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Urbański

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(54) BALANCING DISTANCES BETWEEN NODES ON A TOKEN RING

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(Continued)

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G06F 15/173 (2006.01)
H04L 12/24 (2006.01)

(Continued)

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

CPC ***H04L 41/145*** (2013.01); ***H04L 12/417*** (2013.01); ***H04L 12/433*** (2013.01); ***H04L 67/1025*** (2013.01)

(58) **Field of Classification Search**

CPC ... H04L 41/145; H04L 12/417; H04L 12/433; H04L 67/1025

(Continued)

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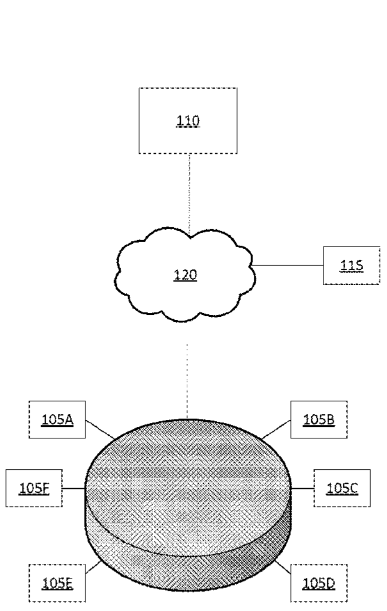
(57) **ABSTRACT**

Nodes on a token ring are rebalanced from an initial condition to a condition in which the load is optimally distributed based on a specified level of balance. Nodes are treated as electrically charged particles for purposes of the simulation and are assigned simulation values based on proportions between the size of the cluster, the computing power of the nodes, and the specified level of balance. A simulation module performs the rebalancing simulation by assigning the specified values to the particles and outputting, for each corresponding node, a token indicating the particle's final position and the position of the node on the token ring. The tokens are input to a redistribution module, which rebalances the cluster based on the generated tokens.

20 Claims, 5 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/454,985, filed on Feb. 6, 2017.

(51) **Int. Cl.**

H04L 12/433	(2006.01)
H04L 29/08	(2006.01)
H04L 12/417	(2006.01)

(58) **Field of Classification Search**
USPC 709/223
See application file for complete search history.

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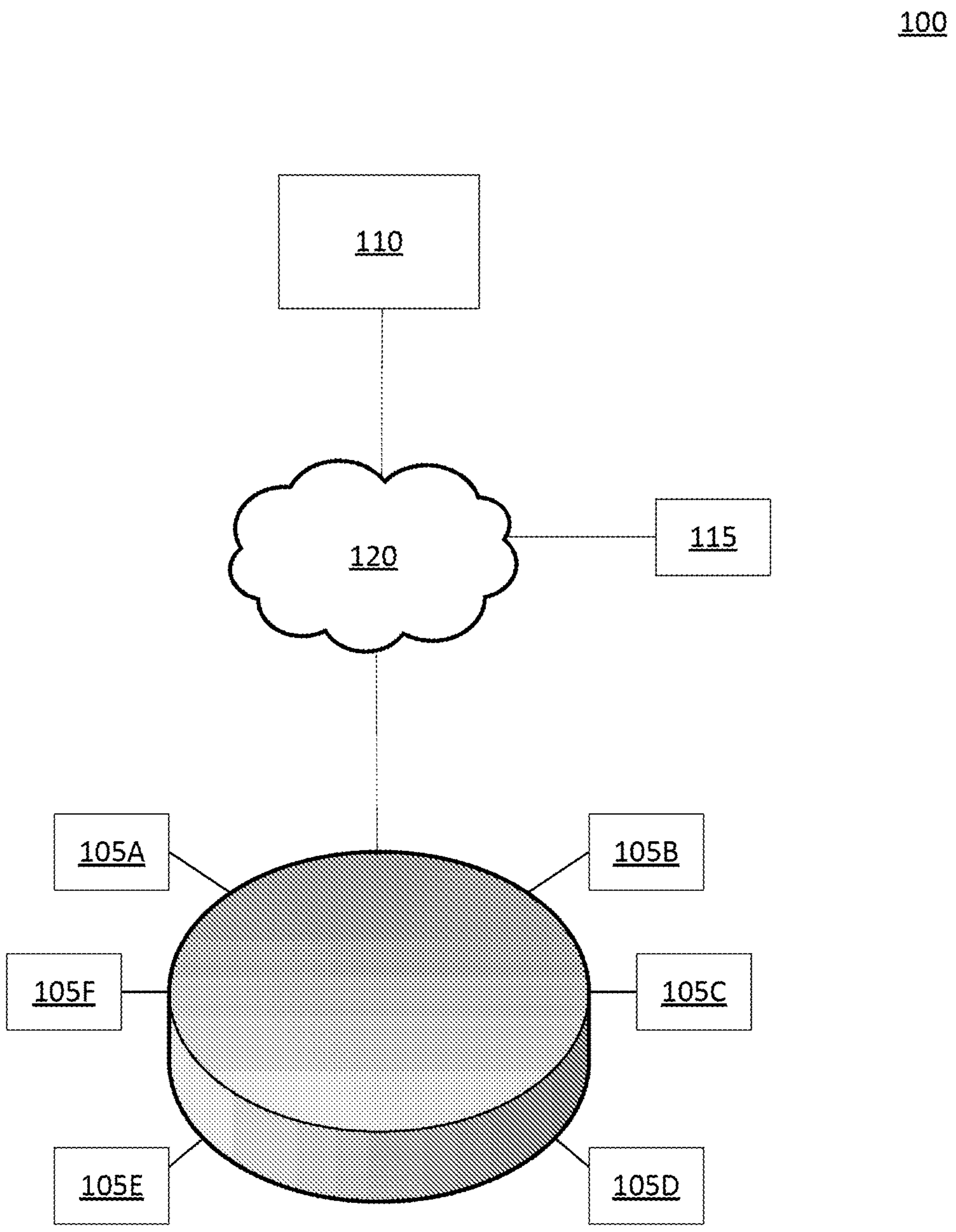

