, in which case Site I starts to behave as a target backup site, and Site II starts to behave as a source production site. Such change of replication direction is referred to as a "failover". A failover may be performed in the event of a disaster at the production site, or for other reasons. In some data architectures, Site I or Site II behaves as a production site for a portion of stored data, and behaves simultaneously as a backup site for another portion of stored data. In some data architectures, a portion of stored data is replicated to a backup site, and another portion is not.

The production site and the backup site may be remote from one another, or they may both be situated at a common site, local to one another. Local data protection has the advantage of minimizing data lag between target and source, and remote data protection has the advantage is being robust in the event that a disaster occurs at the source side.

The source and target sides communicate via a wide area network (WAN) **128**, although other types of networks may be used.

Each side of system **100** includes three major components coupled via a storage area network (SAN); namely, (i) a storage system, (ii) a host computer, and (iii) a data protection appliance (DPA). Specifically with reference to FIG. **1**, the source side SAN includes a source host computer **104**, a source storage system **108**, and a source DPA **112**. Similarly, the target side SAN includes a target host computer **116**, a target storage system **120**, and a target DPA **124**. As well, the protection agent (sometimes referred to as a splitter) may run on the host, or on the storage, or in the network or at a hypervisor level, and that DPAs are optional and DPA code may run on the storage array too, or the DPA **124** may run as a virtual machine.

Generally, a SAN includes one or more devices, referred to as "nodes". A node in a SAN may be an "initiator" or a "target", or both. An initiator node is a device that is able to initiate requests to one or more other devices; and a target node is a device that is able to reply to requests, such as SCSI commands, sent by an initiator node. A SAN may also include network switches, such as fiber channel switches. The communication links between each host computer and its corresponding storage system may be any appropriate medium suitable for data transfer, such as fiber communication channel links.

The host communicates with its corresponding storage system using small computer system interface (SCSI) commands.

System **100** includes source storage system **108** and target storage system **120**. Each storage system includes physical storage units for storing data, such as disks or arrays of disks. Typically, storage systems **108** and **120** are target nodes. In order to enable initiators to send requests to storage system **108**, storage system **108** exposes one or more logical units (LU) to which commands are issued. Thus, storage systems **108** and **120** are SAN entities that provide multiple logical units for access by multiple SAN initiators.

Logical units are a logical entity provided by a storage system, for accessing data stored in the storage system. The logical unit may be a physical logical unit or a virtual logical unit. A logical unit is identified by a unique logical unit number (LUN). Storage system **108** exposes a logical unit **136**, designated as LU A, and storage system **120** exposes a logical unit **156**, designated as LU B.

LU B is used for replicating LU A. As such, LU B is generated as a copy of LU A. In one embodiment, LU B is configured so that its size is identical to the size of LU A. Thus, for LU A, storage system **120** serves as a backup for source side storage system **108**. Alternatively, as mentioned hereinabove, some logical units of storage system **120** may be used to back up logical units of storage system **108**, and other logical units of storage system **120** may be used for other purposes. Moreover, there is symmetric replication whereby some logical units of storage system **108** are used for replicating logical units of storage system **120**, and other logical units of storage system **120** are used for replicating other logical units of storage system **108**.

System **100** includes a source side host computer **104** and a target side host computer **116**. A host computer may be one computer, or a plurality of computers, or a network of distributed computers, each computer may include inter alia a conventional CPU, volatile and non-volatile memory, a data bus, an I/O interface, a display interface and a network interface. Generally a host computer runs at least one data processing application, such as a database application and an e-mail server.

Generally, an operating system of a host computer creates a host device for each logical unit exposed by a storage system in the host computer SAN. A host device is a logical entity in a host computer, through which a host computer may access a logical unit. Host device **104** identifies LU A and generates a corresponding host device **140**, designated as Device A, through which it can access LU A. Similarly, host computer **116** identifies LU B and generates a corresponding device **160**, designated as Device B.

In the course of continuous operation, host computer **104** is a SAN initiator that issues I/O requests (write/read operations) through host device **140** to LU A using, for example, SCSI commands. Such requests are generally transmitted to LU A with an address that includes a specific device identifier, an offset within the device, and a data size. Offsets are generally aligned to 512 byte blocks. The average size of a write operation issued by host computer **104** may be, for example, 10 kilobytes (KB); i.e., 20 blocks. For an I/O rate of 50 megabytes (MB) per second, this corresponds to approximately 5,000 write transactions per second.

