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(54) **METHOD FOR DEVICES IN A NETWORK TO PARTICIPATE IN AN END-TO-END MEASUREMENT OF LATENCY**

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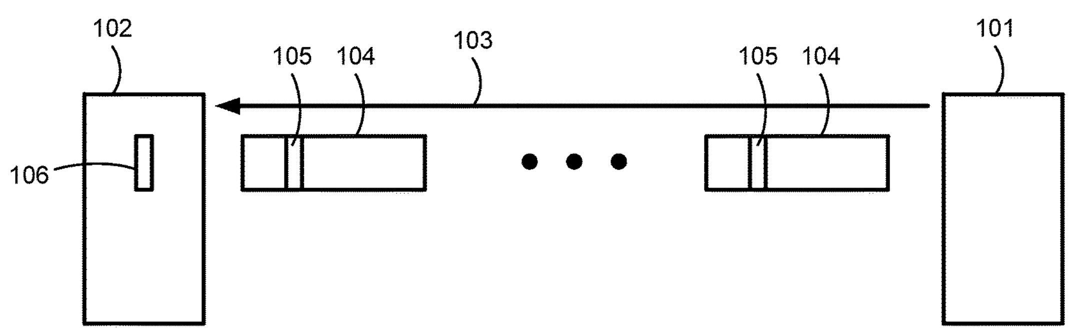
(57) **ABSTRACT**

A method of determining the latency of path segments in a communication network that uses multi-bit data packets comprises generating a test packet for use in determining the latency of path segments in the network; transmitting the test packet from a first device coupled to the network; storing in the test packet the time when a preselected bit in the test packet is transmitted from the first device; when the test packet is received by a second device coupled to the network, storing in the second device at least one of (a) the time when a preselected bit in the test packet is received by the second device and (b) the difference between (i) the time when the preselected bit in the test packet is transmitted from the first device and (ii) the time when the test packet is received by the second device.