FIG. 1

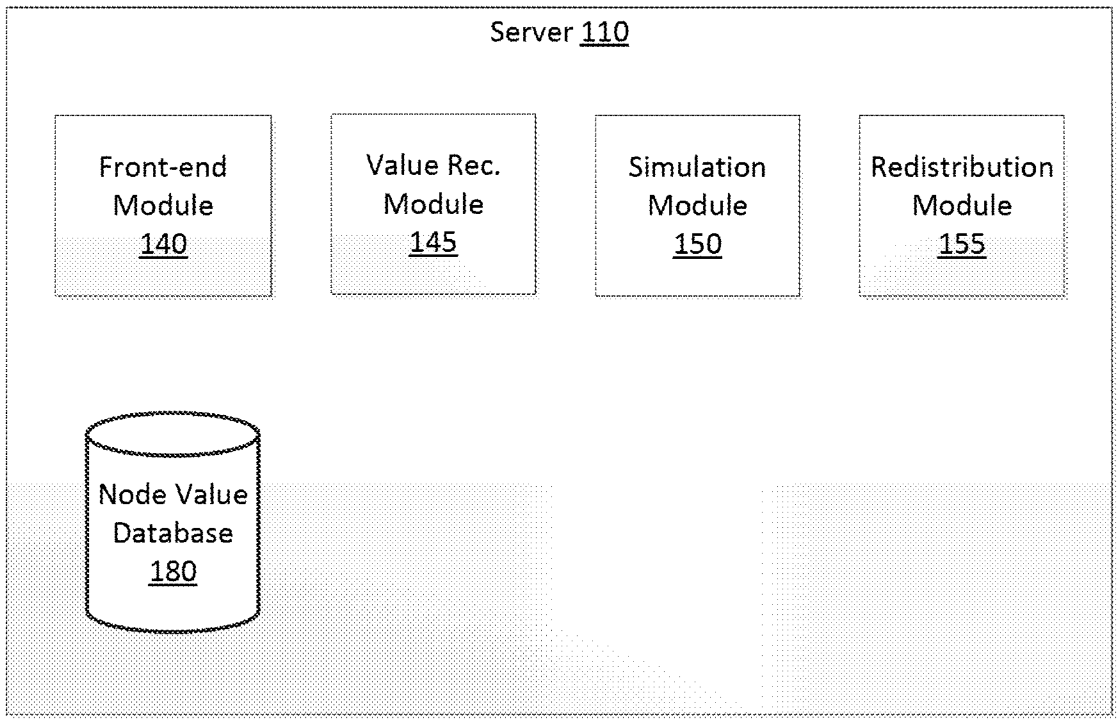
Server 110
Front-end Module 140
Value Rec. Module 145
Simulation Module 150
Redistribution Module 155
Node Value Database 180

FIG. 2

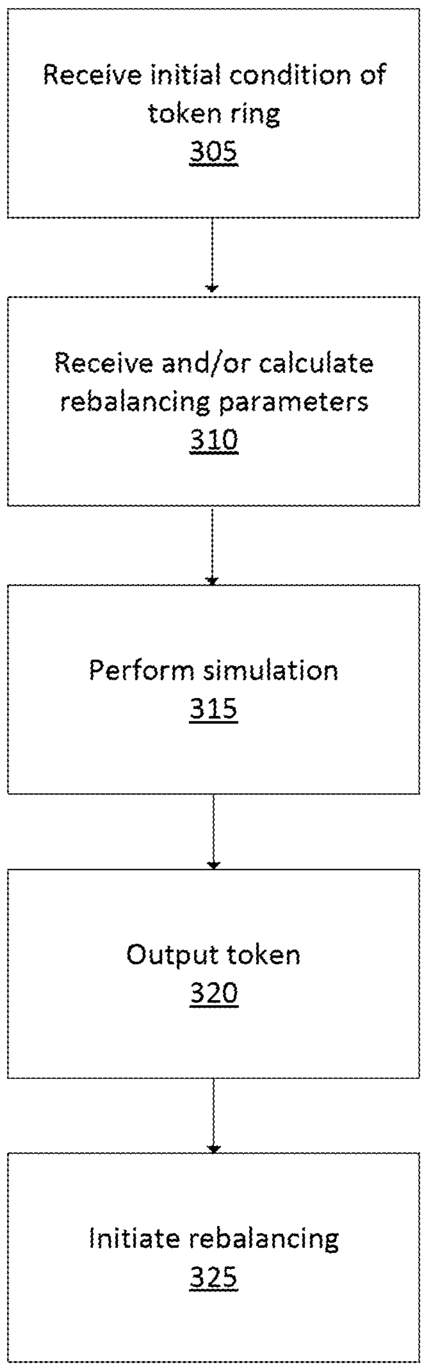
Receive initial condition of token ring
305
Receive and/or calculate rebalancing parameters
310
Perform simulation
315
Output token
320
Initiate rebalancing
325