System **100** includes two data protection appliances, a source side DPA **112** and a target side DPA **124**. A DPA performs various data protection services, such as data replication of a storage system, and journaling of I/O requests issued by a host computer to source side storage system data. As explained in detail herein, when acting as a target side DPA, a DPA may also enable roll back of data to an earlier point in time, and processing of rolled back data at the target site. Each DPA **112** and **124** is a computer that includes inter alia one or more conventional CPUs and internal memory.

For additional safety precaution, each DPA is a cluster of such computers. Use of a cluster ensures that if a DPA computer is down, then the DPA functionality switches over to another computer. The DPA computers within a DPA cluster communicate with one another using at least one communication link suitable for data transfer via fiber channel or IP based protocols, or such other transfer protocol. One computer from the DPA cluster serves as the DPA leader. The DPA cluster leader coordinates between the computers in the cluster, and may also perform other tasks that require coordination between the computers, such as load balancing.

In the architecture illustrated in FIG. **1**, DPA **112** and DPA **124** are standalone devices integrated within a SAN. Alternatively, each of DPA **112** and DPA **124** may be integrated into storage system **108** and storage system **120**, respectively, or integrated into host computer **104** and host computer **116**, respectively. Both DPAs communicate with their respective host computers through communication lines such as fiber channels using, for example, SCSI commands or any other protocol.

DPAs **112** and **124** are configured to act as initiators in the SAN; i.e., they can issue I/O requests using, for example, SCSI commands, to access logical units on their respective storage systems. DPA **112** and DPA **124** are also configured with the necessary functionality to act as targets; i.e., to reply to I/O requests, such as SCSI commands, issued by other initiators in the SAN, including inter alia their respective host computers **104** and **116**. Being target nodes, DPA **112** and DPA **124** may dynamically expose or remove one or more logical units.

As described hereinabove, Site I and Site II may each behave simultaneously as a production site and a backup site for different logical units. As such, DPA **112** and DPA **124** may each behave as a source DPA for some logical units, and as a target DPA for other logical units, at the same time.

Host computer **104** and host computer **116** include protection agents **144** and **164**, respectively. Protection agents **144** and **164** intercept SCSI commands issued by their respective host computers, via host devices to logical units that are accessible to the host computers. A data protection agent may act on an intercepted SCSI commands issued to a logical unit, in one of the following ways: send the SCSI commands to its intended logical unit; redirect the SCSI command to another logical unit; split the SCSI command by sending it first to the respective DPA; after the DPA returns an acknowledgement, send the SCSI command to its intended logical unit; fail a SCSI command by returning an error return code; and delay a SCSI command by not returning an acknowledgement to the respective host computer.

A protection agent may handle different SCSI commands, differently, according to the type of the command. For example, a SCSI command inquiring about the size of a certain logical unit may be sent directly to that logical unit, while a SCSI write command may be split and sent first to a DPA associated with the agent. A protection agent may also change its behavior for handling SCSI commands, for example as a result of an instruction received from the DPA.

Specifically, the behavior of a protection agent for a certain host device generally corresponds to the behavior of its associated DPA with respect to the logical unit of the host device. When a DPA behaves as a source site DPA for a certain logical unit, then during normal course of operation, the associated protection agent splits I/O requests issued by a host computer to the host device corresponding to that logical unit. Similarly, when a DPA behaves as a target device for a certain logical unit, then during normal course of operation, the associated protection agent fails I/O requests issued by host computer to the host device corresponding to that logical unit.

Communication between protection agents and their respective DPAs may use any protocol suitable for data transfer within a SAN, such as fiber channel, or SCSI over fiber channel. The communication may be direct, or via a logical unit exposed by the DPA. Protection agents communicate with their respective DPAs by sending SCSI commands over fiber channel.

Protection agents **144** and **164** are drivers located in their respective host computers **104** and **116**. Alternatively, a protection agent may also be located in a fiber channel switch, or in any other device situated in a data path between a host computer and a storage system or on the storage system itself. In a virtualized environment, the protection agent may run at the hypervisor layer or in a virtual machine providing a virtualization layer.

What follows is a detailed description of system behavior under normal production mode, and under recovery mode.

