

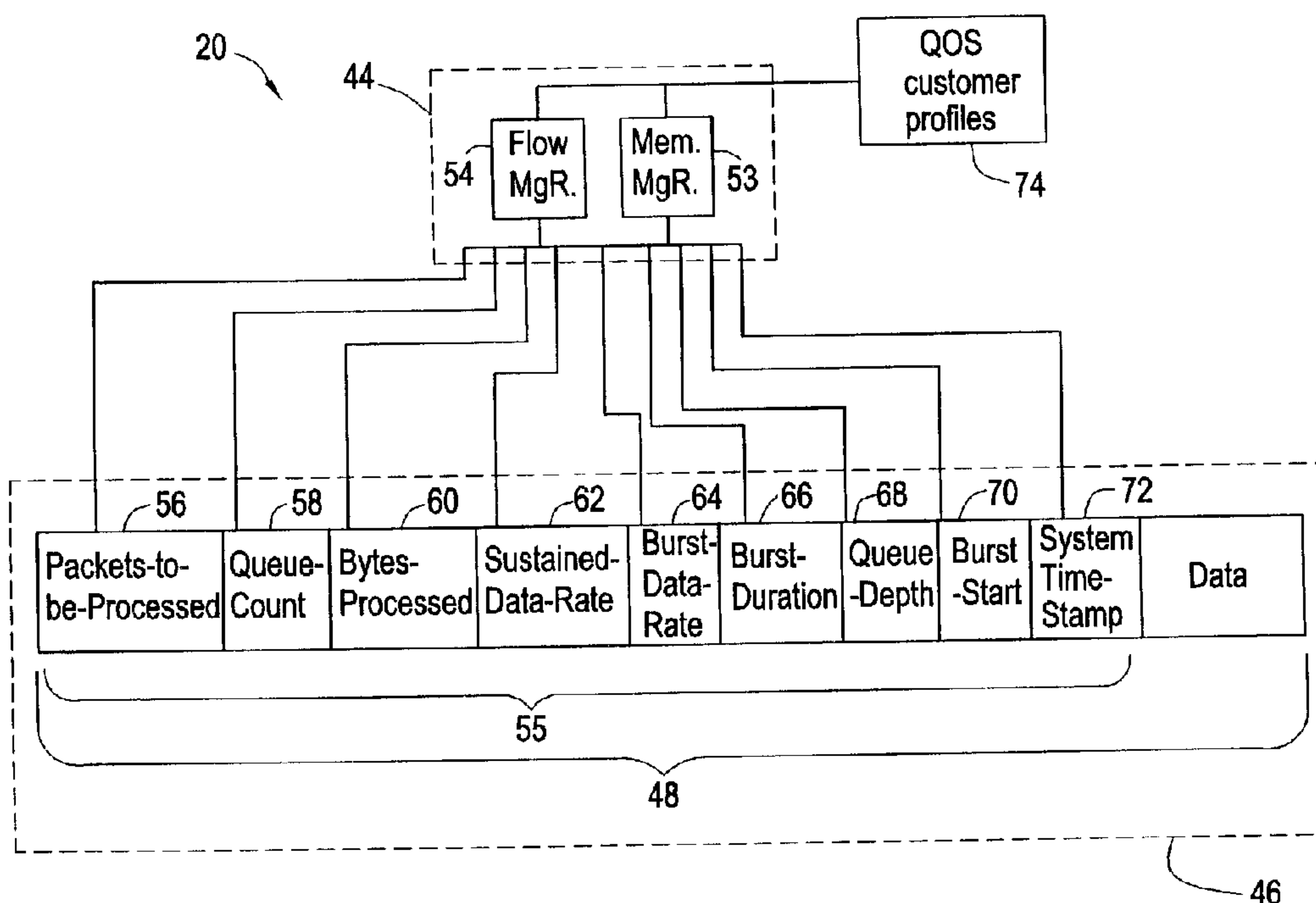


(86) Date de dépôt PCT/PCT Filing Date: 2000/09/25
(87) Date publication PCT/PCT Publication Date: 2001/04/05
(45) Date de délivrance/Issue Date: 2012/11/13
(85) Entrée phase nationale/National Entry: 2002/03/12
(86) N° demande PCT/PCT Application No.: US 2000/026240
(87) N° publication PCT/PCT Publication No.: 2001/024446
(30) Priorités/Priorities: 1999/09/28 (US09/407,712);
1999/09/28 (US09/407,713); 1999/09/28 (US09/407,481)

(51) Cl.Int./Int.Cl. *H04L 12/56* (2006.01),
H04L 29/06 (2006.01)
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(54) Titre : GESTION DE QUALITE DE SERVICE DANS UN SYSTEME D'ACHEMINEMENT DE DONNEES EN
PAQUETS

(54) Title: QUALITY OF SERVICE MANAGEMENT IN A PACKET DATA ROUTER SYSTEM



(57) Abrégé/Abstract:

Methods and system architectures are disclosed for controlling the processing of data packets in one or more routers. Each router stores received data packets in one or more ingress data queues. In a first aspect of the disclosure, packets held in an ingress data queue are processed by the router at a dynamically adjusted packet flow rate. The ingress data queue has a data queue head structure, including a packets-to-be-processed field. The packets-to-be-processed field has a value indicating a selected number of packets to be processed from the ingress data queue in a given processing interval. In this manner, the packet flow rate of the ingress data queue is adjusted by varying the value of the packets-to-be-processed field, based on current operating conditions (e.g., current processor or memory utilization) of the router.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
5 April 2001 (05.04.2001)

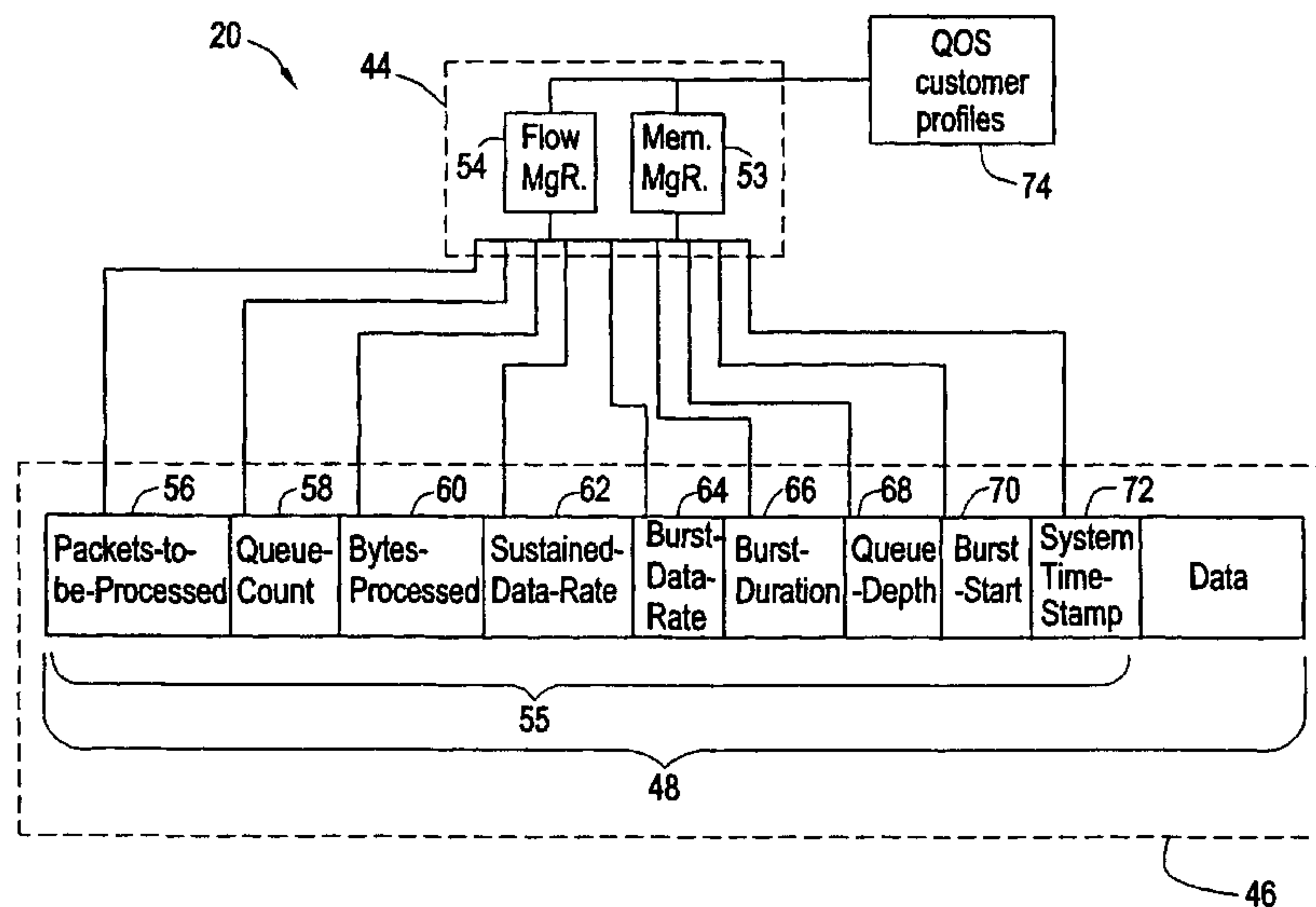
PCT

(10) International Publication Number
WO 01/24446 A3

- (51) International Patent Classification⁷: **H04L 12/56**, 29/06
- (74) Agents: HAN, John, C. et al.; Ericsson Inc., 1010 East Arapaho Road, MS F-11, Richardson, TX 75081 (US).
- (21) International Application Number: PCT/US00/26240
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.
- (22) International Filing Date:
25 September 2000 (25.09.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/407,481 28 September 1999 (28.09.1999) US
09/407,713 28 September 1999 (28.09.1999) US
09/407,712 28 September 1999 (28.09.1999) US
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
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- Published:
— with international search report
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- (88) Date of publication of the international search report:
17 January 2002

[Continued on next page]

(54) Title: QUALITY OF SERVICE MANAGEMENT IN A PACKET DATA ROUTER SYSTEM



(57) Abstract: Methods and system architectures are disclosed for controlling the processing of data packets in one or more routers. Each router stores received data packets in one or more ingress data queues. In a first aspect of the disclosure, packets held in an ingress data queue are processed by the router at a dynamically adjusted packet flow rate. The ingress data queue has a data queue head structure, including a packets-to-be-processed field. The packets-to-be-processed field has a value indicating a selected number of packets to be processed from the ingress data queue in a given processing interval. In this manner, the packet flow rate of the ingress data queue is adjusted by varying the value of the packets-to-be-processed field, based on current operating conditions (e.g., current processor or memory utilization) of the router.