FIG. 3

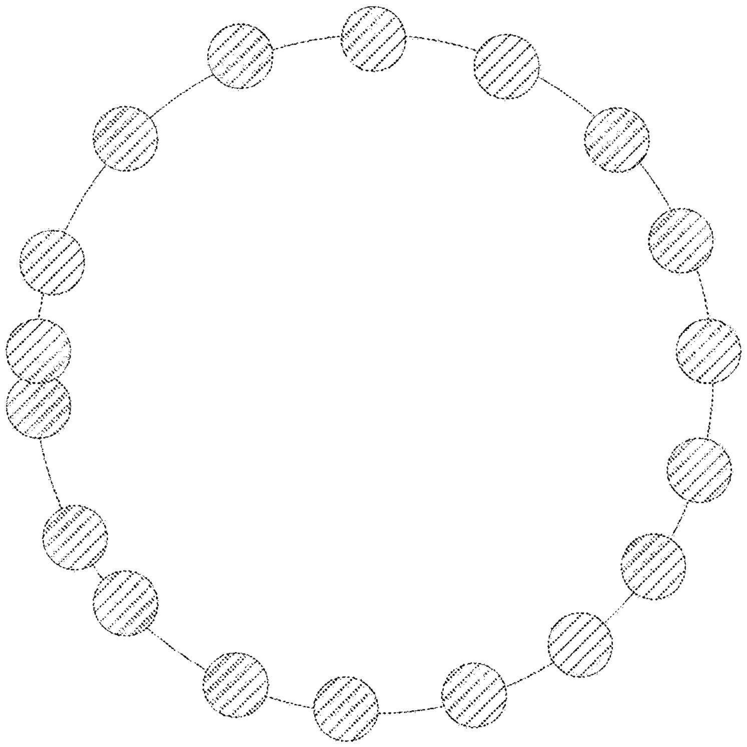

FIG. 4A

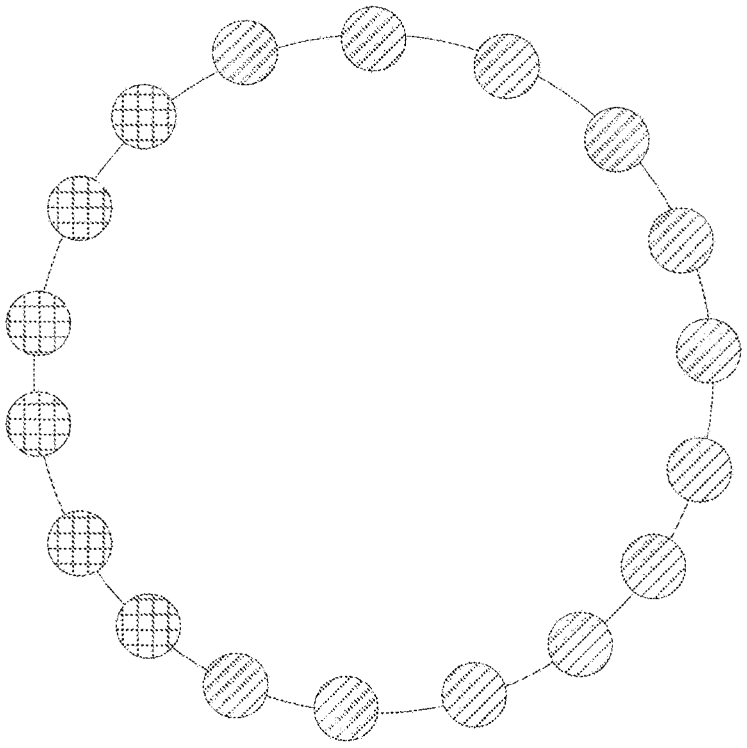

FIG. 4B

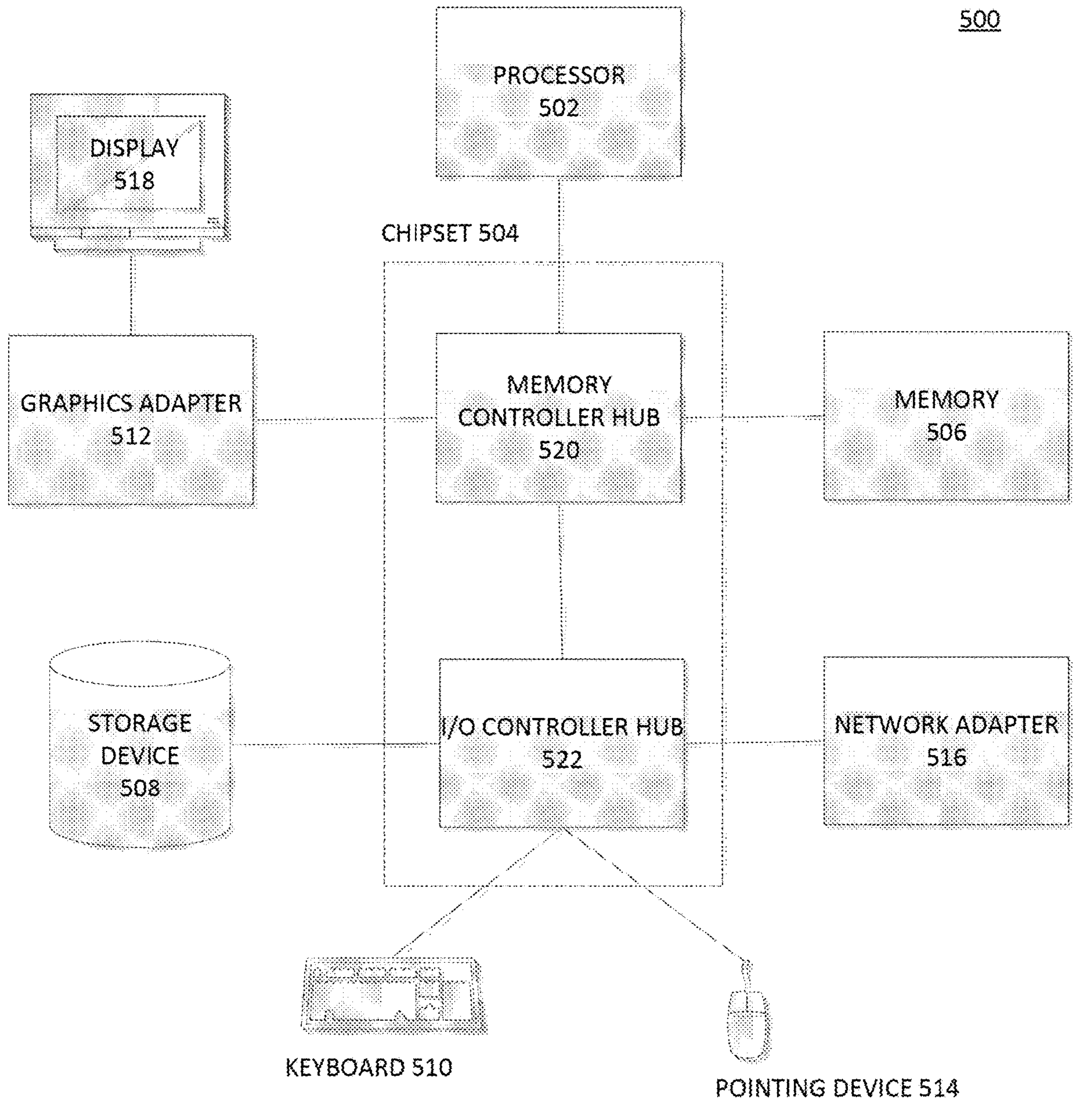
500
PROCESSOR 502
DISPLAY 518
CHIPSET 504
GRAPHICS ADAPTER 512
MEMORY CONTROLLER HUB 520
MEMORY 506
STORAGE DEVICE 508
I/O CONTROLLER HUB 522
NETWORK ADAPTER 516
KEYBOARD 510
POINTING DEVICE 514