In production mode DPA **112** acts as a source site DPA for LU A. Thus, protection agent **144** is configured to act as a source side protection agent; i.e., as a splitter for host device A. Specifically, protection agent **144** replicates SCSI I/O write requests. A replicated SCSI I/O write request is sent to DPA **112**. After receiving an acknowledgement from DPA **124**, protection agent **144** then sends the SCSI I/O write request to LU A. After receiving a second acknowledgement from storage system **108** host computer **104** acknowledges that an I/O command complete.

When DPA **112** receives a replicated SCSI write request from data protection agent **144**, DPA **112** transmits certain I/O information characterizing the write request, packaged as a "write transaction", over WAN **128** to DPA **124** on the target side, for journaling and for incorporation within target storage system **120**.

DPA **112** may send its write transactions to DPA **124** using a variety of modes of transmission, including inter alia (i) a synchronous mode, (ii) an asynchronous mode, and (iii) a snapshot mode. In synchronous mode, DPA **112** sends each write transaction to DPA **124**, receives back an acknowledgement from DPA **124**, and in turns sends an acknowledgement back to protection agent **144**. Protection agent **144** waits until receipt of such acknowledgement before sending the SCSI write request to LU A.

In asynchronous mode, DPA **112** sends an acknowledgement to protection agent **144** upon receipt of each I/O request, before receiving an acknowledgement back from DPA **124**.

In snapshot mode, DPA **112** receives several I/O requests and combines them into an aggregate "snapshot" of all write activity performed in the multiple I/O requests, and sends the snapshot to DPA **124**, for journaling and for incorporation in target storage system **120**. In snapshot mode DPA **112** also sends an acknowledgement to protection agent **144** upon receipt of each I/O request, before receiving an acknowledgement back from DPA **124**.

For the sake of clarity, the ensuing discussion assumes that information is transmitted at write-by-write granularity.

While in production mode, DPA **124** receives replicated data of LU A from DPA **112**, and performs journaling and writing to storage system **120**. When applying write operations to storage system **120**, DPA **124** acts as an initiator, and sends SCSI commands to LU B.

During a recovery mode, DPA **124** undoes the write transactions in the journal, so as to restore storage system **120** to the state it was at, at an earlier time.

As described hereinabove, LU B is used as a backup of LU A. As such, during normal production mode, while data written to LU A by host computer **104** is replicated from LU A to LU B, host computer **116** should not be sending I/O requests to LU B. To prevent such I/O requests from being sent, protection agent **164** acts as a target site protection agent for host Device B and fails I/O requests sent from host computer **116** to LU B through host Device B.

Target storage system **120** exposes a logical unit **176**, referred to as a "journal LU", for maintaining a history of write transactions made to LU B, referred to as a "journal". Alternatively, journal LU **176** may be striped over several logical units, or may reside within all of or a portion of another logical unit. DPA **124** includes a journal processor **180** for managing the journal.

Journal processor **180** functions generally to manage the journal entries of LU B. Specifically, journal processor **180** enters write transactions received by DPA **124** from DPA **112** into the journal, by writing them into the journal LU, reads the undo information for the transaction from LU B. updates the journal entries in the journal LU with undo information, applies the journal transactions to LU B, and removes already-applied transactions from the journal.

Referring to FIG. **2**, which is an illustration of a write transaction **200** for a journal. The journal may be used to provide an adaptor for access to storage **120** at the state it was in at any specified point in time. Since the journal contains the "undo" information necessary to roll back storage system **120**, data that was stored in specific memory locations at the specified point in time may be obtained by undoing write transactions that occurred subsequent to such point in time.

Write transaction **200** generally includes the following fields: one or more identifiers; a time stamp, which is the date & time at which the transaction was received by source side DPA **112**; a write size, which is the size of the data block; a location in journal LU **176** where the data is entered; a location in LU B where the data is to be written; and the data itself.

Write transaction **200** is transmitted from source side DPA **112** to target side DPA **124**. As shown in FIG. **2**, DPA **124** records the write transaction **200** in the journal that includes four streams. A first stream, referred to as a DO stream, includes new data for writing in LU B. A second stream,

referred to as an DO METADATA stream, includes metadata for the write transaction, such as an identifier, a date & time, a write size, a beginning address in LU B for writing the new data in, and a pointer to the offset in the DO stream where the corresponding data is located. Similarly, a third stream, referred to as an UNDO stream, includes old data that was overwritten in LU B; and a fourth stream, referred to as an UNDO METADATA, include an identifier, a date & time, a write size, a beginning address in LU B where data was to be overwritten, and a pointer to the offset in the UNDO stream where the corresponding old data is located.