WO 01/24446 A3

WO 01/24446 A3



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

QUALITY OF SERVICE MANAGEMENT IN A PACKET DATA ROUTER SYSTEM

FIELD OF INVENTION

5 The present invention pertains generally to the field of packet data networks and, more particularly, to system architectures and methods for regulating and managing the flow of data packets in one or more packet data routers.

10 BACKGROUND

 In a typical packet data router, packets originating from various source locations are received via a plurality of communication interfaces. Each packet contains routing information, such as a destination address, which is associated with a respective communication interface of the router, e.g., by a
15 routing table or packet forwarding protocol. The router reads the routing information of each received packet and, if it recognizes the information, forwards the packet to the appropriate communication interface for further transmission to its destination. Packets without known destination address or forwarding protocol information are typically dropped.

20 Due to normal ebbs and flows in packet data traffic patterns and volume, a packet data router may be unable to immediately route newly received packets to respective designated communication interfaces. In particular, packet data traffic tends to have bursts of high activity, which is followed by lulls. Thus, a packet data router may be characterized as having
25 a sustained data rate and a burst data rate. When receiving a burst of packet traffic, the router will temporarily store the received packets in an associated memory until it has the processing capacity available to process and forward the packets to their respective outgoing communication interface. When the sustained or burst data rates of a router are exceeded for a certain period of
30 time, it is inevitable that further incoming packets will be dropped. Of course,

-2-

while sometimes unavoidable, dropping unprocessed packets is undesirable because the source will then retransmit the dropped packet as part of its recovery procedure, which tends to prolong the congested state of the packet router and cause further unprocessed packets to be dropped.

5 Packet data network users often share either a single router, or router system, from a service provider. Multiple different internet users, for example, may connect via respective data modems or primary rate interface ("PRI") lines to a single internet protocol ("IP") router, or IP router system, operated by an internet service provider ("ISP"). These end users may be single
10 customers themselves, or there may be multiple (e.g., networked) users combined as a single customer account by the ISP. Each customer account may be allocated a respective level of service priority and packet throughput bandwidth by the ISP, depending on the type and level of service connectivity that is contracted for.

15 For purposes of clarification, as referred to herein, a "router" is defined as a physical (as opposed to logical) entity having a defined number of physical communication interfaces (e.g., modems) under the control of one or more processors collectively executing a single control function. Typically, a single physical router operates under a single routing domain – i.e., wherein a
20 packet received on any communication interface may be forwarded only to the same, or any other communication interface of the router. As referred to herein, a "router system" is defined as two or more independent routers, with an external controller for selectively directing common (incoming) packet data traffic to respective routers within the system.

25 It is known to implement within a single router one or more virtual router instances ("VRIs"). Each VRI has its own subset of communication interfaces, or logical circuits on a shared communication interface, and its own routing domain, but still under the control of a common control function with the other packet traffic handled by the router. In particular, a VRI exists as a
30 collection of processes performed by the router, which correspond roughly to

-3-

the layers in the TCP/IP protocol model. For example, a private network can be configured as a VRI, so that packet data may only be exchanged between end users on the same network. It has also been proposed to have a single VRI span multiple routers in a router system. For example, one suggested
5 implementation is to have a dedicated interface link bridging respective communication interfaces of multiple routers having a common VRI.

Because of varying and often unpredictable growth rates, as well as other economic factors, a packet router, or packet router system, will not necessarily have the processing or memory capacity to simultaneously
10 provide the contracted for bandwidth allocation for every user or VRI it services. Further, various users will connect to the IP router at different, often unpredictable, times and with varying rates and bandwidth needs.

An IP router is typically controlled with a real time operating system ("RTOS"), which allows multiple processes of different priorities to co-exist
15 under the control of a common control function (e.g., within a single central processing unit). For example, the RTOS may have sensors that provide feedback information regarding current usage characteristics for a given user, which is used to adjust the RTOS operating parameters in response to changes in demand. Common applications for the RTOS are process control,
20 motion control and, in certain applications, command and control.

The problem is that these operating systems often fail to effectively accommodate the different priority and bandwidth requirements contracted for by the end user customers of the ISP. In a motion control system, for example, the flow of information from sensors is into the system, and the flow
25 of control signals is out of the system. There may be a lot of sensors, and there may be a lot of subsystems being controlled, but the input information does not circulate through the system and become the output. This has the effect of making the inherent control feature of the RTOS process/task priority ineffectual for controlling the system.

-4-

In particular, a typical IP router is a "packet driven" system. The more data packet it receives, the greater the load, and that load traverses the whole system such that the input is (for all practical purposes) the output. Thus, users whose connection to the router is handling the most packets will tend to monopolize the system resources.

For example, consider a router that is divided into two different VRIs, with each VRI having roughly the same number of end users and paying an ISP for the same quality of service ("QOS"), including identical priority and bandwidth requirements. Thus, the router should be able to provide the end users of each VRI with the same number of bits-per-second ("BPS") system throughput at any given time. Suppose, however, that the router processing capability is barely adequate to handle the peak load of even one of the VRIs without dropping unprocessed packets. If users of the first VRI have, in effect, tied up the router throughput processing capabilities, the users of the second VRI will not receive the service priority and bandwidth they are otherwise entitled to.

Thus, there is a need for methods and system architectures for more fairly regulating the processing of data packets through a packet data router, or router system, whereby the quality of service is balanced for each user and/or VRI, and wherein the system is kept stable, even when heavy loads occur.

SUMMARY OF THE INVENTION

In accordance with a first aspect of the invention, a method is provided for controlling the processing of data packets in a packet data router by dynamically adjusting the rate at which packets held in a respective ingress data queue are processed based on current operating conditions of the router.

In a preferred embodiment, the ingress data queue has a data queue head structure including a packets-to-be-processed field and a sustained-data-rate field. The packets-to-be-processed field stores a value indicating a

number of packets held in the ingress data queue that are to be processed by the router during a given processing interval. In this manner, the packet flow rate of the ingress data queue may be adjusted by increasing or decreasing the value of the packets-to-be-processed field based on current operating
5 conditions of the router, such as, e.g., such as processor or memory utilization. The sustained-data-rate field stores a value indicating a target (e.g., maximum) data processing rate, in bits-per-second, for the ingress data queue. The value of the packets-to-be-processed field is normally based on the sustained-data-rate of the ingress data queue.

10 In accordance with a further aspect of the invention, a method of dynamically adjusting the packet flow rate of an ingress data queue includes detecting whether a burst of data packets has been (or is being) received on the queue. In a preferred embodiment, the data queue head structure includes both a burst-data-rate field and a burst-duration field. The burst-
15 data-rate field stores a value indicating a selected rate for processing data packets held in the ingress data queue if a received burst of data packets has been detected – i.e., which is greater than the sustained-data rate. When a data burst is detected, the packets-to-be-processed field is recalculated based on the burst-data-rate, instead of the sustained-data-rate. The burst-duration
20 field stores a value indicating a time period for sustaining the processing rate of the ingress data queue based on the burst-data-rate. In this manner, the packet flow rate of the ingress data queue may be further controlled by increasing or decreasing the values of the burst-data-rate field or of the burst-duration field.

25 In accordance with a still further aspect of the invention, the data queue head structure of an ingress data queue is also provided with a queue-depth field, which stores a value indicating the current amount of router memory allocated to store data packets in the ingress data queue. Once this limit is reached, any further packets directed to the ingress data queue will be
30 dropped. Depending on current operating conditions of the router, the queue-

depth field may be increased or decreased in order to adjust the memory utilization of the router -- i.e., by limiting the number of packets that may be held in the router memory for processing at any given interval.

5 In accordance with a yet another aspect of the invention, a method is provided for controlling the processing of data packets in a packet data router by dynamically adjusting the rate at which packets held in a plurality of ingress data queues are processed based on current operating conditions of the router.

10 In a preferred embodiment, the packet flow rate of each ingress data queue is adjusted independently of the packet flow of the other ingress data queues, thereby allowing for flexible management and control on an ingress data queue level. The method preferably also includes detecting whether a burst of data has been received on at least one of the plurality of ingress data queues. For example, the packet-flow rate of a first ingress data queue may
15 be increased, while simultaneously decreasing the packet flow rate of a second ingress data queue, in order to accommodate processing of a burst of packets received on the first queue without jeopardizing the overall system throughput and operational stability of the router.

In accordance with a still further aspect of the invention, the data queue
20 head structure of each of a plurality of ingress data queues is provided with a queue-depth field, which stores a value indicating the current amount of memory allocated to store data packets in the respective ingress data queue. In a preferred embodiment, the queue-depth fields of each ingress data queue are independently increased or decreased in order to control memory
25 utilization -- i.e., by limiting the number of packets that may be held in the router memory for processing at any given interval on any given ingress data queue. In a preferred embodiment, memory utilization is also be controlled by adjusting the packet flow rate(s) of one or more ingress data queue(s).

In accordance with still another aspect of the invention, a method is
30 provided for controlling packet data traffic in a router having a plurality of

virtual router instances ("VRIs"), by dynamically adjusting the respective rates at which packets held in one or more ingress data queues associated with one or more VRIs are processed in response to current operating conditions of the router.

