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(54) Title: PACKET SCHEDULING IN A COMMUNICATION NETWORK

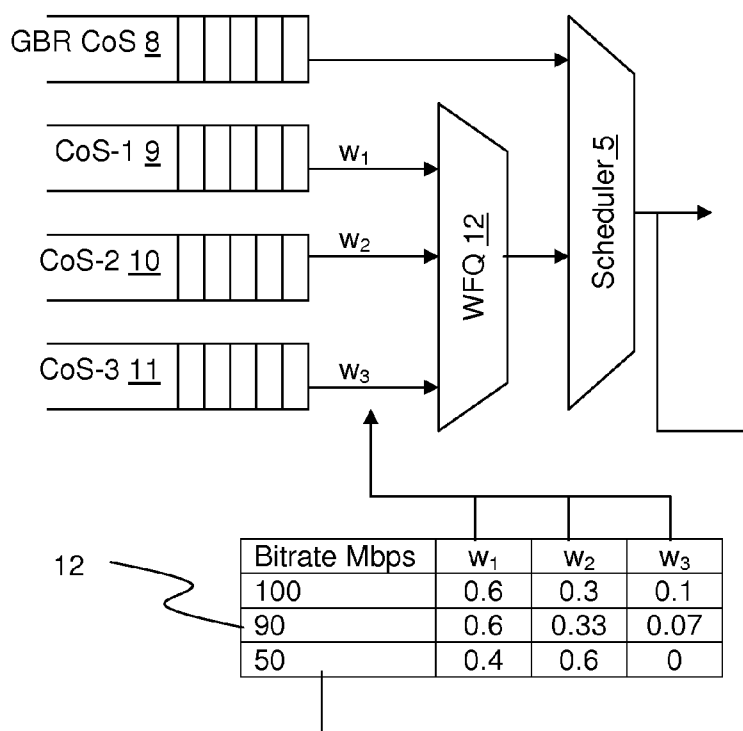


Figure 3

(57) Abstract: A method and apparatus for packet scheduling over a communication link in a communication network. A data packet scheduler accords scheduling weights to at least two sets of data packets to be transmitted, and the sending of the sets of data packets is scheduled in accordance with the scheduling weights. When it is determined that a change in available bandwidth over the communication link has occurred, the scheduler dynamically adjusts the scheduling weight for each set of data packets on the basis of the available bandwidth. This ensures more efficient resource sharing control and resource guarantees when the available bandwidth changes.



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GW, ML, MR, NE, SN, TD, TG).

Packet Scheduling in a Communication Network

TECHNICAL FIELD

- 5 The invention relates to the filed of packet scheduling in a communication network.

BACKGROUND

10 There are many types of transmission systems in communication networks. Each system is typically limited by a capacity of the maximum amount of data that can be carried at any given time. In order to address this, data packets to be sent via the communication network can be prioritized. Some types of data, such as peer to peer and file download data and emails, can tolerate being delayed in the network. Other types of data, such as audio or video in an session between two or more parties, cannot tolerate delays in the network, as this can impact on the quality of service that is provided to the parties. Delay-tolerant data can therefore be sent with a low priority, whereas delay-intolerant traffic can be sent with a higher priority. At times when the communication network is approaching full capacity, the delay-tolerant traffic can be withheld in favour of the delay-intolerant traffic to ensure that the quality of the delay-intolerant traffic is not impacted.

20 There are several schemes for prioritizing and scheduling data packets. One example is weighted fair queuing (WFQ). Data streams comprising data packets are accorded a "weight" that is used to determine how much of the bandwidth resources the data stream can use. Delay-intolerant data will be accorded a higher weight than delay-tolerant data.

30 Strict priority and/or WFQ queuing mechanisms are used among different Classes of Services (CoS) to control packet level resource sharing. Figure 1 illustrates a resource sharing solution. User Equipment (UE) 1 sends data packets having two different CoS (shown by a dotted line and a dashed line) via a base station such as an eNodeB (2) over a radio bearer. Application level congestion control 3 (such as TCP) is applied to ensure best-effort traffic is sent between the UE 1 and a server 4. A scheduler 5 schedules the data packets, including non Guaranteed bit-rate (GBR) data packets, which are sent via a Serving Gateway (6) to a Packet Data Network Gateway (PDN GW) 7. The scheduler 5 uses WFQ to schedule the data packets.