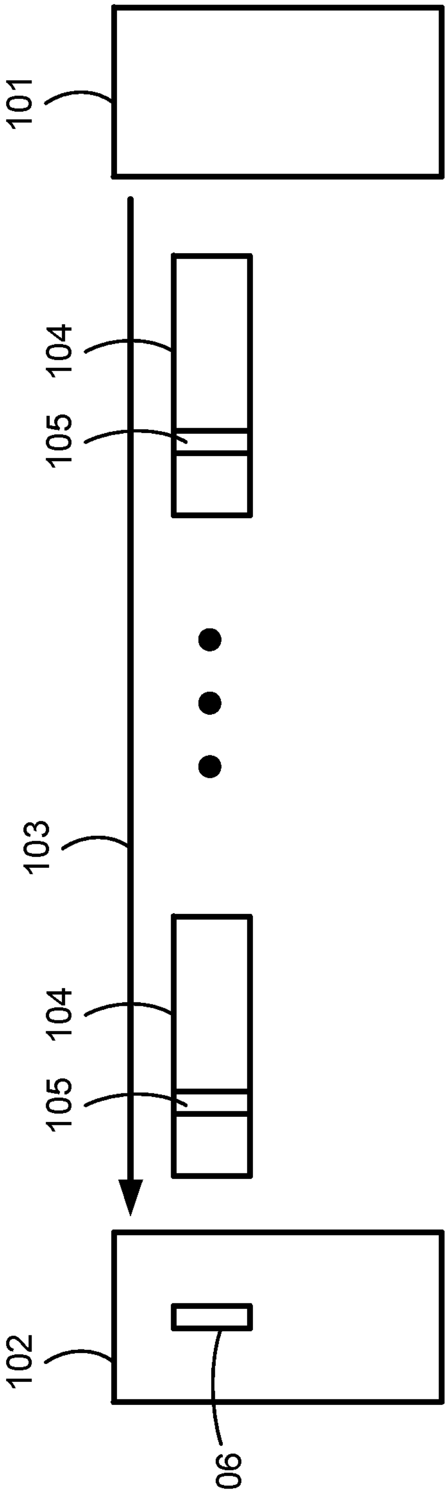
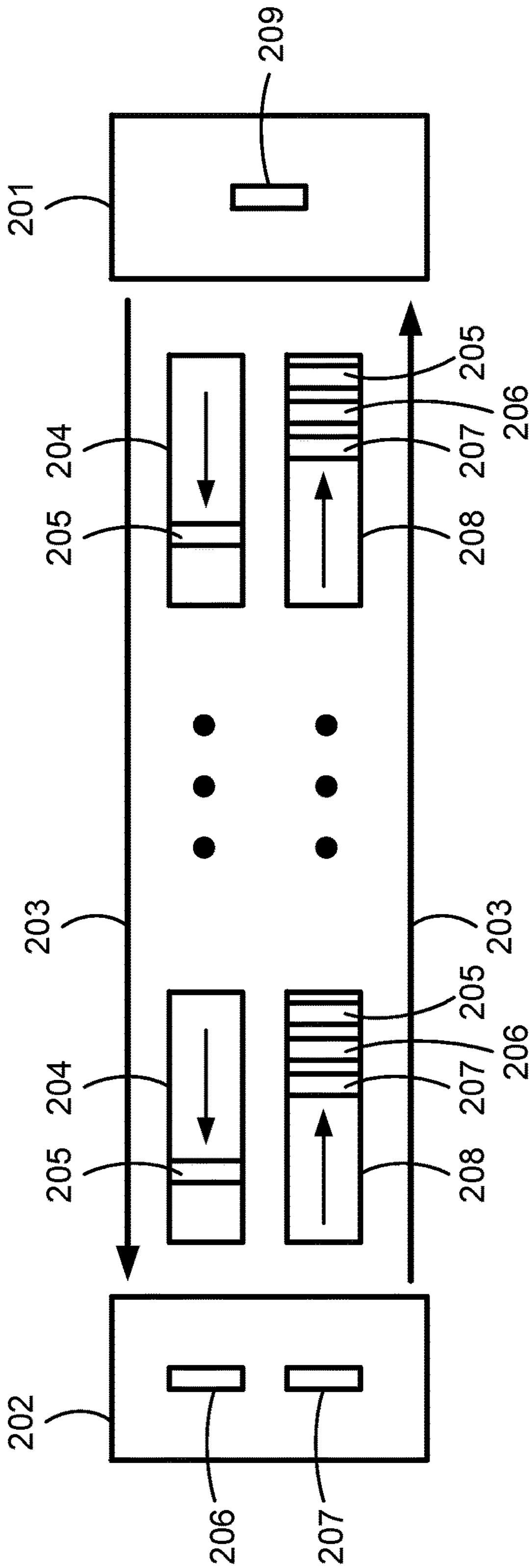