FIG. 5

BALANCING DISTANCES BETWEEN NODES ON A TOKEN RING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of co-pending U.S. application Ser. No. 15/890,010, filed Feb. 6, 2018, which claims the benefit of U.S. Provisional Application No. 62/454,985, filed Feb. 6, 2017, both of which are incorporated by reference in their entirety.

TECHNICAL FIELD

The described subject matter generally relates to the field of network-based computer clustering, and, more particularly, to optimizing load balance among servers in a token ring.

BACKGROUND

Load-balancing computer clusters improve performance over a single computer and provide more computing power in a cost-effective manner. Computational workload is distributed among nodes in the cluster to provide better overall performance and faster response times. Current methods for load balancing among computer clusters aim to achieve an optimal distribution in which all nodes are equidistant and are thus able to handle the same load. These methods use an external tool to generate equidistant token values and move nodes until those values are reached. However, doing so causes all nodes but one to be moved, thus resulting in a large number of moves and a higher transaction cost, which may be particularly burdensome for large systems. Further, because existing tools assume that nodes are homogenous and are able to handle the same load, these systems do not account for a situation in which a more powerful machine is incorporated into the cluster.

SUMMARY

To achieve a reasonably balanced cluster of nodes with the minimum number of moves and thus a lower transaction cost, a server performs a redistribution simulation in which nodes on the cluster are treated as electrically charged particles. While existing methods for balancing load distribution are inefficient and costly for larger systems in which all nodes but one need to be moved, the claimed method increases the efficient functioning of the token ring by assigning higher workloads to more powerful nodes and minimizing the number of tokens that need to be moved.

A user interacts with a front-end module on the server to provide a redistribution instruction for a token ring. An initial condition of the token ring is retrieved, reflecting the number of nodes in the cluster, the computing power of each node, and the initial load balance of the nodes. In some embodiments, the user provides rebalancing parameters indicating the desired level of balance for the cluster and assigns simulation values including charge and static friction coefficients for each node, the terminal velocity for the nodes, and the length of the simulation. Additionally or alternatively, a value recommendation module provides some or all of the recommended simulation values based on proportions between the size of the cluster, the computing power of the nodes, and the desired level of balance.

A simulation module performs the rebalancing simulation by assigning the specified parameters to the particles and

determines how the particles have been redistributed after the simulation ends. For each node on the token ring, the simulation module outputs a token indicating the particle's final position and the position of the corresponding node on the token ring. The tokens are input to a redistribution module, which rebalances the cluster based on the generated token and outputs a visualization of the rebalanced cluster to the user.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a block diagram of an example communications network **100**, in accordance with an embodiment.

FIG. **2** illustrates a block diagram of an example server **110** for redistributing nodes in a token ring, in accordance with an embodiment.

FIG. **3** is a flow chart illustrating interactions among the entities of FIG. **2** to support a load balancing simulation.

FIG. **4A-4B** illustrate example clusters of nodes before and after rebalancing, according to an embodiment.

FIG. **5** illustrates example components of a computer used as part or all of the server **110** and/or the routers **105**, in accordance with an embodiment.

DETAILED DESCRIPTION

The Figures and the following description describe certain embodiments by way 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. Reference will now be made 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.

Turning now to the specifics of the system architecture **100**, FIG. **1** is a block diagram illustrating an example communications network **100**, in accordance with an embodiment. The system architecture **100** comprises a plurality of nodes **105** (e.g., nodes **105**A-**105**F) in communication with each other through a network **120**. While only six nodes **105** are shown in FIG. **1**, embodiments of the system architecture **100** may have many such entities connected to the network **120**.