In practice each of the four streams holds a plurality of write transaction data. As write transactions are received dynamically by target DPA **124**, they are recorded at the end of the DO stream and the end of the DO METADATA stream, prior to committing the transaction. During transaction application, when the various write transactions are applied to LU B, prior to writing the new DO data into addresses within the storage system, the older data currently located in such addresses is recorded into the UNDO stream. In some examples, the metadata stream (e.g., UNDO METADATA stream or the DO METADATA stream) and the data stream (e.g., UNDO stream or DO stream) may be kept in a single stream each (i.e., one UNDO data and UNDO METADATA stream and one DO data and DO METADATA stream) by interleaving the metadata into the data stream.

An Example of a Replication System Used with a Snapshot Shipping Mode (FIGS. **3** and **4**)

Referring to FIG. **3**, a data protection system **300** includes a data protection appliance (DPA) cluster **302*a*** and a storage array **306*a*** at a production site and a DPA cluster **302*b*** and a storage array **306*b*** at a replication site. The DPA clusters **302*a***, **302*b*** are connected by a network **304** (e.g., a WAN, a Fibre Channel and so forth).

The storage array **306*a*** includes a primary storage volume **312*a***, a journal **316*a***, a first snapshot **322*a***, a second snapshot **322*b***, APIs **350*a*** and a delta marking stream **360**. The storage array **306*b*** includes a replica storage volume **312*b*** which replicates the primary storage **312*a***, a journal **316*b***, a list of snapshots **340**, and APIs **350*b***.

Referring to FIG. **4**, an example of a process to send data from the production site to the replication site using a snapshot shipping mode is a process **400**. Process **400** generates a first snapshot of a production storage array (**402**). For example, the DPA cluster **302*a*** generates a first snapshot **322*a*** of the primary storage volume **312*a***. In one example, the DPA cluster **302*a*** generates the first snapshot **322*a*** using the API **350*a***. At first time initialization, the first snapshot is sent to the replica site.

Process **400** generates a second snapshot of a production storage array (**406**). For example, the DPA cluster **302*a*** generates a second snapshot **322*b*** of the primary storage volume **312*a***. In one example, the DPA cluster **302*a*** generates the second snapshot **322*b*** using the API **350*a***.

Process **400** obtains differences between the first snapshot and the second snapshot (**408**). For example, the DPA cluster **302*a*** obtains the differences between the first snapshot **322*a*** and the second snapshot **322*b*** by using the API **350*a***.

In one example, obtaining the differences between the first snapshot and the second snapshot may be performed by executing a vendor specific read difference command. The read difference command is a vendor specific command which returns locations of the difference and data in the locations. In one example, the result of executing the read difference command is a sequence of (location, length); (location, length) and so forth. In other examples, the read difference command returns a change bitmap.

Process **400** adds the differences to a delta marking stream (**410**). For example, the DPA cluster **302***a* adds the differences obtained in processing block **408** to the delta marking stream **360** using an the API **350***a*.

Process **400** deletes the first snapshot (**418**). For example, the DPA cluster **302***a* deletes the first snapshot **322***a*.

Process **400** reads the data that changed in the second snapshot (**422**) and sends the data to the replication site (**440**). For example, the DPA cluster **302***a* reads the data that changed in the second snapshot **322***b* and sends the data to the DPA cluster **302***b*.

Process **400** renames the second snapshot to the first snapshot (**446**) and performs processing block **406**. For example, the DPA cluster **302***a* renames the second snapshot to the first snapshot.

Referring to FIG. **5**, a data protection system **500** includes a data protection appliance (DPA) cluster **502***a* and a storage array **506***a* at a production site and a DPA cluster **502***b* and a storage array **506***b* at a replication site. The DPA clusters **302***a*, **302***b* are connected by a network **504** (e.g., a WAN, a Fibre Channel and so forth). The data protection system **500** can perform continuous replication as described in FIGS. **1** and **2** and can perform snapshot shipping as described in FIGS. **3** and **4**.

The storage array **506***a* includes a data protections agent **510***a* (similar to the data protection agent **144** in FIG. **1** but located at a storage array), a primary storage volume **512***a*, a first snapshot **522***a*, a second snapshot **522***b*, API **550***a*, a delta marking stream **560** and a local journal **580**. The storage array **306***b* includes a data protections agent **510***b* (similar to the data protection agent **164** in FIG. **1** but located at a storage array), a replica storage volume **512***b* which replicates the primary storage **512***a*, a third snapshot **532***a*, a fourth snapshot **532***b*, an intermediary snapshot **532***c*, API **350***b* and a difference journal **582**.