FIG. 1


209
201
204
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202
206
207

FIG. 2

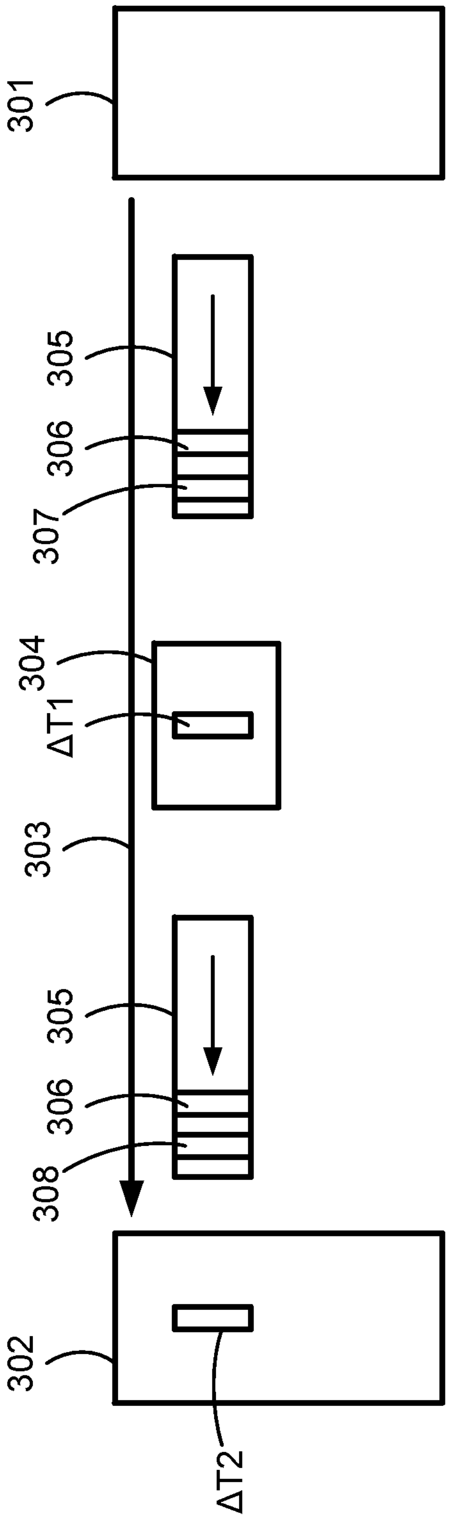


FIG. 3

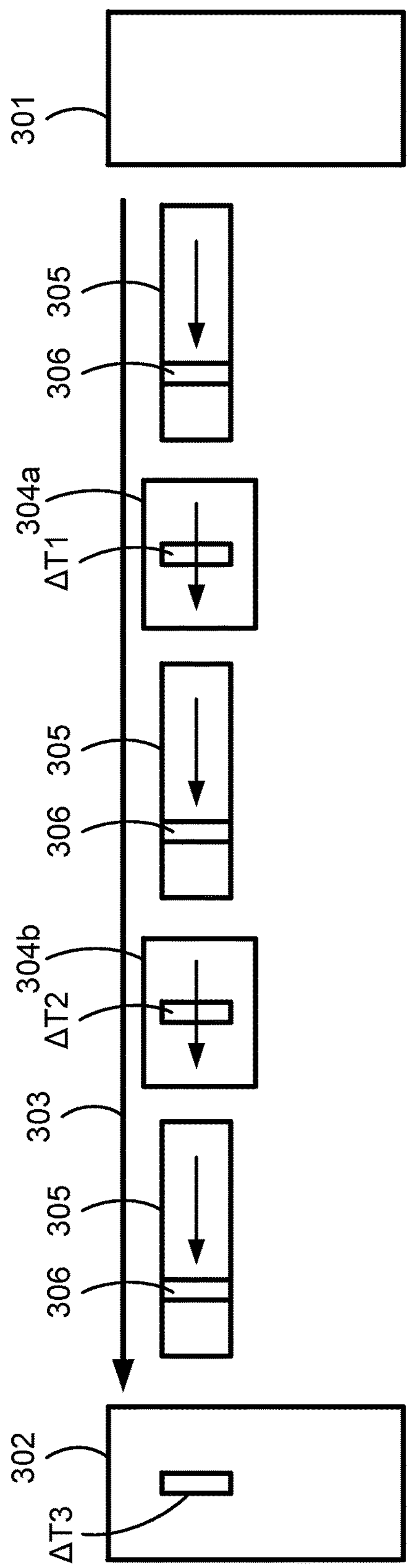
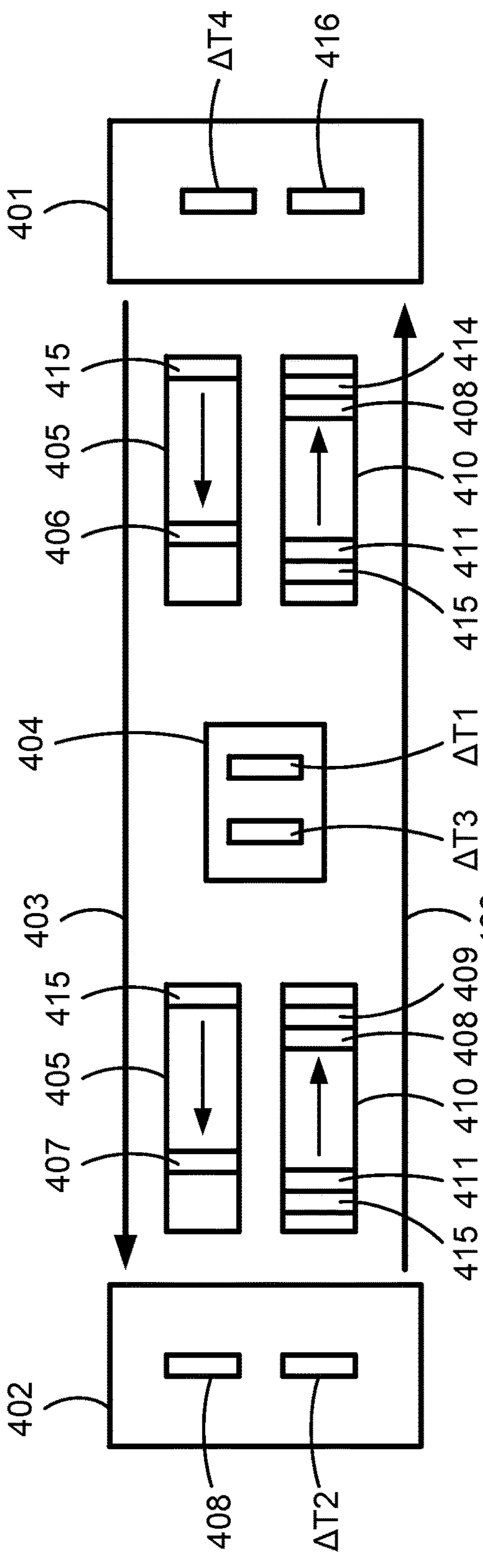
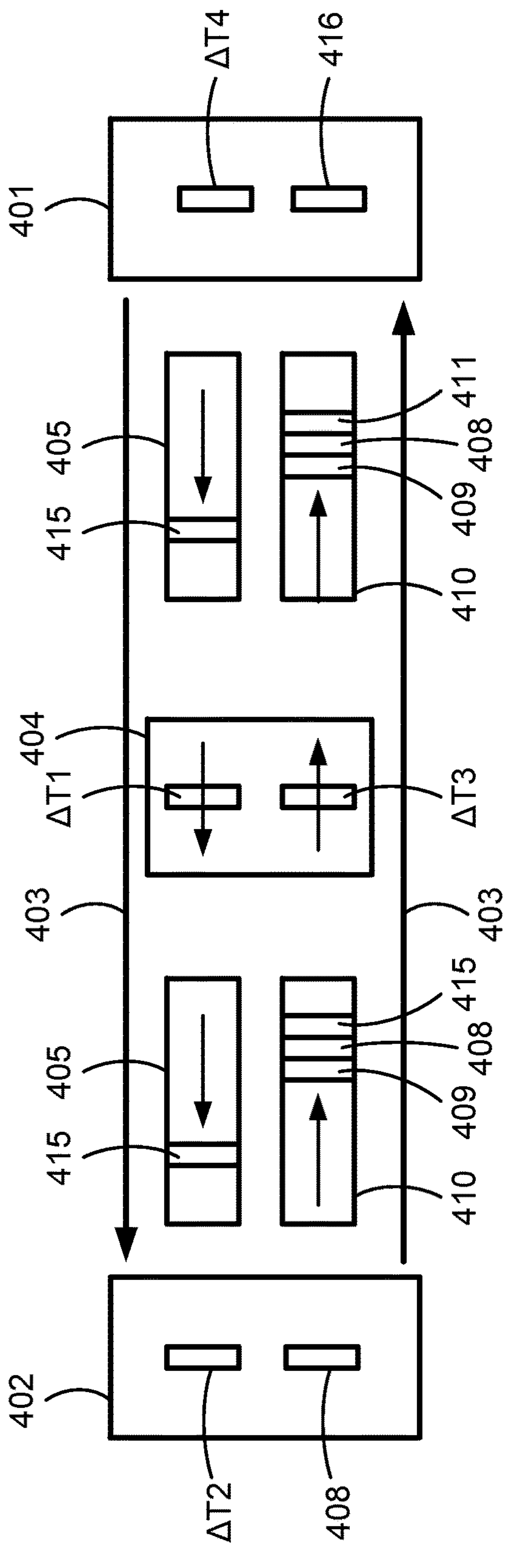


FIG. 3A



ΔT4
416
401
415
405
406
414
408
410
411
415
404
ΔT1
ΔT3
403
403
415
405
407
409
408
410
411
415
402
408
ΔT2

FIG. 4


ΔT4
416
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411
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ΔT1
ΔT3
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410
402
ΔT2
408

FIG. 4A

METHOD FOR DEVICES IN A NETWORK TO PARTICIPATE IN AN END-TO-END MEASUREMENT OF LATENCY

FIELD OF THE INVENTION

[0001] This invention is directed towards creating a method for devices in a network to participate in an end-to-end measurement of latency and also determine segment by segment latency without additional messaging in the network.