In some embodiments, nodes **105** are arranged in a token ring (also described herein as a "cluster"). Example nodes may include networked computing devices capable of receiving user input as well as transmitting and/or receiving data via the network **120**. One or more logical tokens are passed between the nodes, enabling the node holding a logical token to send data packets to neighboring nodes. Each node **105** is responsible for the portion of the cluster between itself and its predecessor.

The distance between the nodes **105** on the token ring reflects the amount of data that each node **105** can process. In some embodiments, the initial position of the nodes **105** on the token ring is equidistant such that there is equal distribution of load among the nodes **105**. The nodes can be rearranged to create small imbalances to alter the amount of data that a particular node **105** can handle. In other embodiments, the initial position of the nodes **105** on the token ring varies, reflecting a load balance in which some nodes **105** handle more data than others. The nodes **105** can be rearranged to create a more balanced distribution of data.

The nodes **105** are configured to communicate with a server **110** via the network **120**, which may comprise any combination of local area and/or wide area networks using both wired and/or wireless communication systems. In one embodiment, the network **120** uses standard communications technologies and/or protocols. For example, the network **120** includes communication links using technologies such as Ethernet, 802.11, worldwide interoperability for microwave access (WiMAX), 3G, 4G, code division multiple access (CDMA), digital subscriber line (DSL), etc. Examples of networking protocols used for communicating via the network **120** include multiprotocol label switching (MPLS), transmission control protocol/Internet protocol (TCP/IP), hypertext transport protocol (HTTP), simple mail transfer protocol (SMTP), and file transfer protocol (FTP). Data exchanged over the network **120** may be represented using any suitable format, such as hypertext markup language (HTML) or extensible markup language (XML). In some embodiments, all or some of the communication links of the network **120** may be encrypted using any suitable technique or techniques.

A client **115** also communicates with the server **110** to provide a rebalancing instruction. A client **115** is a computing device capable of receiving user input as well as communicating via the network **120**. While a single client device **115** is illustrated in FIG. **1**, in practice many client devices **115** may communicate with the systems in the system architecture **100**. In one embodiment, a client device **115** is a conventional computer system, such as a desktop or laptop computer. Alternatively, a client device **115** may be a device having computer functionality, such as a personal digital assistant (PDA), a mobile telephone, or a smartphone.

FIG. **2** illustrates a block diagram of an example server **110** for redistributing nodes in a token ring, in accordance with an embodiment. The server **110** receives the initial distribution of nodes **105** around the token ring and runs a simulation responsive to user input comprising a request to rebalance the nodes **105**. Although only a single server **110** is shown, the server **110** may comprising one or more computing devices executing the simulation function.

In one embodiment, the server **110** performs the rebalancing simulation by representing each node **105** in the cluster as an electrically charged particle and applying Coulomb's Law such that the nodes repel each other with a force proportional to the product of their charges and inversely proportional to the square of their distance, which is calculated as the arc length between the nodes on the ring. During the simulation, charges and static friction values are applied to each node **105** such that a node **105** that has reached its terminal velocity and is exposed to a force acting in the direction opposite to the node's velocity will stop. In one embodiment, the server **110** runs the simulation for several hundred iterations and calculates forces between every pair of nodes **105** and updates the current position and velocity of every node **105** in each iteration. Once the simulation ends, the final positions of the nodes **105** on the ring are taken as the nodes' target token values and may be used to redistribute the nodes.

The server **110** shown by FIG. **2** includes a front-end module **140**, a value recommendation module **145**, a simulation module **150**, a redistribution module **155**, and a node value database **180**. Those of skill in the art will recognize that other embodiments of the server **110** can have different and/or other modules than the ones described here, and that the functionalities can be distributed among the modules in a different manner.

The front-end module **140** facilitates communication between a user providing a rebalancing instruction and the various modules on the server **110** and instructs the modules to perform certain actions responsive to the user input. The front-end module **140** receives an initial condition of nodes **105** in a token ring for which a user has provided a rebalancing instruction. Visualization of the initial condition can be provided by tools such as DataStax OpsCenter.

In one embodiment, the initial condition includes the number of nodes **105** in the cluster, the computing power of each node **105**, and the distribution and load balance of the nodes **105**. The length of the arc between adjacent nodes **105** is proportional to the amount of data that each node **105** can handle. For example, the initial condition might indicate that node A is located close to adjacent node B on the token ring. If the distance between nodes A and B is half of the distance between nodes B and C, then node C is capable of handling twice the amount of data as node B.

In some embodiments, the front-end module **140** also receives user input of rebalancing parameters. The rebalancing parameters include a desired level of balance of the cluster and simulation values for performing the simulation. In one embodiment, the desired level of balance is indicated by a maximum transaction cost that the user is willing to tolerate to rebalance the ring. Alternatively, a desired level of balance can be set by changing the static friction coefficient, as discussed below. In embodiments where each node **105** in the cluster has equal computing power, an optimal balance is equidistance between the nodes **105**. However, the user input may indicate that some of the nodes **105** have greater computing power than other nodes **105** such that an optimal balance for the cluster includes more powerful nodes being located further away from adjacent nodes **105** on the token ring.

In embodiments where the server **110** performs the simulation by representing the nodes **105** as electrically charged particles and applying Coulomb's Law, the simulation values include the charge coefficient and static friction coefficient of each node **105**, the terminal velocity of the nodes **105**, and the length of the simulation. For example, for a system with 2^{64} possible token values, a charge coefficient might be 10^{25}, a static friction coefficient might be 10^{9}, and a terminal velocity might be $7.2*10^{16}$.