Referring to FIG. **6**A, an example of a first snapshot **522***a*' of the primary storage volume **512***a* includes four offsets (locations) labeled **1** to **4** with I/O data a, b, c and d respectively. An example of a second snapshot **522***a*' of the primary storage volume **512***a* includes four offsets (locations) labeled **1** to **4** with I/O data e, b, c and f respectively. Thus, the only changes that occurred between the first and second snapshots are at offset **1** and offset **4**.

Between the first snapshot and the second snapshot there are three increments of time where I/O data was written to the primary storage volume **512***a*. At time **1**, the offset **1** with I/O data a is overwritten with I/O data x. At time **2**, offset **4** with I/O data d is overwritten with I/O data f. At time **3**, offset **1** with I/O data x is overwritten with I/O data e.

Referring to FIG. **6**B, an example of a difference journal **582** is a difference journal **582**'. The difference journal **582**' records the changes between the first and second snapshots. For example, each journal entry in the differences journal **582** includes an offset of where the I/O data was written but may or may not include I/O data for that change. I/O data may not be included if it is already part of the second snapshot.

In this example, at time **1**, an entry includes the offset **1** and data x. At time **2**, an entry includes offset **4**. No data needs to be included since the data (data f) written at time **2** is part of the second snapshot for that offset. At time **3**, an entry includes offset **1**. Again, no data needs to be included since the data (data e) written at time **3** is part of the second snapshot for that offset. Data is included in the difference journal **582** if and only if the location was overwritten more than twice during the time period between the two different snapshots that the difference journal **582** describes and the data in the location is not already part of the second snapshot (since otherwise the data is on the second snapshot and only the metadata is needed).

Referring to FIG. **7**, an example of a process to send written changes to a volume between two snapshots is a process **700**. In particular, the difference journal **582** between the first and second snapshots is sent to the replica site if there is sufficient bandwidth.

Process **700** generates the first snapshot (**702**) and sends the first snapshot to the replica site (**708**). For example, the API **550***a* is called to generate the first snapshot **522***a* of the primary storage volume **512***a* and ships the first snapshot **522***a* to the replica site to be stored at the storage array **506***b* as the third snapshot **532***a*.

Process **700** tracks the differences in the local journal (**712**). For example, the data protection agent **510***a* tracks data written in the primary storage volume **512** in a local journal **580**. In another example, the data protection agent **510***a* sends the changes to the DPA **502***a* which tracks the changes in the local journal **580**.

Process **700** generates the second snapshot of the primary volume (**718**). For example, the API **550***a* is called to generate the second snapshot **522***b* of the primary storage volume **512***a*

The differences between the second snapshot **522***b* and the first snapshot **522***a* are sent to the replica site (**720**) and a fourth snapshot **532***b* is generated at the replica site (**722**). For example, the differences between the first and second snapshots **522***a*, **522***b* are added to the third snapshot **532***a* to form the fourth snapshot **532***b*.

Process **700** determines if there is sufficient bandwidth to send the difference journal between the first and second snapshots (**728**) (i.e., the journal containing the changes which allow access to any point in time between first and second snapshots). For example, DPA **502***a* determines the size of the difference journal and the amount of bandwidth available after sending the differences between snapshots **522***a* and **522***b* to the replica site.

If there is sufficient bandwidth to send the difference journal between the first and second snapshots, process **700** sends the difference journal to the replica site (**732**), renames second snapshot of the primary volume to be first snapshot (**736**) and returns to processing block **712**. For example, the difference journal is sent and stored as the difference journal **582**.

If there is not sufficient bandwidth to send the difference journal between the first and second snapshots, process **700** erases entries in the local journal **580** describing changes between first and second snapshots (**734**), renames second snapshot of the primary volume to be first snapshot (**736**) and returns to processing block **712**.

Referring to FIG. **8**, an example of a process to access a point in time between two snapshots at the replica site is a process **800**. In particular, the process **800** enables access to an intermediary snapshot at a time between the two times the two snapshots were taken by using the differences journal **582**.

Process **800** generates a copy of the third snapshot (**802**). For example, the API **550***a* is called to generate a copy of the third snapshot **532***a* to form the intermediary snapshot **532***c*.