BACKGROUND OF THE INVENTION

[0002] When an Ethernet circuit (or other type of circuit) is activated in a network, there is a need to be able to obtain precise performance measurements to make sure the circuit is fully functional in accordance with the performance specification of the operator. Unidirectional (1-way) and bi-directional (2-way) delay measurements are an essential performance measurement that needs to be obtained as part of the service activation. These measurements are also very useful to measure the performance of the Ethernet circuit while IN SERVICE.

[0003] These measurements, though useful, do not take into account the multiple segments that may exist within a network path and give no information to isolate the segment delay within the absolute path. To find such a segment over a multi-segment path requires numerous tests, excessive messaging and time.

[0004] There is a need to be able to discover a segment by segment latency along a path when an end-to-end latency measurement is requested and not increase messaging as a by-product of this segment by segment measurement.

[0005] An example of a unidirectional (1-way) measurement is illustrated in FIG. **1**. When a unidirectional delay measurement is requested between network devices **101** and **102** along a network path **103**, a test packet **104** is created and a timestamp **105** is inserted into the packet **104** denoting the time when the first bit of packet **104** is transmitted. When the packet **104** arrives at the network device **102**, a second timestamp **106** is taken to denote the time when the last bit of the packet **104** arrives at the device **102**. The difference in time between timestamp **105** and timestamp **106** denotes the delay in time to traverse the entire path between devices **101** and **102**. All intermediate nodes between the devices are not deemed relevant. It is also to be noted that the clocks between the network devices must be precisely synchronized by one of the many methods known to one skilled in the art.

[0006] An example of a bi-directional (2-way) measurement is illustrated in FIG. **2**. When a bi-directional delay measurement is requested between network devices **201** and **202** along a network path **203**, a test packet **204** is created and a timestamp **205** is inserted into the packet **204** denoting the time when the first bit of the packet **204** is transmitted. When the packet **204** arrives at network device **202**, a second timestamp **206** is taken to denote the time when the last bit of the packet **204** arrives at device **202**. Then the addresses of the test packet **204** are modified and transmitted back to the device **201** containing the original timestamp **205**, with the timestamp **206** and a timestamp **207** that denotes with the first bit of the packet **208** is transmitted on the network. When the final bit of the packet **208** arrives at the network device **201**, a final timestamp **209** is taken. The difference in time between timestamp **205** and **206** ADDED to the difference in time between the timestamp **207** and **209** gives the total round-trip delay of the bi-directional path. Another method to determine the round-trip delay is to deduct the timestamp **205** from the timestamp **209**. All intermediate nodes between the devices are not deemed relevant. It is also to be noted that the clocks between the network devices must be precisely synchronized by one of the many methods known to one skilled in the art.

SUMMARY OF THE INVENTION

[0007] In accordance with one embodiment, a method of determining the latency of path segments in a communication network that uses multi-bit data packets comprises generating a test packet for use in determining the latency of path segments in the network; transmitting the test packet from a first device coupled to the network; storing in the test packet the time when a preselected bit in the test packet is transmitted from the first device; when the test packet is received by a second device coupled to the network, storing in the second device at least one of (a) the time when a preselected bit in the test packet is received by the second device and (b) the difference between (i) the time when the preselected bit in the test packet is transmitted from the first device and (ii) the time when the test packet is received by the second device. In one implementation, the time when a preselected bit in the test packet is received by the second device is stored in the second device, and the latency of the path segment between the first and second devices is determined to be the difference between the two stored times. In another implementation, the difference between (i) the time when the preselected bit in the test packet is transmitted from the first device and (ii) the time when the test packet is received by the second device, is stored in the second device, and the latency of the path segment between the first and second devices is determined by retrieving the difference from the second device.