The WFQ weights used are determined on the basis of the desired resource sharing and the actual capacity of the link. Examples of desired resource sharing, with an
5 associated WFQ weight setting, are as follows:

- Guarantee a fixed bitrate for a CoS. For example, it may be required to guarantee a bit-rate of 30 Mbps for a CoS over a shared 100 Mbps link. In this example, 100 Mbps is the dominant capacity. When determining WFQ weights, the
10 normalized weight for this CoS must be at least 0.3.

- Avoiding starvation of low priority traffic. Low priority traffic, such as data packets sent by a peer-to-peer (p2p) application can, when the bandwidth is being used by higher priority traffic, be throttled back so no low priority traffic is sent at all. In
15 this case, the WFQ for this CoS can be given a low weight (e.g. 1/10) to avoid 'starvation' of this CoS. This ensures that low priority traffic has at least a guaranteed bandwidth share, and the remaining 90% of the bandwidth capacity is enough for higher priority traffic at the highest modulation.

20 The solutions described above to configure the scheduler 5 are static. A problem with these solutions arises when Adaptive Modulation is used, as this gives rise to variable link capacity. In wireless communication networks, link adaptation is used to refer to the matching of the modulation, coding and other signal and protocol parameters to the conditions on the radio link. Conditions may vary owing to, for example, interference
25 from other signals, sensitivity, transmitter power and so on. Rate adaption algorithms are used to adapt the modulation according to the quality of the radio link. Adaptive Modulation systems require knowledge of the condition of the radio link, which can be easily measured at the receiver, and the information provided to the transmitter. The sending rate at the transmitter can therefore be dynamically adapted depending on the
30 condition (and available bandwidth) of the radio link.

However, Adaptive Modulation of a radio link can result in variable link capacity, giving lower modulations with lower bitrates. In the example shown in Figure 1, the parameters of the scheduler 5 (e.g. WFQ weights) are determined on the basis of the
35 link capacity. In the case of Adaptive Modulation, the dominant modulation level is

used to set the scheduling according to the corresponding capacity. The dominant modulation level can be, for example, the lowest (or highest) modulation depending on the applied design method.

- 5 Where the scheduler 5 is configured with static rules, as described above, and Adaptive Modulation is used, then the static rules used by the scheduler 5 can become non-optimal. Static settings cannot provide the guaranteed bandwidth for a CoS at lower modulation level (assuming that the static weights were optimized for highest modulation level). For example, consider the case where the bandwidth of a link
10 changes from 100 Mbps to 50 Mbps due to a modulation change. A static weight of 0.3 weight guarantees only 15 Mbps for that CoS instead of 30 Mbps. It will be appreciated that when the weights are determined for the lowest modulation level, then the required bandwidth is guaranteed at all modulation levels. However, during normal operation (in other words, most of the time), a much higher bandwidth guarantee is
15 unnecessarily provided for that CoS. This conservative static setting can be non-optimal for other CoS at higher modulation levels.

To further illustrate this by way of an example, consider the case where an operator wishes to use two types of CoSs. Both CoSs have the same priority, and so the
20 desired resource sharing among them is equal sharing. However, the first CoS requires a minimal bandwidth guarantee. The bandwidth share between the CoSs should be 50%-50%, but the bandwidth share of the first class must be at least 30 Mbps if possible. Assume that at the highest modulation level the link capacity is 100 Mbps, but at lowest modulation level it is 50 Mbps. If a WFQ weight of 0.6 is set for the
25 first CoS (based on the capacity of the lowest modulation level), the required 30 Mbps can be provided for the first CoS at all modulation level. However, the resource sharing among the two CoSs is not the desired 50%-50% sharing (the sharing will be 60%-40%). In other words, the first CoS that has higher minimal bandwidth guarantee has higher priority in bandwidth resource sharing, which is not desired

30

As a further example, when we low priority traffic, as described above, is accorded a WFQ weight, then it is guaranteed a bandwidth share even at lower modulation levels. In some circumstances, when the link is experiencing a lower bandwidth capacity, it may be desirable to allocate that share to a CoS with a higher priority (such as a CoS
35 that requires a minimum absolute bandwidth). During normal operation, it is

reasonable to accord a weight to the low priority traffic to avoid starvation, but at lower modulations it may be required to protect higher priority traffic first. Static configuration of WFQ weights does not allow for this.