5 Preferably, the respective packet flow rates of the ingress data queues associated with the each VRI are independently adjusted. By way of example, in a preferred embodiment, the packet flow rates of the one or more ingress data queues associated with a first virtual router instance are decreased, and the packet flow rates of the one or more ingress data queues
10 associated with the second virtual router instance are increased, respectively, in response to the same current operating conditions of the router.

 In accordance with another aspect of the invention, a method is provided for controlling packet data traffic in a router having one or more processors collectively executing a single control function and having a
15 processor utilization during operation of the router, the router further having a plurality of virtual router instances ("VRIs"), by dynamically adjusting the respective rates at which packets held in one or more ingress data queues associated with one or more VRIs are processed in response to current processor utilization of the router. Again, the respective packet flow rates of
20 the ingress data queues associated with the each VRI are preferably independently adjusted.

 By way of example, in a preferred embodiment, the packet flow rates of the one or more ingress data queues associated with a first VRI are decreased, and the packet flow rates of the one or more ingress data queues
25 associated with the second VRI are increased, respectively, in response to the same processor utilization.

 In accordance with yet another aspect of the invention, the packet flow rates of the one or more ingress data queues associated with one or more VRIs are periodically adjusted in order to maintain processor utilization, or
30 memory utilization, or both, within a selected operating range.

In accordance with a still further aspect of the invention, the amount of memory allocated for storing packets in each of the one or more ingress data queues associated with one or more VRIs is periodically adjusted in order to maintain utilization of a memory associated with the router within a selected
5 operating range.

In accordance with a yet another aspect of the invention, a method for controlling the processing of data packets is provided for a packet data router system having a plurality of routers and configured to support a plurality of virtual router instances ("VRIs"), at least one VRI appearing on multiple
10 routers, wherein each virtual router instance storing received data packets in one or more queues located in each router in which the virtual router instance appears. Data stored in any one queue is processed by the respective router at a data processing rate associated with the respective queue.

In a preferred implementation, the method includes independently
15 adjusting the data processing rates of one or more queues associated with a first VRI located on a first router; and the data processing rates of one or more queues associated with the first VRI located on a second router based on current operating conditions of the first or second router. By way of example, the data processing rates of one or more queues associated with the first VRI
20 located on the first router may be decreased, while the data processing rates of the one or more queues associated with the first VRI located on the second router increased, in response to current operating conditions of the first router.

In another preferred implementation, in which first and second VRIs appear on both first and second routers, the method includes adjusting the
25 respective data processing rates of one or more queues associated with the first and second VRIs located on both routers in response to current operating conditions of one or both routers. In particular, the data processing rates of the queues associated with the first VRI are adjusted independently of the data processing rates of the queues associated with the second VRI.

By way of example, the data processing rates of one or more queues associated with a first VRI located on a first router may be decreased, and the data processing rates of one or more queues associated with the first VRI located on a second router are increased, while at the same time the data processing rates of one or more queues associated with a second VRI located on the first router are increased, and the data processing rates of one or more ingress data queues associated with the second VRI located on the second router are decreased, respectively, in response to the same current operating conditions in the first or second router.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings, in which like reference numerals refer to like components, and in which:

15 FIG. 1 is a simplified block diagram of a preferred packet data router employed as an internet gateway for multiple end users;

FIG. 2 is a simplified block diagram of ingress data queues stored in memory in the router of FIG. 1;

20 FIG. 3 is a box diagram illustration of a preferred packet flow and memory management process in the router of FIG. 1;

FIG. 4 is a flow chart illustrating a preferred method employed in the router of FIG. 1 to detect and adjust for a received packet data burst on an ingress data queue;

25 FIG. 5 is a simplified block diagram of a preferred packet data router system employed as an internet gateway for multiple customer networks;

FIG. 6 is a further simplified block diagram of the router system of FIG. 5, illustrating the distribution of incoming upstream packets to respective routers of the system; and

30 FIG. 7 is a box diagram illustration of a preferred packet flow and memory control process in the router system of FIG. 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a preferred packet data router 20 employed as an internet gateway by an internet service provider ("ISP") 22. The router 20 receives "upstream" data packets from a plurality of different end users 24. Based on routing information contained in each received data packet, the router 20 either (1) forwards the packet to a respective internet server 38; (2) forwards the packet to an end user 24 connected to the router 20; or (3) drops the packet due to it having an unknown destination address or being otherwise undeliverable. The router 20 also receives "downstream" data packets from the internet server(s) 38 and, if possible, forwards the received downstream packets to respective end users 24.

The end users 24 may comprise individuals connected to the router 20 over a traditional public switched telephone network ("PSTN") 26 via, e.g., dial-up modem connections 28, or a basic rate integrated digital services network ("ISDN") line 30. Respective end user networks 32A and 32B, each comprising a substantial number of end users 24, are connected to the router 20 via respective dedicated T1 lines 34A and 34 B, which are also provided as part of the PSTN 26. From the PSTN 26, the respective communication links are forwarded via plurality of dedicated lines 36 to the router 20 at the ISP 22. Other communication links are also possible, such as, e.g., a wireless modem link (not shown), or a coaxial cable modem connection provided over a cable television network (not shown).

Referring to FIG. 2, the router 20 includes one or more processors collectively executing a single control function, which for ease in illustration are collectively shown in FIG. 2 and referred to herein as a single central processing unit ("CPU") 44. The router 20 also includes a shared buffer memory 46, which is preferably implemented as a dynamic random access memory ("DRAM"). At the router 20, the communication lines 36 from the PSTN 26 are terminated at a communication interface 40, comprising a plurality of a software configurable digital signal processors ("DSPs") 42.

-11-

Upstream packets processed (i.e., demodulated) by the DSPs 42 are initially held in respective ingress data queues 48 formed as linked lists in the memory 46.

As will be appreciated by those skilled in the art, the ingress data queues 48 are software data structures that hold the stored packets for processing in a first-in, first-out (FIFO) fashion. The ingress data queues 48 implemented in the router 20 have the concept of "depth," – i.e., a maximum number of stored packets that the respective queue can hold. The particular configuration of the ingress data queues 48 in the memory 46 may vary without departing from the inventive concepts taught herein. Notably, in the embodiment depicted in FIG. 2, each end user 24, networked end user group 32A/32B or VRI 50/52, may have one or more dedicated ingress data queues 48 for storing packets received by the router 20.

For example, data packets received from a first end user group 32A, and only packets received from group 32A, are stored in a first dedicated plurality of ingress data queues 48A. Likewise, data packets received from a second end user group 32B, and only packets received from group 32B, are stored in a second dedicated plurality of ingress data queues 48B. Alternatively, two or more end users 24 may share one or more ingress data queues 48, with a number of possible configurations.

In the embodiment depicted in FIG. 2, the ingress data queues 48A are implemented within the router 20 as a first VRI 50, and the ingress data queues 48B are implemented as a second VRI 52, with each VRI 50 and 52 having its own routing domain. Notably, the packet processing, or "flow rates" for VRI 50 or VRI 52 are the flow rates of the corresponding respective ingress data queues 48A and 48B.

There may be further VRIs implemented in the router 20, but only the first and second VRIs 50 and 52 are shown for ease in illustration in the inventive concepts herein. What is significant is that each VRI within the router 20 is assigned one or more manageable ingress data queues 48. In

-12-

alternate preferred embodiments, the location of the manageable queues may be between VRI protocol layers, where the packet drop and delay parameters are known, instead of at the ingress points.

The CPU 44 selectively retrieves packets from the ingress data queues
5 48 on a FIFO basis, and forwards them to output queues (not shown) associated with the respective output destinations, or otherwise drops packets that are non-deliverable. The packets from each respective ingress data queue 48 are processed by the CPU 44 at a given "packet flow rate," which is defined generally as a number of packets processed by the CPU 44 from the
10 respective ingress data queue 48 during a given processing interval. The packet flow rates of each ingress data queue 48 may differ and, as described in greater detail are controlled by a flow management process, or "flow manager" 53, which is a part of the RTOS of the router 20.

As will be apparent, if immediate processing by the CPU 44 of packets
15 held in a given ingress data queue 48 is not possible, the length of the queue will increase accordingly. Of course, the memory 46 has a finite capacity for storing packets, and each ingress data queue 48 is allocated only a certain amount of buffer space in the memory 46. The number of stored packets of each ingress data queue 48 is tracked by a memory management process, or
20 "memory manager" 53, which is a part of the RTOS of the router 20. Notably, the stored packet lengths may vary.

Generally, shared buffer memories, such as DRAMs, are well suited for use in a packet data router in that they provide relatively inexpensive, high storage capacity in a compact form. However, each read or write access into
25 the memory 46 can be relatively time consuming because of the limited data bus bandwidth between the CPU 44 and the memory 46, as well as the inherent row address strobe latency in a DRAM (if applicable). In other words, it is relatively time and processor resource consuming for the CPU 44 to store (write) or retrieve (read) each data packet into or out of the memory
30 46.

-13-

Referring to FIG. 3, the function of the flow manager 54 is to manage and control the data flow of the ingress data queues 48. In a presently preferred embodiment, the flow manager 54 is implemented as a system task that is repeated at a selected interval, e.g., once every second, for each
5 ingress data queue 48. The flow manager 54 monitors the processing of data packets held in each ingress data queue 48 to manage the overall data flow through the router 20 and, in particular, utilization of the CPU 44 and memory 46.

Towards this end, the flow manager 54 maintains a data queue head
10 structure 55 stored in the memory 46 as a header to each respective ingress data queue 48. The data queue head structure 55 includes several data fields employed by the flow manager 54 for controlling the packet flow rate and amount of memory allocated for the respective ingress data queue 48. In a preferred embodiment, the data fields in the data queue head structure 55
15 include:

(1) A "packets-to-be-processed" field 56 having a value indicating a number of packets held in the respective data queue 48 that are to be processed by the CPU 44 during a given processing interval.