Process **800** reads next journal entry for I/O data (**806**). For example, the DPA **502***b* reads the first journal entry from the difference journal **582** recorded after the first snapshot of the primary storage volume.

Process **800** determines if the journal entry includes I/O data (**812**). For example, the DPA **502***b* determines if the journal entry in the differences journal **582** includes an offset and I/O data.

If the journal entry includes I/O data with an offset, process **800** applies the data to the intermediary snapshot (**814**). For example, the I/O data is applied to the offset in intermediary snapshot **532***c* formed at processing block **802**.

If the journal entry does not include I/O data, process **800** reads I/O data pointed to by the differences journal (**816**) and applies the I/O data pointed to by the difference journal to the intermediary snapshot (**822**). For example, if there is no I/O data then the I/O data stored at the same offset in the fourth snapshot **532***b* is applied to the intermediary snapshot **532***c*.

Process **800** determines if there are more journal entries (**832**). If there are more journal entries, process **800** returns to processing block **806**. If there are no more journal entries, process **800** ends.

Referring to FIG. **6**C, an example of the intermediary journal **532***c* is an intermediary journal **532***c*', which is generated using the process **800** with the difference journal **582***b*' (FIG. **6**B) at time=2.

Referring to FIG. **9**, an example of a process to populate the difference journal is a process **900**. Process **900** reads journal entries from the local journal **580** (**902**) and determines if a journal entry includes I/O data for a location (offset) that is not the same I/O data for the same location (offset) in the second snapshot **522***b* (**908**).

If the journal entry includes I/O data for a location that is not the same I/O data for the same location in the second snapshot **522***b*, process **900** sends metadata of the journal entry with the data to the difference journal **582** (**912**). If the journal entry includes I/O data for a location that is the same I/O data for the same location in the second snapshot **522***b*, only the metadata is sent to the difference journal **582** (**922**). In one example, the metadata includes at least one of an offset, a volume ID, a length of the I/O data or a number of blocks in a volume that is changed.

Referring to FIG. **10**, in one example, a computer **1000** includes a processor **1002**, a volatile memory **1004**, a non-volatile memory **1006** (e.g., hard disk) and the user interface (UI) **1008** (e.g., a graphical user interface, a mouse, a keyboard, a display, touch screen and so forth). The non-volatile memory **1006** stores computer instructions **1012**, an operating system **1016** and data **1018**. In one example, the computer instructions **1012** are executed by the processor **1002** out of volatile memory **1004** to perform all or part of the processes described herein (e.g., processes **700**, **800** and **900**).

The processes described herein (e.g., processes **700**, **800** and **900**) are not limited to use with the hardware and software of FIG. **10**; they may find applicability in any computing or processing environment and with any type of machine or set of machines that is capable of running a computer program. The processes described herein may be implemented in hardware, software, or a combination of the two. The processes described herein may be implemented in computer programs executed on programmable computers/machines that each includes a processor, a non-transitory machine-readable medium or other article of manufacture that is readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and one or more output devices. Program code may be applied to data entered using an input device to perform any of the processes described herein and to generate output information.

The system may be implemented, at least in part, via a computer program product, (e.g., in a non-transitory machine-readable storage medium such as, for example, a non-transitory computer-readable medium), for execution by, or to control the operation of; data processing apparatus (e.g., a programmable processor, a computer, or multiple computers)). Each such program may be implemented in a high level procedural or object-oriented programming language to communicate with a computer system. However, the programs may be implemented in assembly or machine language. The language may be a compiled or an interpreted language and it may be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program may be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network. A computer program may be stored on a non-transitory machine-readable medium that is readable by a general or special purpose programmable computer for configuring and operating the computer when the non-transitory machine-readable medium is read by the computer to perform the processes described herein. For example, the processes described herein may also be implemented as a non-transitory machine-readable storage medium, configured with a computer program, where upon execution, instructions in the computer program cause the computer to operate in accordance with the processes. A non-transitory machine-readable medium may include but is not limited to a hard drive, compact disc, flash memory, non-volatile memory, volatile memory, magnetic diskette and so forth but does not include a transitory signal per se.

The processes described herein are not limited to the specific examples described. For example, the processes **700**, **800** and **900** are not limited to the specific processing order of FIGS. **7** to **9**, respectively. Rather, any of the processing blocks of FIGS. **7** to **9** may be re-ordered, combined or removed, performed in parallel or in serial, as necessary, to achieve the results set forth above.