[0008] The test packet may be transmitted serially from the second device to a plurality of additional devices coupled to the network. Each time the test packet is received by one of the additional devices, the information stored in the additional device includes at least one of (a) the time when a preselected bit in the test packet is received by the additional device and (b) the difference between (i) the time when the preselected bit in the test packet is transmitted from the first device and (ii) the time when the test packet is received by the additional device. The test packet may also be returned from the second device to the first device, or from one of the additional devices to the first device via the same devices traversed by the test packet during transmission from the first device to the one additional device.

[0009] The test packet may be transmitted to and from the various devices while normal packets are being transported through the network.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The invention may best be understood by reference to the following description taken in conjunction with the accompanying drawings.

[0011] FIG. **1** is a diagrammatic illustration of a one-way latency measurement in a packet-based communication network.

[0012] FIG. **2** is a diagrammatic illustration of a two-way latency measurement in a packet-based communication network.

[0013] FIG. **3** is a diagrammatic illustration of one-way latency measurements for path segments, as well as the entire path, in a packet-based communication network.

[0014] FIG. **3***a* is a diagrammatic illustration of modified one-way latency measurements for path segments, as well as the entire path, in a packet-based communication network.

[0015] FIG. **4** is a diagrammatic illustration of two-way latency measurements for path segments, as well as the entire path, in a packet-based communication network.

[0016] FIG. **4***a* is a diagrammatic illustration of modified two-way latency measurements for path segments, as well as the entire path, in a packet-based communication network.

DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS

[0017] Although the invention will be described in connection with certain preferred embodiments, it will be understood that the invention is not limited to those particular embodiments. On the contrary, the invention is intended to cover all alternatives, modifications, and equivalent arrangements as may be included within the spirit and scope of the invention as defined by the appended claims.

[0018] To allow the tracking of the delays of the individual segments of the end-to-end path of the circuit, a new field is defined within the packet that is used during the test. This new value stores the time stamp created when the first bit of the packet is transmitted for each segmented hop along the end-to-end path. This new value can be used by each device along the path to calculate the delay from the last device to itself, while preserving the information needed to determine the delay in the end-to-end path. This also allows devices that are not aware of this capability to operate normally. The intermediate hop devices can then be interrogated later to easily find the segment delay problem if the end-to-end path has an unacceptable delay measurement.

[0019] FIG. **3** illustrates an example of a unidirectional (1-way) measurement. When a unidirectional delay measurement is requested between a pair of network devices **301** and **302** along a network path **303** that includes an intermediate network device **304**, a test packet **305** is created and transmitted from the device **301** onto the path **303**. A timestamp **306** is inserted into the packet **305** to denote the time when the first bit of the packet **305** is transmitted. A second timestamp field **307** is set at the same timestamp value, as this is the originating device.

[0020] The first network device to receive the packet **305** along the path **303** is the intermediate device **304**. When the test packet **305** arrives at the device **304**, the time difference ΔT**1** between the time when the last bit is received and the value in the timestamp **307** is calculated and stored in the network device **304**. (Alternatively, the timestamp can be taken upon receiving the first bit of the packet **305**.) This value ΔT**1** is the delay of the path segment from device **301** to device **304**. A new timestamp **308**, denoting the time when the first bit of the packet **305** is transmitted from the device **304**, is taken and stored in the field where the timestamp **307** had been stored.

[0021] When the packet **305** arrives at the end-point device **302**, the time when the last bit arrives is recorded in the device **302**, and the time difference ΔT**2** between the timestamp **308** and the recorded time can be stored in the device **302** as the delay of the path segment from device **304** to device **302**. The time difference between the arrival time stored in device **302** and the time stored in **306** is the value of the end-to-end delay in the path **303**.

[0022] FIG. **3***a* illustrates a modified embodiment of a unidirectional delay measurement made between network devices **301** and **302** along a network path **303** that includes two intermediate network devices **304***a* and **304***b*. A test packet **305** is created and transmitted from the first device **301** onto the path **303**, and a timestamp **306** is inserted into the packet **305** denoting the time when the first bit of the packet is transmitted from the first device **301**.

[0023] When the packet **305** arrives at the first intermediate device **304***a*, the time difference ΔT**1** between the time when the last bit is received by the device **304***a* and the time when the first bit was transmitted from the device **301** (the value in timestamp **306**) is calculated and stored in the device **304***a*. This value ΔT**1** is the delay of the path segment from device **301** to device **304***a*. The test packet **305** is then forwarded to the next network device **304***b* in the test path.