5 SUMMARY

It is an object of the invention to improve the scheduling of data packets when using Adaptive Modulation. According to a first aspect, there is provided a method of packet scheduling over a communication link in a communication network. A data packet scheduler accords scheduling weights to at least two sets of data packets to be transmitted, and the sending of the sets of data packets is scheduled in accordance with the scheduling weights. When it is determined that a change in available bandwidth over the communication link has occurred, the scheduler dynamically adjusts the scheduling weight for each set of data packets on the basis of the available bandwidth. This ensures more efficient resource sharing control and resource guarantees when the available bandwidth changes.

As an option, the scheduling weights for each set of data packets are dynamically modified by obtaining, for each set of data packets, scheduling weights stored at a database.

The method optionally includes determining that a change in a number of bearers of a set of data packets has occurred, and dynamically adjusting the scheduling weight for each set of data packets on the basis of the change in the number of bearers. By considering the number of ongoing bearers, more sophisticated resource sharing policies can be implemented. As a further option, the scheduling weights for each set of data packets are optionally dynamically adjusted using an algorithm taking into account the number of bearers of a set of data packets.

Each set of data packets is optionally identified by a Class of Service.

While the method may be used to account for a change in available bandwidth owing to any cause, it is particularly useful when the change in available bandwidth is caused by adaptive modulation of the communication link.

As an option, after dynamically adjusting the scheduling weights, a timer is started. No further scheduling weight adjustments are performed for the duration of the timer.

As an option, a number of bearers of a set of data packets is determined by either
5 parsing signalling messages or analysing header information.

According to a second aspect, there is provided a data packet scheduler for scheduling data packets to be sent via a communication link in a communication network. The data packet scheduler is provided with a weight function for according scheduling
10 weights to at least two sets of data packets. A scheduling function is provided for scheduling data packets in accordance with the scheduling weights. A processor is provided for determining that a change in available bandwidth over the communication link has occurred. The processor is arranged to dynamically adjust the scheduling weight for each set of data packets in accordance with the available bandwidth.

15 As an option, the data packet scheduler is provided with a database for storing scheduling weights to be accorded to each set of data packets.

As a further option, the processor is arranged to determine that a change in a number
20 of bearers of a set of data packets has occurred, and dynamically adjust the scheduling weight for each set of data packets on the basis of the change in the number of bearers. As a further option, the scheduling weights for each set of data packets are dynamically adjusted using an algorithm taking into account the number of bearers of a set of data packets.

25 The data packet scheduler is optionally provided with a timer for starting a time after an adjustment in scheduling weights, during which no further scheduling weight adjustments are performed by the processor.

30 The processor is optionally arranged to determine a number of bearers of a set of data packets by any of parsing signalling messages and analysing header information.

According to a third aspect, there is provided a computer program comprising computer readable code which, when run on a data packet scheduler, causes the data packet
35 scheduler to perform the method as described above in the first aspect.

According to a fourth aspect, there is provided computer program product comprising a computer readable medium and a computer program as described above in the third aspect, wherein the computer program is stored on the computer readable medium.

5

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates schematically in a block diagram a network architecture for packet scheduling;

10

Figure 2 illustrates schematically in a block diagram an example of data packet scheduling according to an embodiment of the invention;

Figure 3 illustrates schematically in a block diagram an example of data packet scheduling in the event of Adaptive Modulation changes to the available bandwidth according to an embodiment of the invention;

15

Figure 4 is a flow diagram illustrating steps of an embodiment of the invention;

Figure 5 illustrates schematically in a block diagram an example of data packet scheduling on a per-Bearer basis according to an embodiment of the invention; and

20

Figure 6 illustrates schematically in a block diagram a scheduler according to an embodiment of the invention.