The charge coefficient indicates the strength of the charge on each of the nodes **105**. In one embodiment, assigning a high charge coefficient to a node **105** causes the node to repel other nodes **105** more strongly and thus creates more space between the node **105** and the adjacent nodes **105** on the token ring. In embodiments where the distance between nodes **105** on the ring is directly proportional to the amount of data that each node **105** is able to process, nodes **105** with a high charge coefficient are assigned more data to process than nodes **105** with lower charge coefficients. Similarly, nodes **105** with high charge coefficients are more easily able to overcome static friction to repel adjacent nodes **105**.

The static friction coefficient represents the force required to move a node **105** during the rebalancing simulation. In one embodiment, the static friction coefficient is adjustable such that, during the simulation, the user may change the coefficient based on how willing the user is to accept moves and the resulting transaction costs. For example, assigning a low static friction coefficient will cause more nodes **105** to move during the rebalancing process and thus result in higher transaction costs. By contrast, a high coefficient of static friction might prevent any of the nodes **105** from moving if the system is unable to overcome the friction. As noted above, in embodiments where the user input includes a high static friction coefficient, a higher charge coefficient will be required to cause the nodes **105** to be able to overcome the static friction and repel adjacent nodes **105** on the ring.

The terminal velocity of the nodes **105** represents the maximum velocity that a node **105** can reach during the simulation. A node **105** that has reached its terminal velocity will stop when exposed to a force acting in the opposite direction of the node's velocity, thus causing the simulation to run more quickly than if dynamic friction were used to slow down the nodes **105** until they reached their final position.

In one embodiment, the terminal velocity remains at a constant during the rebalancing simulation to produce a well-balanced cluster. If the terminal velocity is too low, the nodes **105** will move more slowly, resulting in a longer simulation and higher transaction cost. By contrast, if the terminal velocity is too high, a node **105** might overshoot the user's desired balance state and stop too close to a neighboring node **105**, causing the neighboring node **105** to move during the next iteration of the simulation.

The simulation values additionally include the length of the rebalancing simulation. In one embodiment, the length of the simulation is measured in iterations. Alternatively, the simulation may be time-based. In either embodiment, the length of the simulation is longer if the terminal velocity or charges are low because the forces acting on the nodes **105** are small, causing the nodes **105** to travel shorter distances and requiring the simulation to run longer for the desired balance to be achieved. By contrast, a higher terminal velocity and lower static friction coefficient will result in a shorter simulation.

In embodiments where the user input does not include the charge or static friction coefficients, the terminal velocity, and/or the length of the simulation, the front-end module **140** instructs the value recommendation module **145** to provide recommended simulation values based on proportions between the size of the token ring, the computing power of the nodes **105**, and the desired level of balance. For example, if a first node **105** in the cluster is twice has twice the computing power of other nodes **105**, the value recommendation module **145** recommends doubling the charge coefficient assigned to the first node **105** to cause the first node **105** to repel the other nodes **105** more strongly, thus resulting in greater distance between the first node **105** and adjacent nodes **105**. Similarly, the value recommendation module **145** recommends a high static friction coefficient if the user is unwilling to tolerate a high transaction cost for the simulation (i.e., the user is willing to accept a higher level of imbalance between the nodes **105** in order to reduce the total number of moves). In embodiments where the desired level of balance is specified by a maximum transaction cost, the value recommendation module **145** generates an estimated transaction cost for performing the simulation using the recommended values.

In one embodiment, the value recommendation module **145** sends the recommended values to the front-end module **140** for output to the user. If the user accepts the recommended values, the front-end module **140** instructs the simulation module **150** to perform the rebalancing simulation based on the approved values. If the user does not accept the recommended values and/or provides additional user input (e.g., an updated maximum transaction cost), the front-end module **140** instructs the value recommendation module **145** to generate new recommendations based on the additional user input. In other embodiments, the value recommendation module **145** sends the recommended values directly to the simulation module **150** without outputting the values to the user.

The simulation module **150** performs the rebalancing simulation using the initial positions of the nodes **105** on the ring, the charge and static friction coefficients, the terminal velocity, and the length of the simulation based on the user input and/or on the recommendations from the value recommendation module **145**. For each of the nodes **105**, the simulation module **150** outputs a new token that indicates the node's final simulation position on the ring and the amount of data that the node **105** is responsible for (i.e., the distance between each node **105** and its predecessor node **105**).

The simulation module **150** sends the tokens for each node **105** to the redistribution module **155**, along with an instruction to initiate the rebalancing of the cluster. The redistribution module **155** redistributes the nodes from the initial condition on the ring based on the generated tokens and outputs a visualization of the rebalanced cluster to the user through the front-end module **140**. The redistribution visualization includes the location of each node **105** on the ring, the distance between each of the nodes **105**, and the amount of data that each node **105** is responsible for processing. In some embodiments, the output to the user includes an option to run the simulation for additional iterations and/or change the simulation input values, if, for example, the user is willing to tolerate a higher transaction cost or wants some of the nodes **105** to handle more data than others.

The node value database **180** stores the user input, the recommended values, and the generated tokens for later use by the modules of the server **110**. In some embodiments, the value recommendation module **145** queries the node database **180** for stored values from previous simulations to generate recommended values for a new simulation. Additionally or alternatively, when the user provides an instruction to perform a rebalancing simulation of a token ring, the front-end module **140** queries the node value database **180** to determine whether the cluster has previously been rebalanced. If the node value database **180** indicates that the server **110** has previously performed a redistribution simulation for the cluster, the node value database **180** returns the values associated with the redistribution to the front-end module **140** for display to the user, allowing the user to indicate whether the same values or different values should be used for the subsequent simulation.