In other examples, one of ordinary skill in the art would recognize that increasing and decreasing reference counts may be done opposite as described. For example, the reference count can be decreased and then increased. One of ordinary skill in the art would also recognize that a value is changed from a first state to a second state when the signature data is needed to avoid erasure of the data and when the data is no longer needed the value returns to a first state.

The processing blocks (for example, in the processes **700**, **800** and **900**) associated with implementing the system may be performed by one or more programmable processors executing one or more computer programs to perform the functions of the system. All or part of the system may be implemented as, special purpose logic circuitry (e.g., an FPGA (field-programmable gate array) and/or an ASIC (application-specific integrated circuit)). All or part of the system may be implemented using electronic hardware circuitry that include electronic devices such as, for example, at least one of a processor, a memory, a programmable logic device or a logic gate.

Elements of different embodiments described herein may be combined to form other embodiments not specifically set forth above. Other embodiments not specifically described herein are also within the scope of the following claims.

What is claimed is:

1. A method comprising:

sending a snapshot of a primary volume to a replica site, sending the snapshot of the primary volume comprises sending a first snapshot of the primary volume to form a third snapshot;

determining if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume;

sending the changes from the primary volume if the bandwidth is available;

tracking the changes in a local journal;
generating a second snapshot of the primary volume:
sending the differences between the first and second snapshots to the replica site;
generating a fourth snapshot at the replica site by applying the differences between the first and second snapshots to the third snapshot; and
accessing an intermediary snapshot between the first snapshot and the second snapshot,
wherein accessing the intermediary snapshot comprises:
copying the third snapshot to form an intermediary snapshot;
for each journal entry in a difference journal, determining if the journal entry includes I/O data;
applying I/O data from the difference journal to the intermediary snapshot if the journal entry comprises I/O data; and
applying I/O data pointed to by the difference journal if the journal entry does not include I/O data.

2. The method of claim **1**, further comprising generating the difference journal comprising:
reading journal entries in the local journal;
for each journal entry in the local journal, determining if the I/O includes I/O data for a location that is not the same I/O data for the same location in the second snapshot;
sending metadata and I/O data to the difference journal if the I/O includes I/O data for a location that is not the same I/O data for the same location in the second snapshot; and
sending metadata to the difference journal if the I/O includes I/O data for a location that is the same I/O data for the same location in the second snapshot.

3. The method of claim **2** wherein sending metadata to the difference journal if the I/O includes I/O data for a location that is the same I/O data for the same location in the second snapshot comprises sending metadata comprising at least one of at least one of an offset, a volume ID, a length of the I/O data or a number of blocks in a volume that is changed.

4. A method comprising:
sending a snapshot of a primary volume to a replica site, sending the snapshot of the primary volume comprises sending a first snapshot of the primary volume to form a third snapshot;
determining if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume;
sending the changes from the primary volume if the bandwidth is available;
tracking the changes in a local journal:
generating a second snapshot of the primary volume;
sending the differences between the first and second snapshots to the replica site:
generating a fourth snapshot at the replica site by applying the differences between the first and second snapshots to the third snapshot; and
if the bandwidth is not available:
erasing the local journal;
renaming the second snapshot to be the first snapshot; and
repeating the tracking of changes in the local journal.

5. An apparatus, comprising:
electronic hardware circuitry configured to:
send a snapshot of a primary volume to a replica site;
determine if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume;

send the changes from the primary volume if the bandwidth is available;
track the changes in a local journal;
generate a second snapshot of the primary volume:
send the differences between a first snapshot and the second snapshot to the replica site;
generate a fourth snapshot at the replica site by applying the differences between the first and second snapshots to a third snapshot; and
access an intermediary snapshot between the first snapshot and the second snapshot comprising circuitry,
wherein the circuitry configured to send a snapshot of the primary volume comprises circuitry configured to send the first snapshot of the primary volume to form the third snapshot,
wherein the circuitry configured to access an intermediary snapshot between the first snapshot and the second snapshot comprises circuitry configured to:
copy the third snapshot to form an intermediary snapshot;
for each journal entry in a difference journal, determine if the journal entry includes I/O data;
apply I/O data from the difference journal to the intermediary snapshot if the journal entry comprises I/O data; and
apply I/O data pointed to by the difference journal if the journal entry does not include I/O data.

6. The apparatus of claim **5** wherein the circuitry comprises at least one of a processor, a memory, a programmable logic device or a logic gate.