(2) A "queue-count" field 58 having a value indicating the number of
20 packets presently held in the respective data queue 48.

(3) A "bytes-processed" field 60 having a value indicating the number of data bytes processed from the respective data queue 48 during a present processing interval.

(4) A "sustained-data-rate" field 62 having a value, in bits per second,
25 indicating a target maximum data processing rate for the respective data queue 48, e.g., based on a customer service agreement by the ISP 22.

(5) A "burst-data-rate" field 64 having a value, in bits per second, indicating an increased maximum data processing rate for the respective data queue 48, to be temporarily implemented upon receipt of a data burst.

(6) A "burst-duration" field 66 having a value, in seconds (or some fraction thereof, indicating a maximum duration of time for which the data rate specified in the burst-data-rate field 64 shall be maintained upon receipt of a data burst.

5 (7) A "queue-depth" field 68 indicating the maximum number of packets allowed to be held in the respective data queue 48 at one time – i.e., wherein any further received packets will be dropped until existing stored packets are processed to make room for more to be stored.

(8) A "burst-start" field 70 for holding a time stamp value indicating
10 when receipt of a data burst on the respective data queue 48 has been detected.

(9) A "system-time-stamp" field 72 for holding a time stamp value indicating when a poll of the data queue head structure 54 was last performed.

15

As will be appreciated by those skilled in the art, the actual order of the data fields (1)-(9) is of no particular significance, and many variations are possible without departing from the inventive concepts disclosed herein.

In accordance with a general aspect of the invention, the flow and
20 memory managers 54 and 53 constantly monitor the current operating conditions of the router 20, e.g., processor and memory utilization. The data fields (1)-(9) in each data queue head structure 55 are used by the flow and memory managers 54 and 53 to perform several tasks, including monitoring and adjusting the flow rate, managing the burst data rate and adjusting the
25 memory allocation and usage, respectively, of each ingress data queue 48.

The flow manager 54 also monitors, e.g., as a periodic task, the respective flow rates of each ingress data queue 48 and, if appropriate, makes corresponding adjustments to the packet flow rate of one or more ingress data queues 48 in order to ensure overall system stability is
30 maintained in a manner least impacting end user quality of service (QOS). In

-15-

particular, system stability of the router 20 and, most importantly, the QOS for each user 24, user group 32A/32B and/or VRI 50/52 served by the router 20 may be best managed through control of the respective packet flow rates and proportional memory allocation of each of the individual ingress data queues
5 48.

For example, in accordance with a general aspect of the present invention, if processor utilization approaches or exceeds the upper end of a desired operating range, the flow manager 54 will decrease the packet flow rate of one or more ingress data queues 48 by decreasing the corresponding
10 values of the packets-to-be processed field(s) 56. Conversely, if the processor utilization approaches or falls under the lower end of a desired operating range, the flow manager 54 may increase the packet flow rate of one or more ingress data queues 48 by increasing the corresponding values of the packets-to-be processed field(s) 56.

15 An advantage of controlling the processing of data packets on an ingress data queue level is that the system resources of the router 20 can be fairly distributed, or restricted, without individual end users 24, user groups 32A/32B or VRIs 50/52 being disproportionately impacted. A traditional RTOS of a router, on the other hand, cannot differentiate between end users
20 having the same QOS, but accessing the router on different ingress data queues.

By way of illustration, suppose VRI 50 and VRI 52 have identical QOS profiles, but that at a given instance VRI 50 has only one active end user 24 on their network, while at the same instance VRI 52 has nineteen active end
25 users 24. A traditional router RTOS system would allocate (and restrict) resources equally among the different users, i.e., with 5% of the total bandwidth to each end user 24, despite the fact that the lone end user 24 of VRI 50 should have half (50%) of the available router bandwidth, with the nineteen end users 24 of VRI 52 sharing the other half among themselves.

-16-

By being able to control the flow rates of individual ingress data queues, the present invention overcomes this drawback in the prior art. Also, individual user or VRI bandwidth guarantees (i.e., on an ingress data queue level) are possible with the present invention. Further, by controlling the data processing speed of an ingress data queue 48, an ISP 22 may enforce sub-rate bandwidth rates on high speed modems, e.g., allow a 56K modem connection for an end user whose QOS profile is only rated for 28.8K. Most importantly, independent control over the ingress data queues 48 allows for more predictability in dealing with peak traffic loads.

10 In accordance with this aspect of the invention, the flow manager 54 preferably adjusts the respective flow rates of the ingress data queues 48 independently of one another. Based on respective QOS profiles 74 maintained by the ISP 22, the flow manager 54 will adjust the flow rate of those ingress data queue(s) 48 that will least adversely impact QOS criteria
15 for any one end user 24, user group 32A or 32B and/or VRI 50 or 52.

Certain aspects of each customer QOS profile are maintained in the data queue head structure 55 of each ingress data queue 48. For example, the sustained-data-rate field 62 sets forth a target maximum data processing rate for the respective ingress data queue 48, upon which the value of the
20 packets-to-be-processed field 56 for the respective data queue 48 is calculated. In a preferred embodiment, the sustained-data-rate 62 for each ingress data queue 48 is initially determined based on the maximum allotted rate of any end user 24, user group 32A/32B or VRI 50/52 associated with the respective data queue 48. Thereafter, the sustained-data-rate 62 for each
25 ingress data queue 48 is dynamically based on current operating conditions of the router 20. For example, the packet flow rates of one or more data queues 48A associated with VRI 50 and/or VRI 52 may be periodically adjusted in order to maintain processor utilization of the router 20 within a selected operating range.

The flow manager 54 also manages data bursts that may be received on each ingress data queue 48. The QOS user profiles 74 preferably provide for an end user 24 to be given an additional amount of packet processing bandwidth for a short period of time in order to accommodate for occasional
5 burst packet traffic. For example, an end user 24 may need to transfer a large file once a month. Instead of having to pay for a more expensive sustained data rate bandwidth, the ISP 22 can offer the end user 24 an additional "burst data rate" for a specified duration of time (i.e., "burst duration").

In a preferred embodiment, the burst-data-rate 64 for a respective
10 ingress data queue 48 is initially determined based on the highest maximum burst data rate guaranteed by the ISP 22 to any end user 24 associated with the respective ingress data queue 48. Similarly, the burst-duration field 66 for a respective ingress data queue 48 is initially determined based on the highest maximum burst duration guaranteed by the ISP 22 to any end user 24
15 associated with the respective ingress data queue 48. Thereafter, the burst-data-rate 64 and burst-duration 66 are dynamically adjusted for each ingress data queue 48 based on current operating conditions of the router 20.

Notably, the flow manager 54 may allocate differing sustained-data-rate 62, burst-data-rate 64 and burst-duration 66 values for one or more
20 ingress data queues 48 based on off-peak usage criteria, e.g., time of day variances, but will preferably not decrease the flow rate of any ingress data queue 48 below the highest minimum rate guaranteed by the ISP 22 to any end user 24 (e.g., based on the user's QOS profile), associated with the respective ingress data queue 48, unless absolutely necessary to preserve
25 system integrity.

FIG. 4 depicts one preferred process by which the flow manager 54 detects whether a data burst is being received on a respective ingress data queue 48. The flow manager 54 periodically polling each ingress data queue 48 and calculating (at step 78) its current data flow rate 78 (in bits per
30 second). In a preferred embodiment, the flow manager 54 calculates the

current flow rate by multiplying the value of the bytes-processed field 60 of the data head queue structure 55 for the respective ingress data queue 48 by eight. The resultant product is then divided by the difference between the current time and the value of the system time-stamp field 72. The flow
5 manager 54 then compares (at step 80) the calculated current packet flow rate with the value in the sustained-data-rate field 62.

If the calculated rate is greater than the sustained-data-rate, the flow manager 54 assumes a data burst is occurring on the respective ingress data queue 48. The flow manager 54 then recalculates (at step 82) the value of
10 the packets-to-be-processed field 56 based on the value of the burst-data-rate field 64, and places a time stamp with the present time in the burst-start field 70. If no received burst is detected, -- i.e., if the calculated data rate is equal to or less than the sustained-data-rate field 62, -- the flow manager 54 (at step 85) updates the system time stamp field 72 and resets the value of the bytes-processed field 60 for the next polling cycle.
15

If a data burst is detected on an ingress data queue 48, the flow manager 54 periodically calculates (at step 84) the duration of the data burst by calculating the difference between the present time and the time stamp in the burst-start field 70. The flow manager then compares (at step 86) the
20 calculated burst duration with the value in the burst-duration field 66.

If the duration of a present data burst is less than the value of the burst-duration field 66, the flow manager maintains (at step 88) the value of the packets-to-be-processed field 56 based on the value of the burst-data-rate field 64. If the duration of the burst has lasted longer than the value of the
25 burst-duration field 66, the flow manager 54 recalculates the value of the packets-to-be-processed field 56 based on the value of the sustained-data-rate field 62.

In a preferred embodiment, the values of the burst-data-rate field 64 and the burst-duration field 66 may be adjusted by the flow manager 54 based
30 on current operating conditions in the router. By way of example, as a

customer service benefit, the ISP 22 may configure the flow manager 54 to increase the values of the burst-data-rate field 64 and the burst-duration field 66 so long as the processor utilization of the router 20 is at or below a specified operating range.

5 With reference back to FIG. 3, the memory manager 53 monitors the respective queue-count and queue-depth fields 58 and 68 for each ingress data queue 48 as part of the memory management process. If overall utilization of the router memory 46 approaches or exceeds the upper end of a desired range, the memory manager 53 will decrease the amount of memory
10 allocated for one or more ingress data queues 48 by decreasing the values of the corresponding queue-depth field(s) 68. Conversely, if utilization of the memory 46 approaches or falls under the lower end of a desired range, the memory manager 54 may increase the amount of memory allocated for one or more ingress data queues 48 by increasing the corresponding values of the
15 queue-depth field(s) 68. In a preferred embodiment, the memory manager 53 increases the queue-depth field 68 of an ingress data queue 48 upon detecting a received data burst. In doing so, it may be necessary to simultaneously decreasing the queue-depth fields 68 of one or more other ingress data queues 48 in order to maintain memory utilization.