FIG. **3** is a flow chart illustrating interactions among the entities of FIG. **2** to support a load balancing simulation, in accordance with an embodiment. The steps of FIG. **3** represent the perspective of the server **110**. However, some or all of the steps may be performed by other modules or entities. In addition, some embodiments may perform the steps in parallel, perform the steps in different orders, or perform different steps.

The method begins with the front-end module **140** receiving **305** an initial condition of a token ring for which a user has provided a rebalancing instruction. In one embodiment, the initial condition includes the number of nodes **105** in the cluster, the computing power of each node **105**, and the distribution of the nodes **105** on the token ring (i.e., the distance between the nodes **105** and the corresponding load balance assigned to each node **105**).

At **310**, rebalancing parameters including simulation values are received from the user through the front-end server **140** and/or calculated by the value recommendation module **145**. In some embodiments, initial input provided by the user includes the desired level of balance for the cluster, which may be indicated by a maximum transaction cost for the rebalancing and/or a maximum number of nodes that may be moved during the rebalancing.

In embodiments where the server **110** performs the rebalancing simulation by representing the nodes **105** as electrically charged particles, simulation values also include the charge coefficient and static friction coefficient of each node **105**, the terminal velocity of the nodes **105**, and the length of the simulation, as discussed above with respect to FIG. **2**. In some embodiments, the simulation values are provided via user input through the front-end module **140**. Alternatively, some or all of the simulation values may be calculated by the value recommendation module **145** based on proportions between the number of nodes **105** in the cluster, the computing power of each node **105**, and the desired level of balance.

At **315**, the simulation module **150** performs the rebalancing simulation using the parameters provided by the user and/or calculated by the value recommendation module **145**. Each node is represented as a particle to which the charge and static friction coefficients and the terminal velocity are applied. The simulation module **150** applies Coulomb's Law, whereby electrically charged particles with the same charge sign repeal each other with a force proportional to the product of their charges and inversely proportional to the square of their distance, which is calculated as the arc length between nodes on the token ring.

The simulation module **150** determines how the particles have been redistributed after the specified number of iterations or period of time, and for each node **105**, outputs **320** a token indicating the particle's final position in the simulation and the corresponding position of the node **105** on the token ring.

The simulation module **150** sends the tokens to the redistribution module **155**, which initiates **325** the rebalancing of the cluster based on the generated tokens. In some embodiments, the front-end module **140** outputs a visualization of the rebalanced cluster to the user along with an option to run the simulation for additional iterations and/or to change the rebalancing parameters.

FIGS. **4A-4B** illustrate example clusters of nodes **105** before and after the rebalancing simulation, in accordance with an embodiment. The example cluster shown in FIG. **4A** includes 18 nodes **105** that are unevenly distributed around the token ring such that the nodes **105** are responsible for processing different amounts of data. In embodiments where the nodes **105** have the same computing power, an optimal distribution is equal distance between the nodes **105**. Alternatively, if the computing power differs among the nodes **105**, an optimal distribution includes an increased distance between a more powerful node **105** and its predecessor on the token ring such that the more powerful node **105** is assigned a greater workload.

The embodiment shown in FIG. **4A** illustrates the initial condition of the nodes **105** prior to the rebalancing simulation. Responsive to the simulation module **150** beginning the simulation, the particles representing each node **105** begin to repel each other at velocities determined by the charge and static friction coefficients and the terminal velocities assigned to the nodes **105**. The simulation module **150** performs the simulation for the specified number of iterations or for the specified period of time and outputs a token for each node **105** based on the final positions of the particles.

FIG. **4B** illustrates the result of the rebalancing simulation. As shown in FIG. **4B**, while the particles representing

the nodes **105** are more evenly spaced than those shown in FIG. A (i.e., prior to the rebalancing), in some embodiments the output of the simulation is not equidistance between the nodes. Rather, the user may specify an optimal balance for the cluster based on the maximum transaction cost or a desired static friction coefficient. For example, in FIG. **4B**, the nodes **105** shown with a diagonal pattern represent those particles that did not move during the simulation while those with a checkered pattern represent particles that did move. The simulation represented in FIGS. **4A-4B** therefore represents a rebalancing simulation in which six of the eighteen particles moved and the remaining twelve particles did not move. The distance between each particle shown in FIG. **4B** and its predecessor is directly proportional to the amount of data that each node **105** will be responsible for processing.

FIG. **5** is a block diagram illustrating physical components of a computer **400** used as part or all of the server **110** and/or the routers **105**, in accordance with an embodiment. Illustrated are at least one processor **502** coupled to a chipset **504**. Also coupled to the chipset **504** are a memory **506**, a storage device **508**, a graphics adapter **512**, and a network adapter **516**. A display **518** is coupled to the graphics adapter **512**. In one embodiment, the functionality of the chipset **504** is provided by a memory controller hub **520** and an I/O controller hub **522**. In another embodiment, the memory **506** is coupled directly to the processor **502** instead of the chipset **504**.

The storage device **508** is any non-transitory computer-readable storage medium, such as a hard drive, compact disk read-only memory (CD-ROM), DVD, or a solid-state memory device. The memory **506** holds instructions and data used by the processor **502**. The graphics adapter **512** displays images and other information on the display **518**. The network adapter **516** couples the computer **500** to a local or wide area network.

As is known in the art, a computer **500** can have different and/or other components than those shown in FIG. **5**. In addition, the computer **500** can lack certain illustrated components. In one embodiment, a computer **500**, such as a host or smartphone, may lack a graphics adapter **512**, and/or display **518**, as well as a keyboard **510** or external pointing device **514**. Moreover, the storage device **508** can be local and/or remote from the computer **500** (such as embodied within a storage area network (SAN)).