7. An apparatus, comprising:
electronic hardware circuitry configured to:
send a snapshot of a primary volume to a replica site;
determine if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume;
send the changes from the primary volume if the bandwidth is available;
track the changes in a local journal;
generate a second snapshot of the primary volume:
send the differences between a first snapshot and the second snapshot to the replica site;
generate a fourth snapshot at the replica site by applying the differences between the first and second snapshots to a third snapshot;
erase the local journal if the bandwidth is not available;
rename the second snapshot to be the first snapshot if the bandwidth is not available; and
repeat the tracking of changes in the local journal if bandwidth is not available,
wherein the circuitry configured to send a snapshot of the primary volume comprises circuitry configured to send the first snapshot of the primary volume to form the third snapshot.

8. The apparatus of claim **7**, further comprising circuitry configured to generate the difference journal comprising circuitry configured to:
read journal entries in the local journal;
for each journal entry in the local journal, determine if the I/O includes I/O data for a location that is not the same I/O data for the same location in the second snapshot;
send metadata and I/O data to the difference journal if the I/O includes I/O data for a location that is not the same I/O data for the same location in the second snapshot; and

send metadata to the difference journal if the I/O includes I/O data for a location that is the same I/O data for the same location in the second snapshot.

9. The apparatus of claim **8** wherein the circuitry configured to send metadata to the difference journal if the I/O includes I/O data for a location that is the same I/O data for the same location in the second snapshot comprises circuitry configured to send metadata comprising at least one of an offset, a volume ID, a length of the I/O data or a number of blocks in a volume that is changed.

10. An article comprising:

a non-transitory computer-readable medium that stores computer-executable instructions, the instructions causing a machine to:

send a snapshot of a primary volume to a replica site;

determine if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume;

send the changes from the primary volume if the bandwidth is available;

track the changes in a local journal;

generate a second snapshot of the primary volume:

send the differences between a first snapshot and the second snapshot to the replica site;

generate a fourth snapshot at the replica site by applying the differences between the first and second snapshots to a third snapshot; and

access an intermediary snapshot between the first snapshot and the second snapshot,

wherein the instructions causing the machine to send a snapshot of the primary volume comprises instructions causing the machine to send a first snapshot of the primary volume to form a third snapshot,

wherein the instructions causing the machine to access an intermediary snapshot between the first snapshot and the second snapshot comprises instructions causing the machine to:

copy the third snapshot to form an intermediary snapshot;

for each journal entry in a difference journal, determine if the journal entry includes I/O data;

apply I/O data from the difference journal to the intermediary snapshot if the journal entry comprises I/O data; and

apply I/O data pointed to by the difference journal if the journal entry does not include I/O data.

11. The apparatus of claim **10**, further comprising instructions causing the machine to generate the difference journal comprising instructions causing the machine to:

read journal entries in the local journal;

for each journal entry in the local journal, determine if the I/O includes I/O data for a location that is not the same I/O data for the same location in the second snapshot;

send metadata and I/O data to the difference journal if the I/O includes I/O data for a location that is not the same I/O data for the same location in the second snapshot; and

send metadata to the difference journal if the I/O includes I/O data for a location that is the same I/O data for the same location in the second snapshot.

12. The apparatus of claim **11** wherein the instructions causing the machine to send metadata to the difference journal if the I/O includes I/O data for a location that is the same I/O data for the same location in the second snapshot comprises instructions causing the machine to send metadata comprising at least one of an offset, a volume ID, a length of the I/O data or a number of blocks in a volume that is changed.

13. An article comprising:

a non-transitory computer-readable medium that stores computer-executable instructions, the instructions causing a machine to:

send a snapshot of a primary volume to a replica site;

determine if a bandwidth is available to send changes in the primary volume to the replica site to allow any point in time recovery of data in the primary volume;

send the changes from the primary volume if the bandwidth is available;

track the changes in a local journal;

generate a second snapshot of the primary volume;

send the differences between a first snapshot and the second snapshot to the replica site;

generate a fourth snapshot at the replica site by applying the differences between the first and second snapshots to a third snapshot;

erase the local journal if the bandwidth is not available;

rename the second snapshot to be the first snapshot if the bandwidth is not available; and

repeat the tracking of changes in the local journal if bandwidth is not available,

wherein the instructions causing the machine to send a snapshot of the primary volume comprises instructions causing the machine to send a first snapshot of the primary volume to form a third snapshot.

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