20 As with the packet flow rates, the amount of memory allocated for storing packets in each ingress data queue 48 is preferably determined independently of the memory allocated for all other queues 48. In a preferred embodiment, the queue-depth field 68 is initially determined based on the collective maximum amount of memory allotted for every end user 24, user
25 group 32A/32B and/or VRI 50/52 associated with the respective data queue 48. Thereafter, the queue-depth field 68 for each ingress data queue 48 is dynamically based on current operating conditions of the router 20. For example, the queue-depth fields 68 of one or more data queues 48A associated with VRI 50 and/or VRI 52 may be periodically adjusted in order to
30 maintain utilization of the memory 46 within a selected range.

-20-

The memory manager 53 will adjust the queue-depth fields 68 of those ingress data queue(s) 48 that will least adversely impact QOS criteria for any one end user 24, user group 32A or 32B and/or VRI 50 or 52, e.g., based on respective QOS profiles 74 maintained by the ISP 22. Preferably, the
5 memory manager 53 will not decrease the queue-depth field 68 of any ingress data queue 48 below the highest minimum rate guaranteed by the ISP 22 to the collective end users 24, user groups 32A/32B and/or VRIs 50/52 associated with the respective data queue 48.

The operating processes making up the respective memory manager
10 53 and flow manager 54 are preferably linked to improve the management tools available for the router 20. For example, if processor resources are available, the flow manager 54 will decrease the packet flow rate(s) of one or more ingress data queues 48, -- i.e., to increase the processing rate of the stored packet back load, -- in order to decrease memory utilization. In fact, if
15 possible, it may be preferred from a QOS point of view to temporarily increase the packet flow rates of those ingress data queues 48 having the highest queue-count fields 58, rather than reduce the queue-depth fields 68, in order to avoid or minimize dropped packets.

FIG. 5 illustrates an alternate preferred packet data router system 110
20 employed as an internet gateway by an ISP 100. The router system 110 includes a plurality of routers 112, 114, 116 and 118, which receive and process data packets from a plurality of different end user networks 124, via the PSTN 26. Based on routing information contained in each received data packet, the router system 110 either forwards the packet to a respective
25 internet server 38; forwards the packet to an end user network 124; or drops the packet due to it having an unknown destination address or being otherwise undeliverable. The router system 110 also receives "downstream" data packets from the internet server(s) 38 and, if possible, forwards the received downstream packets to respective end user networks 124.

The end user networks 124 include at least three distinct customer accounts, 124(A), 124(B) and 124(C). The router system 110 may have numerous other end users and customer accounts, including both individuals and networks. However, only the networks 124(A), 124(B) and 124(C) are shown for ease in illustration of still further aspects of the invention.

Referring to FIG. 6, each router 112, 114, 116 and 118 of the router system 110 is configured substantially identical to router 20. Each router 112, 114, 116 and 118 has one or more processors collectively executing a single control function, which for ease in illustration are collectively shown and referred to herein as a single CPU 144. Each router 112, 114, 116 and 118 also includes a shared buffer memory 146, which is preferably implemented as a DRAM.

In the illustrated preferred embodiment, the communication lines 36 from the PSTN 26 are terminated at a system communication interface 140, comprising a plurality of a software configurable DSPs 142. In an alternate preferred embodiment, one or more of the individual routers 112, 114, 116 and 118 have their own respective communication interfaces, with at least one interface connection to each of the other respective routers in order to allow for shifting incoming packet traffic.

Upstream packets processed by the DSPs 142 are initially held in respective ingress data queues 148 formed as linked lists in the respective memories 146 of each of the routers 112, 114, 116 and 118. As with the above described ingress data queues 48 in router 20, the ingress data queues 148 of the respective routers 112, 114, 116 and 118 of the router system 110 are software data structures that hold the stored packets for processing in a FIFO fashion, each queue 148 having a respective depth, – i.e., a maximum number of stored packets that the respective queue can hold. As will be described in greater detail herein, the router system 110 includes a system QOS controller 120, which monitors the operating conditions of the respective routers 112, 114, 116 and 118, and dynamically controls how the upstream

-22-

packet data traffic is distributed to the various respective ingress data queues 148.

Referring to FIG. 7, one or more of the ingress data queues 148A in each of the routers 112, 114, 116 and 118 are implemented as a first VRI for customer A ("VRI-A"); one or more of the ingress data queues 148B in routers 112 and 116 are implemented as a second VRI for customer B ("VRI-B"); and one or more of the ingress data queues 148C in routers 114 and 118 are implemented as a third VRI for customer C ("VRI-C"). Each VRI has its own routing domain within the respective routers that it appears on. Each router 112, 114, 116 and 118 may have one or more further VRIs, but only VRI-A, VRI-B and VRI-C are shown for simplification.

Each router 112, 114, 116 and 118 of the system 110 includes a QOS manager 152, flow manager 154 and memory manager 156, which are all part of the RTOS of the respective router. The QOS manager 152 is the control interface between the respective flow and memory managers 154 and 156 of each router 112, 114, 116 and 118, and the system QOS controller 120. As with the flow and memory managers 54 and 53 in router 20, the respective memory and flow managers 154 and 156 in each of the routers 112, 114, 116 and 118 manages and controls the data flow of the ingress data queues 148 of the respective router. In a presently preferred embodiment, the flow and memory managers 154 and 156 are implemented as system task that is repeated at a selected interval, e.g., once every second, for each ingress data queue 148 of the respective router 112, 114, 116 and 118.

In particular, the respective flow and memory managers 154 and 156 monitor the processing of data packets held in each ingress data queue 148 to manage the overall data flow through the router and, in particular, utilization of the respective routers' CPU 144 and memory 146. The respective flow and memory managers 154 and 156 monitor and maintain a data queue head structure for each ingress data queue 148 of each respective router 112, 114, 116 and 118, including, at least, each of the same fields as in the data queue

head structure 55 of router 20. Thus, as with router 20, each router 112, 114, 116 and 118 of the router system 110 has the ability to control the individually control the packet flow rate and allocated memory of each ingress data queue 148. Further, the system QOS controller 120, in conjunction with each of the
5 router QOS managers 152, has the ability to shift incoming packet traffic between respective ingress data queues 148 of the respective routers 112, 114, 116 and 118, based on operating conditions of any one router.

For example, in accordance with one further aspect of the invention, the data processing rates of one or more ingress data queues 148 associated
10 with VRI-A on one or more the routers 112, 114, 116 and 118 are adjusted based on current operating conditions of router 112. Preferably, the data processing rates of the respective one or more ingress data queues 148 associated with VRI-A of each respective router 112, 114, 116 and 118 are adjusted independently of the processing rates of the respective one or more
15 ingress data queues 148 associated with VRI-A located on the other routers. In addition to adjusting the flow rates of the individual data queues, the system QOS controller 120 may reallocate incoming packet traffic between ingress data queues 148 associated with any one VRI in order to better balance the system load.

20 While preferred embodiments and applications of the present invention have been shown and described, as would be apparent to those skilled in the art, many modifications and applications are possible without departing from the inventive concepts herein. Thus, the scope of the disclosed invention is not to be restricted except in accordance with the appended claims.

SUBSTITUTE SHEET

24

What is claimed is:

1. A method for controlling processing of data packets in a router, the router storing received data packets in an ingress data queue that has a data queue head structure that comprises a packets-to-be-processed field having a value indicating a number of packets held in the ingress data queue to be processed by the router during a given processing interval, wherein packets held in the ingress data queue are processed by the router at a selected packet flow rate, the method comprising:

adjusting the packet flow rate based on current operating conditions in the router by increasing or decreasing the value of the packets-to-be-processed field;

wherein the data queue head structure further comprises a sustained-data-rate field for indicating a target maximum packet processing rate, the value of the packets-to-be-processed field being based on a value of the sustained-data-rate field if no data burst is detected on the ingress data queue, wherein a determination of whether a burst of data has been received is made by:

setting a value of the sustained-data-rate field to a selected non-burst packet flow rate;

calculating a current packet flow rate of the ingress data queue; and

comparing the calculated packet flow rate with the value of the sustained-data-rate field.

2. The method of claim 1, wherein the data queue head structure further comprises a burst-data-rate field, wherein the value of the packets-to-be-processed field is based on a value of the burst-data-rate field for a selected duration of time if a data burst is detected on the ingress data queue.

3. The method of claim 1, wherein the data queue head structure further comprises a burst-duration field having a value indicating the selected duration of time for basing the value of the packets-to-be-processed field on the value of the burst-data rate field.

4. The method of claim 3, wherein the value of one or both of the burst-data-rate field and burst-duration field is adjusted based on current operating conditions in the router.

SUBSTITUTE SHEET

25

5. The method of claim 1, further comprising detecting whether a burst of data is being received at the ingress data queue, and temporarily increasing the packet flow rate upon detecting that the data burst is being received.
6. The method of claim 5, wherein the data queue head structure further comprises a time-stamp field and a bytes-processed field, wherein the current packet flow rate of the ingress data queue is calculated by:
 - setting a value of the time-stamp field to a time a last calculation of the current packet flow rate was made;
 - setting the value of the bytes-processed field to reflect the number of bytes of data processed since the last packet flow rate calculation; and
 - calculating the packet flow rate of the ingress data queue based on the respective values of the time-stamp field and the bytes-processed field.
7. The method of claim 1, wherein the router comprises a memory, the ingress data queue having an allocated amount of the memory in which to store received data packets, wherein the method further comprises adjusting the amount of memory allocated to store data packets in the ingress data queue based on current utilization of the memory.
8. The method of claim 1, wherein the router has one or more processors collectively executing a common control function, the one or more processors having a processor utilization, wherein the packet flow rate of the ingress data queue is adjusted based on current processor utilization.
9. The method of claim 1, wherein the router has a memory, wherein the packet flow rate of the ingress data queue is adjusted based on current utilization of the memory.
10. A method for controlling a processing of packets in one or more ingress data queues in a router, at a selected packet flow rate, comprising:
 - managing and controlling a packet flow rate of each of the one or more ingress data queues, which are maintained in a memory in the router, by utilizing a data queue head structure as a header for each of the one or more ingress data queues, wherein the data queue head structure comprises a plurality of data fields comprising:

SUBSTITUTE SHEET

26

a packets-to-be-processed field, having a value indicating a number of packets held in the one or more ingress data queues to be processed by the router during a given processing interval, wherein the packet flow rate is adjusted by increasing or decreasing the value of the packets-to-be-processed field; and

a sustained-data-rate field for indicating a target maximum packet processing rate, wherein a determination of whether a burst of data has been received is made by:

setting the value of the sustained-data-rate field to a selected non-burst packet flow rate;

calculating a current packet flow rate of the one or more ingress data queues; and

comparing the calculated packet flow rate with the value of the sustained-data-rate field.