[0024] When the packet **305** arrives at the third device **304***b*, the time difference ΔT**2** between the time when the last bit is received by the device **304***b* and the time when the first bit was transmitted from the device **301** (the value in timestamp **306**) is calculated and stored in the device **304***b*. Alternatively, the timestamp can be taken upon receiving the first bit of the packet **305**. The value ΔT**2** is the total delay of the path segments from device **301** to device **304***b*. The test packet **305** is then forwarded to the last network device **302** in the test path.

[0025] When the packet **305** arrives at the final device **302**, the time difference ΔT**3** between the time when the last bit is received by the device **302** and the time when the first bit was transmitted from the device **301** (the value in timestamp **306**) is calculated and stored in the device **302**. This value is the total end-to-end delay of the path from device **301** to device **302**. The stored time differences ΔT**1**, ΔT**2** and ΔT**3** in the respective network devices **304***a*, **304***b* and **302** along the test path **303** can then be retrieved centrally by any of several well known techniques for retrieving data from distributed network devices.

[0026] In FIG. **4**, when a bi-directional delay measurement is requested between network devices **401** and **402** along a network path **403**, a test packet **405** is created and transmitted from the device **401** along the path **403**. A timestamp **415** is inserted into the packet **405**, denoting the time when the first bit of the packet **405** is transmitted. A second timestamp field **406** is set at the same value as the timestamp **415**, as this is the originating device.

[0027] When the packet **405** arrives at an intermediate network device **404**, the time difference ΔT**1** between the time when the last bit is received by the device **404** and the value in the timestamp **406** is calculated and stored in the device **404**. This value ΔT**1** is the delay of the path segment from device **401** to device **404**. A new timestamp **407**, denoting the time when the first bit of the packet **405** is transmitted from the device **404**, replaces the timestamp **406** previously stored in the packet **405**.

[0028] When the packet **405** arrives at the third device **402**, the time when the last bit in the packet **405** arrives at the device **402** is recorded in the device **402** as a timestamp **408**. The time difference ΔT**2** between timestamp **408** and the time stored in timestamp **407** is calculated and stored in the device **402**. This value ΔT**2** is the delay of the path segment from device **404** to device **402**.

[0029] Next, the addresses of the original test packet **405** are reversed in a packet **410** that is transmitted in the reverse direction along the network path **403**, from device **402** to device **401** via the intermediate device **404**. The packet **410** still contains the original timestamp **415**, the recorded timestamp **408** and new timestamps **409** and **411**, both denoting the time when the first bit of the packet **410** is transmitted from the device **402**.

[0030] When the packet **410** arrives at the intermediate network device **404**, the time difference ΔT**3** between the time when the last bit is received by the device **404** and the value in the timestamp **409** is calculated and stored in the device **404**. This value ΔT3 is the delay of the path segment between from device **402** to device **404**. A new timestamp **414**, denoting the time when the first bit of the packet **415** is transmitted from the device **404** toward the device **401**, replaces the timestamp **409** in the packet **410**.

[0031] When the packet **410** arrives at the third device **401**, which is the end point of the return path, the time when the last bit in the packet **410** arrives at the device **401** is recorded in the device **401** as a timestamp **416**. The time difference ΔT4 between the recorded time **416** and the time stored in timestamp **414** is calculated and stored in the device **401**. This value ΔT4 is the delay of the path segment between from device **404** to device **401**.

[0032] Also, the difference in time between timestamp **415** and **408** ADDED to the difference in time between timestamp **411** and **416** gives the total round-trip delay of the bi-directional path. An alternative method to calculate the total round-trip delay is to deduct the timestamp **415** from timestamp **416**. It is also to be noted that the clocks between the network devices must be precisely synchronized by one of the many methods known to one skilled in the art.