As is known in the art, the computer **500** is adapted to execute computer program modules for providing functionality described herein. As used herein, the term "module" refers to computer program logic utilized to provide the specified functionality. Thus, a module can be implemented in hardware, firmware, and/or software. In one embodiment, program modules are stored on the storage device **508**, loaded into the memory **506**, and executed by the processor **502**.

The foregoing description has been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible in light of the above disclosure.

Some portions of this description describe embodiments in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations while described functionally computationally or logically are understood to be implemented by computer programs or equivalent electrical circuits microcode or the like. Furthermore, it has also proven convenient at times to refer to these arrangements of operations as modules without loss of generality. The described operations and their associated modules may be embodied in software firmware hardware or any combinations thereof.

Any of the steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules alone or in combination with other devices. In one embodiment a software module is implemented with a computer program product comprising a computer-readable medium containing computer program code which can be executed by a computer processor for performing any or all of the steps, operations, or processes described.

Embodiments may also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes and/or it may comprise a general-purpose computing device selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a non-transitory tangible computer readable storage medium or any type of media suitable for storing electronic instructions which may be coupled to a computer system bus. Furthermore, any computing systems referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

Embodiments may also relate to a product that is produced by a computing process described herein. Such a product may comprise information resulting from a computing process where the information is stored on a non-transitory tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the invention be limited not by this detailed description but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments of the invention is intended to be illustrative but not limiting of the scope of the invention which is set forth in the following claims.

The invention claimed is:

1. A method for determining an optimal rebalancing of nodes on a token ring, the method comprising:

- receiving, from a client device, an instruction to rebalance nodes on a token ring;
- receiving an initial condition of the token ring, the initial condition indicating a number and distribution of the nodes on the token ring and a measure of computing power of each node;
- generating recommended rebalancing parameters for the token ring, the rebalancing parameters including simulation values for performing a rebalancing simulation;
- performing the rebalancing simulation based on the initial condition and the rebalancing parameters; and
- determining, for each node, a final simulation position of the node on the token ring.

2. The method of claim **1**, further comprising rebalancing the nodes based on the final simulation positions.

3. The method of claim **1**, wherein the recommended simulation values are based at least in part on the initial condition of the token ring.

4. The method of claim **3**, further comprising generating an estimated transaction cost for performing the simulation using the recommended simulation values.

5. The method of claim **1**, wherein the nodes are represented as charged particles and wherein the simulation values include: a charge coefficient of each node, a static friction coefficient of each node, a terminal velocity of the nodes, and a length of the simulation.

6. The method of claim **1**, wherein the rebalancing parameters include a level of balance of the token ring.

7. The method of claim **6**, wherein the level of balance is indicated by a maximum transaction cost for the rebalancing.

8. A non-transitory computer-readable storage medium storing computer program instructions executable by a processor to perform operations comprising:

- receiving, from a client device, an instruction to rebalance nodes on a token ring;
- receiving an initial condition of the token ring, the initial condition indicating a number and distribution of the nodes on the token ring and a measure of computing power of each node;
- generating recommended rebalancing parameters for the token ring, the rebalancing parameters including simulation values for performing a rebalancing simulation;
- performing the rebalancing simulation based on the initial condition and the rebalancing parameters; and
- determining, for each node, a final simulation position of the node on the token ring.

9. The non-transitory computer-readable storage medium of claim **8**, further comprising rebalancing the nodes based on the final simulation positions.

10. The non-transitory computer-readable storage medium of claim **8**, wherein the recommended simulation values are based at least in part on the initial condition of the token ring.

11. The non-transitory computer-readable storage medium of claim **10**, further comprising generating an estimated transaction cost for performing the simulation using the recommended simulation values.

12. The non-transitory computer-readable storage medium of claim **8**, wherein the nodes are represented as charged particles and wherein the simulation values include: a charge coefficient of each node, a static friction coefficient of each node, a terminal velocity of the nodes, and a length of the simulation.

13. The non-transitory computer-readable storage medium of claim **8**, wherein the rebalancing parameters include a level of balance of the token ring.

14. The non-transitory computer-readable storage medium of claim **13**, wherein the level of balance is indicated by a maximum transaction cost for the rebalancing.

15. A system comprising:

- a computer processor for executing computer program instructions; and
- a non-transitory computer-readable storage medium storing computer program instructions executable by the processor to perform operations comprising:
  - receiving, from a client device, an instruction to rebalance nodes on a token ring;
  - receiving an initial condition of the token ring, the initial condition indicating a number and distribution of the nodes on the token ring and a measure of computing power of each node;

generating recommended rebalancing parameters for the token ring, the rebalancing parameters including simulation values for performing a rebalancing simulation;

performing the rebalancing simulation based on the initial condition and the rebalancing parameters; and

determining, for each node, a final simulation position of the node on the token ring.

16. The system of claim **15**, further comprising rebalancing the nodes using based on the final simulation positions.

17. The system of claim **15**, wherein the recommended simulation values are based at least in part on the initial condition of the token ring.

18. The system of claim **15**, wherein the nodes are represented as charged particles and wherein the simulation values include: a charge coefficient of each node, a static friction coefficient of each node, a terminal velocity of the nodes, and a length of the simulation.

19. The system of claim **15**, wherein the rebalancing parameters include a level of balance of the token ring.

20. The system of claim **19**, wherein the level of balance is indicated by a maximum transaction cost for the rebalancing.

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