11. The method of claim 10, wherein the data queue head structure for each of the one or more ingress data queues, further comprises: a burst-data-rate field for indicating an increased maximum data processing rate, wherein the value of the packets-to-be-processed field is based on the value of the sustained-data-rate field if no data burst is detected on the one or more ingress data queues or the value of the burst-data-rate field, for a selected duration of time, if a data burst is detected on the one or more ingress data queues.

12. The method of claim 11, wherein the data queue head structure further comprises a burst-duration field having a value indicating the selected duration of time for basing the value of the packets-to-be-processed field on the value of the burst-data rate field.

13. The method of claim 12, wherein the values of the burst-data-rate field and burst-duration field are adjusted based on current operating conditions in the router.

14. The method of claim 10, further comprising detecting whether a burst of data is being received at one of the one or more ingress data queues, and if true, temporarily increasing the packet flow rate of the one of the one or more ingress data queues upon detecting the received data burst.

SUBSTITUTE SHEET

27

15. The method of claim 10, wherein the data queue head structure further comprises a time-stamp field and a bytes-processed field, wherein a current packet flow rate of the one or more ingress data queues is calculated by:

 setting the value of the time-stamp field to a time that a last calculation of the current packet flow rate was made;

 setting the value of the bytes-processed field to reflect the number of bytes of data processed since the last packet flow rate calculation; and

 calculating the packet flow rate of the one or more ingress areas data queues based on the respective values of the time-stamp field and the bytes-processed field.

16. The method of claim 10, wherein each of the one or more ingress data queues having an allocated amount of memory in the router in which to store received packets, further comprises the steps of: adjusting the amount of memory allocated to store the received packets in each of the one or more ingress data queues based on current utilization of the memory, wherein the data queue head structure of each of the one or more ingress data queues further comprises: a queue-depth field for indicating the maximum number of packets allowed to be held in an associated ingress data queue, wherein the queue depth field can be simultaneously adjusted with respect to the queue-depth fields associated with other of the one or more ingress data queues; a queue-count field for indicating the number of packets presently held in the associated ingress data queue; and monitoring and adjusting the queue-depth field and the queue-count field for optimizing the amount of memory allocated to the received packets in each of the one or more ingress data queues according to a predetermined range.

17. The method of claim 10, further comprising adjusting the packet flow rate of the one or more ingress queues based on current utilization of a router processor.

18. The method of claim 10, wherein the router has a memory, and wherein the packet flow rate of the ingress data queue is adjusted based on current utilization of the memory.

19. The method of claim 10, wherein the packet processing rate of each ingress data queue is adjusted independently of the packet processing rate of every other ingress data queue.

SUBSTITUTE SHEET

28

20. The method of claim 19, further comprising the steps of: increasing a packet processing rate of a first queue; and decreasing a packet processing rate of a second queue upon detecting that a burst of data has been received on the first queue.

21. The method of claim 10, wherein the router comprises one or more processors collectively executing a common control function, the one or more processors having a processor utilization, and wherein the packet processing rate of the first queue and the packet processing rate of the second queue are adjusted independently.

22. An apparatus for controlling processing of packets in one or more ingress data queues in a router, at a selected packet flow rate, comprising:

a flow manager for managing and controlling a packet flow rate of each of the one or more ingress data queues, which are maintained in a memory in the router, wherein the flow manager utilizes a data queue head structure as a header for each of the one or more ingress data queues and the data queue head structure comprises a plurality of data fields comprising:

a sustained-data-rate field for indicating a target maximum data processing rate;

a packets-to-be-processed field, having a value indicating a number of packets held in the one or more ingress data queues to be processed by the router during a given processing interval, wherein the packet flow rate is adjusted by increasing or decreasing the value of the packets-to-be-processed field;

a burst-data-rate field for indicating an increased maximum data processing rate, wherein the value of the packets-to-be-processed field is based on the value of the sustained-data-rate field if no data burst is detected on the one or more ingress data queues or the value of the burst-data rate field, for a selected duration of time, if a data burst is detected on the one or more ingress data queues; and

a burst-duration field having a value indicating a selected duration of time for basing the value of the packets-to-be-processed field on the value of the burst-data rate field, wherein the flow manager can determine whether a burst of data has been received by:

setting the sustained-data-rate field to a selected non-burst packet flow rate;

SUBSTITUTE SHEET

29

calculating a current packet flow rate of the one or more ingress data queues; and
comparing the calculated packet flow rate with the value of the sustained-data-rate field.

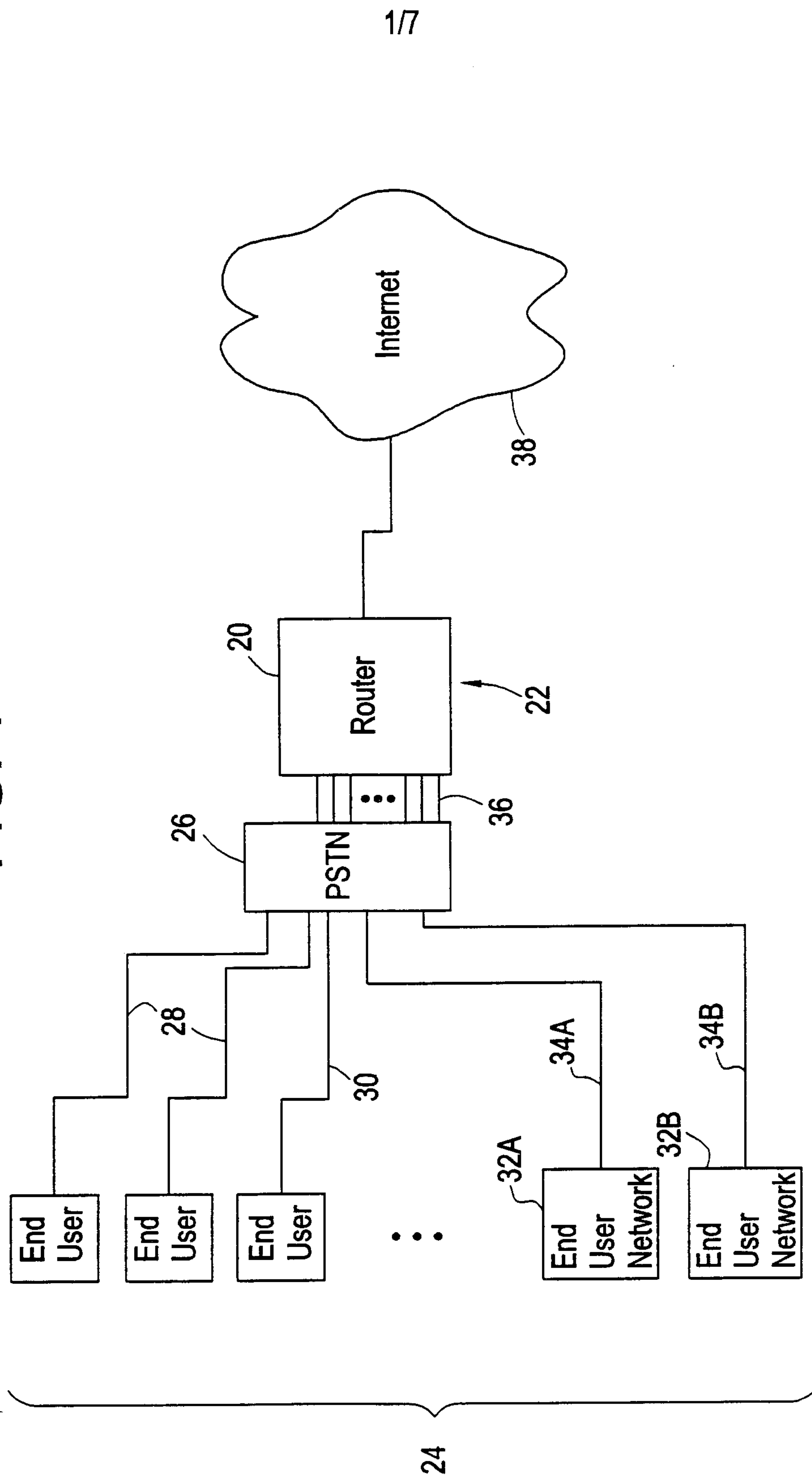
23. The apparatus of claim 22, wherein the flow manager can adjust the value of the burst-data-rate field and the burst-duration field is based on current operating conditions in the router.

24. The apparatus of claim 22, wherein the flow manager can detect whether a burst of data is being received at one of the one or more ingress data queues, and temporarily increase the packet flow rate of the one of the one or more ingress data queues upon detecting the received data burst.

25. The apparatus of claim 22, wherein the data queue head structure further comprises a time-stamp field for indicating when a poll of the data queue head structure was last performed; a bytes-processed field for indicating the number of data bytes processed during a present processing interval, wherein the time-stamp field and the bytes-processed field are utilized for calculating the packet flow rate of the each of the one or more ingress data queues based on the respective values of the time-stamp field and the bytes-processed field.