[0033] In another embodiment illustrated in FIG. **4***a*, a two-way delay measurement is made between network devices **401** and **402** along a network path **403** that includes an intermediate network device **404**. A test packet **405** is created at the first device **401**, and a timestamp **415** is inserted into the packet **405** denoting the time when the first bit of the packet is transmitted from the first device **401**. When the packet **405** arrives at the second device **404**, the time difference ΔT**1** between the time when the last bit is received by the device **404** and the time when the first bit was transmitted from the device **401** (the value in timestamp **415**) is calculated and stored in the device **404**. This value ΔT**1** is the segment delay of the path segment from device **401** to device **404**. The test packet **405** is then forwarded to the next network device **402** in the test path.

[0034] When the packet **405** arrives at the third device **402**, the time difference ΔT**2** between the time when the last bit is received by the device **402** (stored as timestamp **408**) and the time when the first bit was transmitted from the device **401** (the value in timestamp **415**) is calculated and stored in the device **402**. The value ΔT**2** is the total segment delay of the path segment from device **401** to device **402**.

[0035] Then the addresses of the original test packet **405** are reversed in a packet **410** that is transmitted to the device **401** in the reverse direction along the network path **403**. A timestamp **409** is inserted into the packet **410**, denoting the time when the first bit of the packet is transmitted from the device **402** onto the return path. Timestamps **415** and **408** are also inserted into the packet. When the packet **410** arrives at the intermediate device **404**, the time difference ΔT**3** between the time when the last bit is received by the device **404** and the time when the first bit was transmitted from the device **402** (the value in timestamp **409**) is calculated and stored in the device **404**. This value ΔT**3** is the delay of the path segment from device **402** to device **404**. The test packet **410** is then forwarded to the network device **401**, which is the end point of the path being tested.

[0036] When the packet **410** arrives at the device **401**, the time difference ΔT**4** between the time when the last bit is received by the device **401** (stored as timestamp **416** in device **401**) and the time when the first bit was transmitted from the device **402** (the value in timestamp **409**) is calculated and stored in the device **401**. This value ΔT**4** is the delay of the path from device **402** to device **401**.

[0037] The stored time difference values ΔT**1**, ΔT**2**, ΔT**3**, and ΔT**4** stored in the network devices **401**, **402** and **404** along the test path can be retrieved centrally. It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

[0038] Also, the difference in time between timestamp **415** and **408** ADDED to the difference in time between timestamp **409** and **416** gives the total round-trip delay of the bi-directional path. An alternative method to calculate the total round-trip delay is to deduct the timestamp **415** from timestamp **416**. It is also to be noted that the clocks between the network devices must be precisely synchronized by one of the many methods known to one skilled in the art.

1-9. (canceled)

10. A method of determining a one-way latency of a network path in a communication network having at least a first and a second paths said method comprising;

- generating, at a first communication device, a test packet including a timestamp indicative of a time the packet is transmitted to a second communication device at end of said first path;
- computing a first path latency at said second communication device upon reception of the test packet based on the time of reception of the packet and said timestamp;
- storing said first path latency in memory at said third communication device;
- forwarding said test data packet to a third communication device at end of said second path;
- computing a one-way latency at said second communication device upon reception of the test packet based on the time of reception of the packet and said timestamp;
- storing said one-way latency in memory at said third communication device; and
- accessing said first and one-way latency by a central management system.

11. The method of claim **10**, further comprising, storing a second timestamp in said test packet indicative of the time said test packet is transmitted from said second device to said third device.

12. The method of claim **11**, further comprising, computing and storing, at said third device, a path latency, indicative of the latency on the path between the second and third device based on said second timestamp.

13. An apparatus for determining a one-way latency of a path in a communication network, having at least a first and second paths:

a first network device at the first end of the first path generating and transmitting a test packet including a first timestamp indicative of the time the packet is transmitted to a second device at the second end of the first path;

the second network device receiving said test packet and computing and storing a first path latency based on a first current time and the first timestamp in the test packet;

the second network device transmitting said test packet to a third network device at end of said second path;

the third network device receiving said test packet and computing and storing a one-way latency based on a second current time and said first timestamp; and

a management system accessing said path and one-way latency.

14. The method of claim **13**, wherein the second network device stores a second timestamp in said test packet indicative of the time said test packet is transmitted from said second device to said third device.

15. The method of claim **14**, wherein said third device computes and stores a path latency, indicative of the latency on the path between the second and third device based on said second timestamp and said current time.

* * * * *