26. The apparatus of claim 22, wherein each of the one or more ingress data queues having an allocated amount of the router memory in which to store received packets, further comprises a memory manager for monitoring and adjusting the amount of memory allocated to store the received packets in each of the one or more ingress data queues based on current utilization of the memory, wherein the data queue head structure further comprises: a queue-depth field for indicating the maximum number of packets allowed to be held in an associated ingress data queue, wherein the memory manager can adjust the queue-depth field in the one or more ingress data queues that will least adversely impact quality of service criteria; and a queue-count field for indicating the number of packets presently held in the associated ingress data queue.

FIG. 1



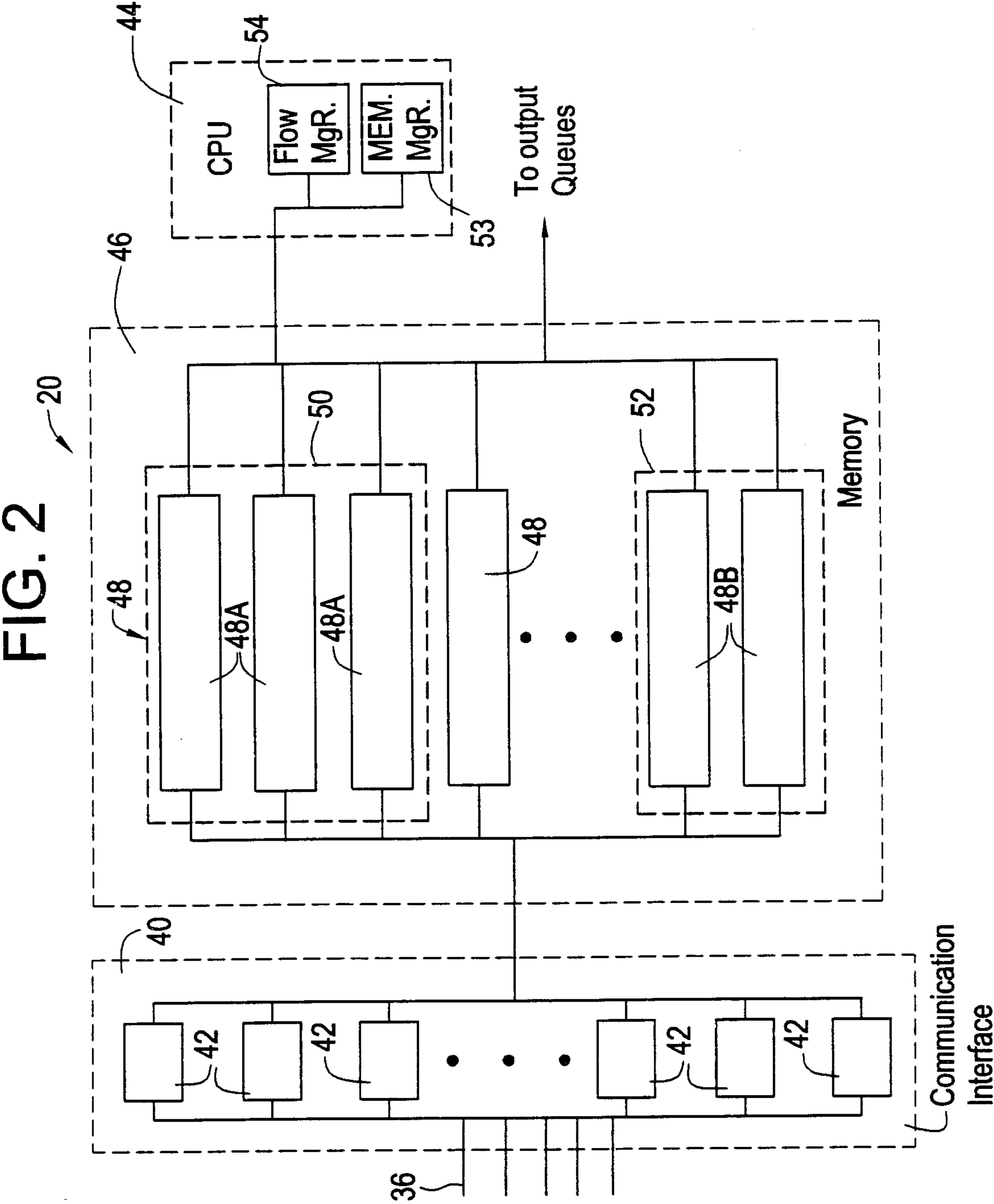
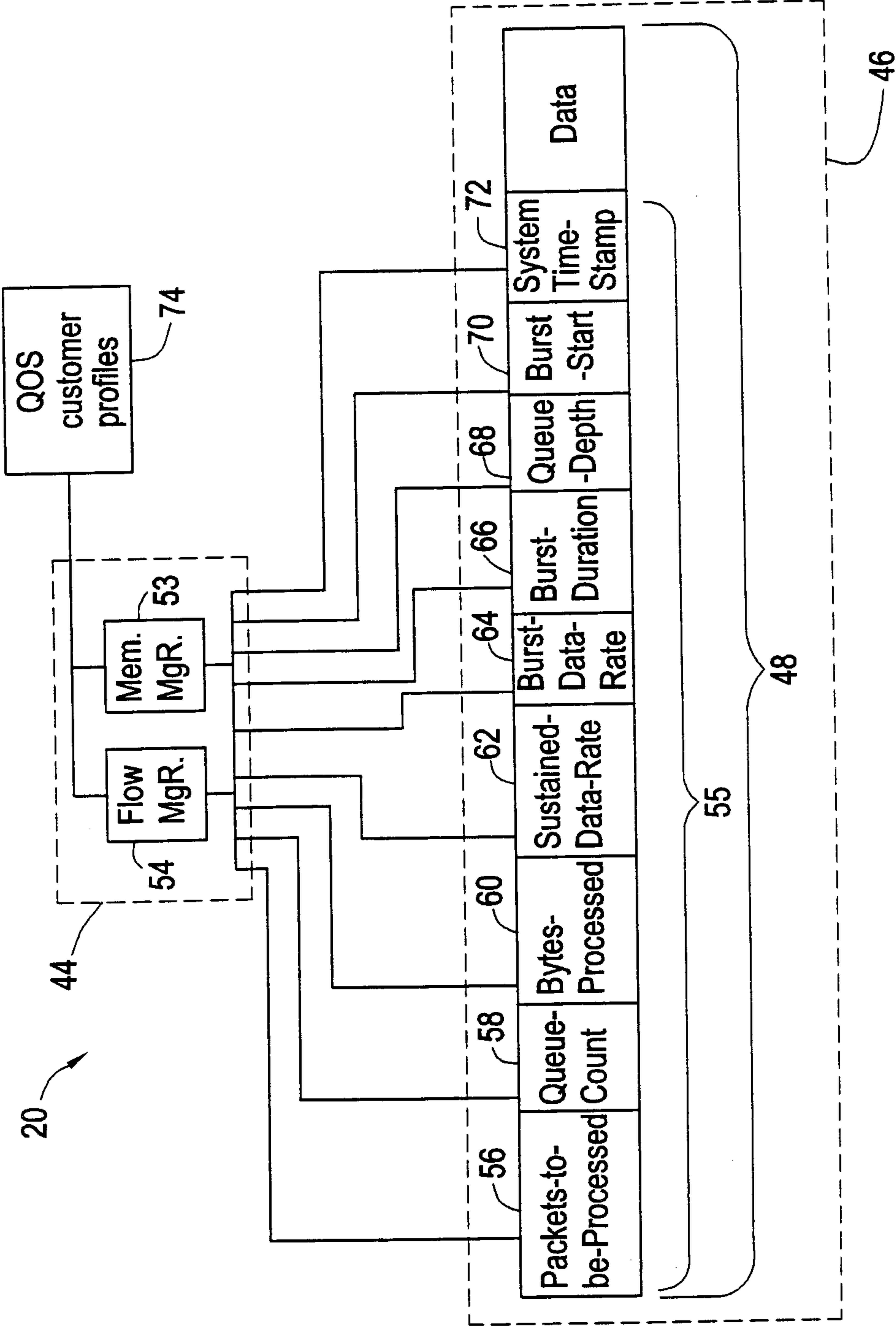


FIG. 3



4/7

FIG. 4

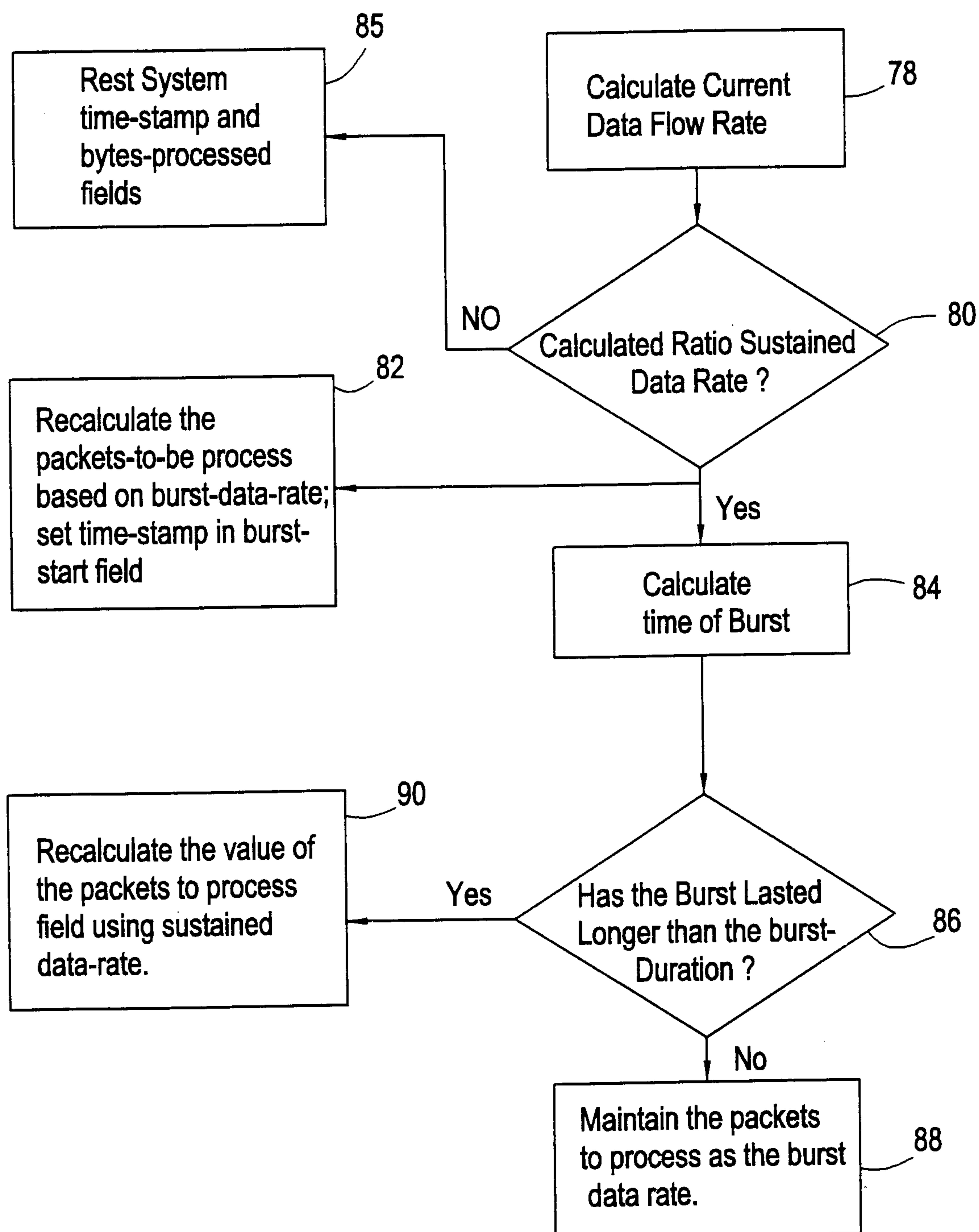
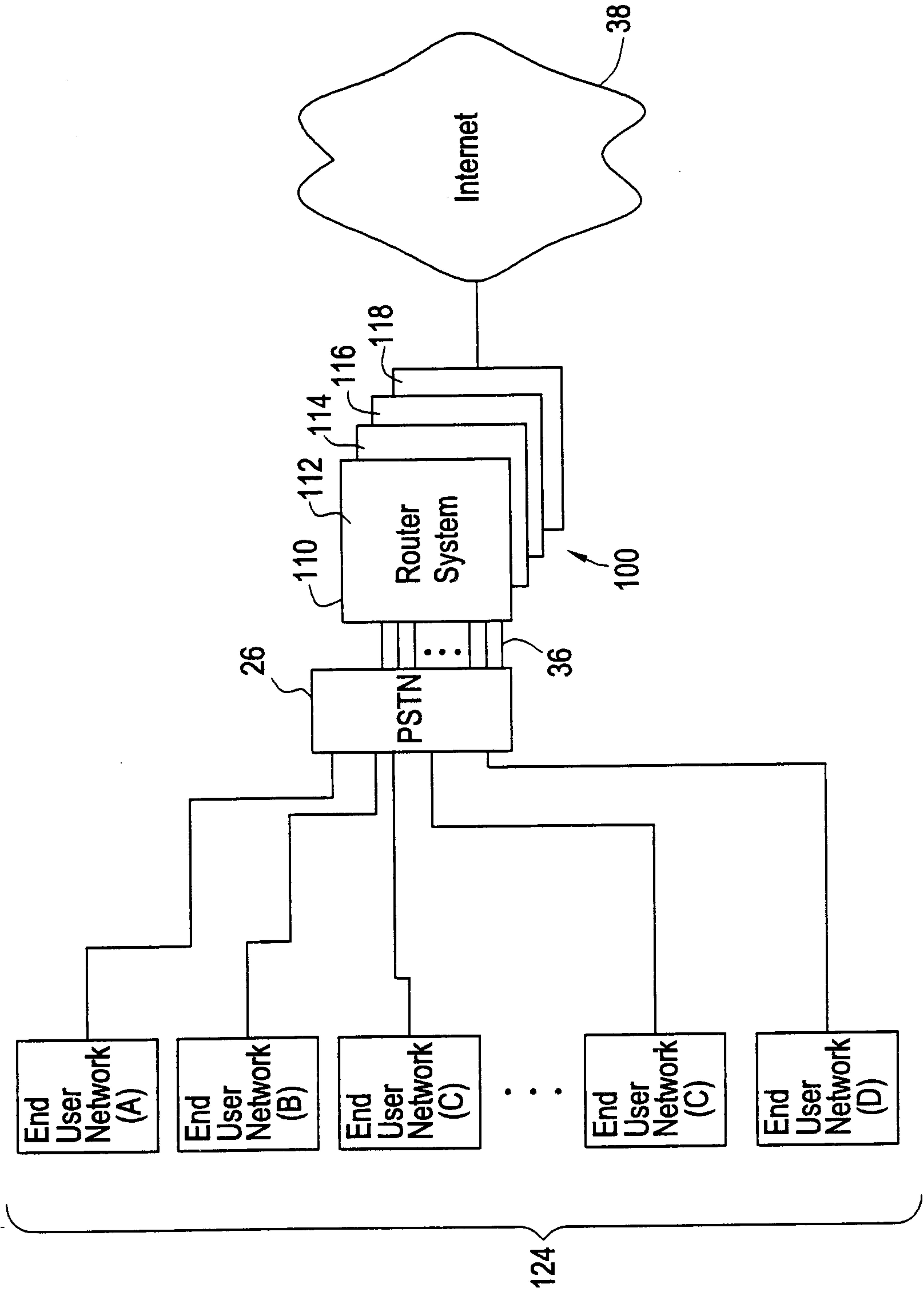


FIG. 5



6/7

FIG. 6

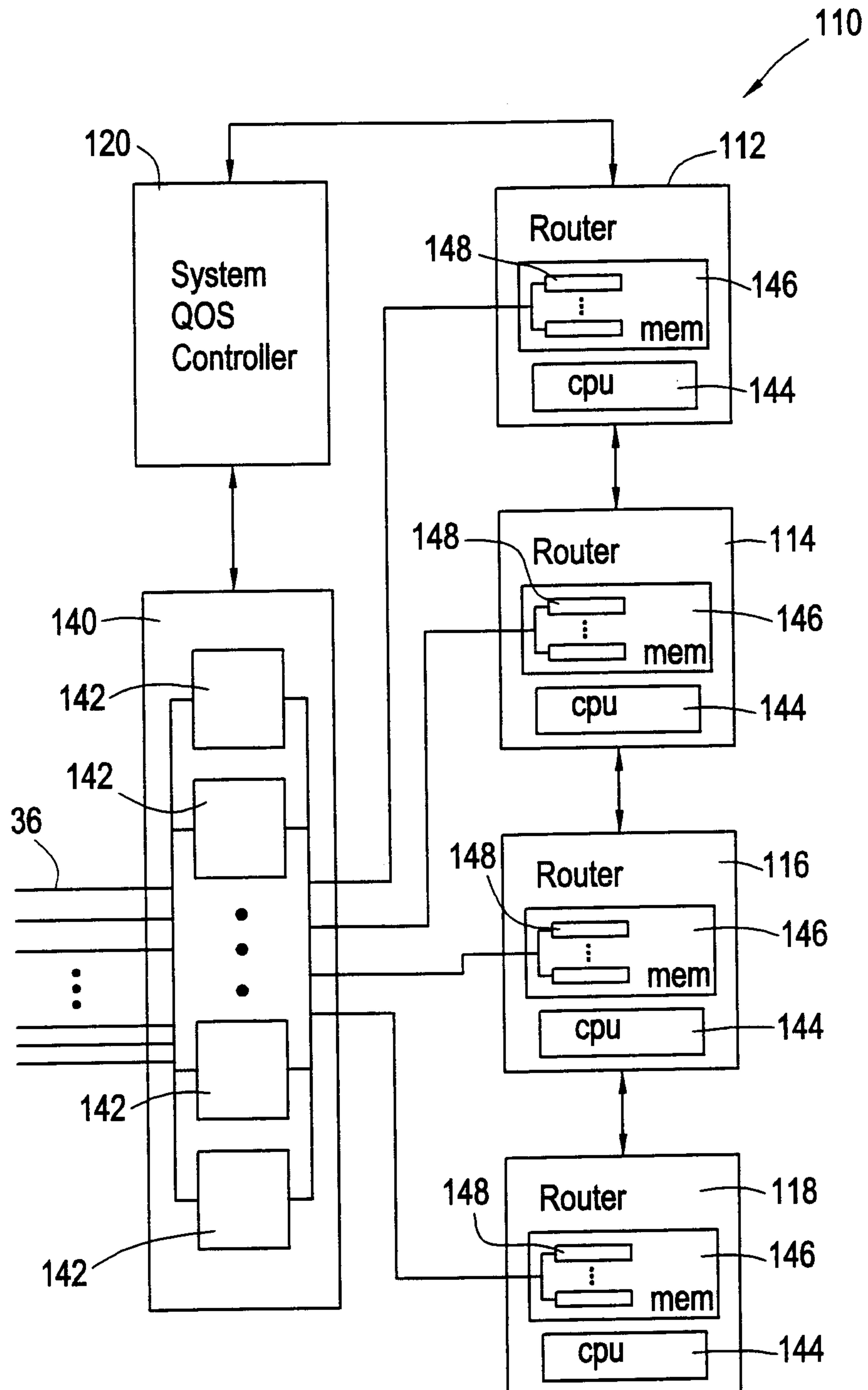


FIG. 7