25

DETAILED DESCRIPTION

Data packet scheduling can be greatly improved if WFQ weights are dynamically modified as the available bandwidth increases or decreases as a result of Adaptive Modulation. Figure 2 illustrates the case where there is one class of guaranteed bit-rate (GBR) traffic 8, a first non-GBR CoS 9, a second non-GBR CoS 10 and a third non-GBR CoS 11. The third non-GBR CoS 11 may be placed in a alternative queue for low priority traffic, such as p2p data packets. In the scheduler, the three non-GBR CoSs are scheduled using a WFQ function 12.

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The WFQ weights of the three non-GBR CoSs are modified dynamically depending on the current state of Adaptive Modulation of the link. Consider the example in which the first non-GBR CoS requires a guaranteed bit-rate. In the event that Adaptive Modulation causes the available bandwidth to reduce, the WFQ weight for the first non-GBR CoS 9 is increased to ensure that it maintains its guaranteed bit-rate. This may be used, for example, for an Over the Top (OTT) service that requires a bandwidth guarantee for proper operation.

For the low-priority non-GBR Cos 11, its weight is decreased in the event that the Adaptive Modulation causes the available bandwidth to reduce. For example, at lower modulations, a weight of 0 may be set for the third non-GBR CoS to ensure that all available bandwidth is used for higher priority traffic. Of course, when the Adaptive Modulation leads to the available bandwidth increasing, the WFQ weight of the low-priority non-GBR traffic can be increased once more.

Per-Bearer level information (e.g. #ongoing Bearers) may also be used when dynamically adjusting the WFQ weights for different CoSs, as described in more detail below.

The WFQ weight settings are typically dynamically adjusted when Adaptive Modulation causes a change in the available bandwidth, as illustrated in Figure 3. The scheduler is provided with data in the form of a table 12 that includes a weight for each CoS and for each modulation level (bit-rate). When the modulation level changes then scheduler 5 consults the table 12 and updates the WFQ weights for each CoS accordingly.

The scheduler may be provided with a prohibit timer to avoid to frequent WFQ reconfiguration. For example, if a 100 ms timer is used then once a WFQ is adjusted as a result of Adaptive Modulation, no further WFQ adjustments can be made until 100 ms have elapsed.

In the example shown in Figure 3, the required resource sharing for each CoS is as follows:

- The first CoS 9 requires a large bandwidth, and so requires a high bandwidth share. However, it is not critical for the first CoS 9 to have the high bandwidth all the time, so there is no requirement for a bandwidth guarantee. An example of a type o data packet that might fall under this CoS is premium Internet access.
5
- The second CoS 10 requires a bandwidth of at least 30 Mbps all the time regardless of the link conditions and the Adaptive Modulation level (in this example, it is assumed that there negligible traffic over the GBR CoS 8). This CoS requires a high (but not guaranteed) bandwidth share, but the absolute bandwidth guarantee is more important. An example of data packets that fall under this CoS is OTT services that require (soft) bandwidth guarantees. An alternative solution is to put this class into a higher priority queue and using a 30 Mbps shaper. However, in this case the CoS does not have the potential of using a larger bandwidth than 30 Mbps, even when other CoSs are not using the available bandwidth.
10
15
- The third CoS 11 is used for low priority traffic. It is preferable, but not necessary, to avoid starvation for this class. This can be used for e.g. non-premium Internet access or special access provided for p2p traffic.
20

The settings shown in the table 12 result in the second CoS 10 having a bandwidth of at least 30 Mbps regardless of the total available bandwidth. The first CoS 9 maintains a high bandwidth share at all times, but this is necessarily reduced in the event that the total available bandwidth falls to 50 Mbps, in order to ensure that the second CoS 10 maintains the required bandwidth of 30 Mbps. The third CoS 11 has its bandwidth share reduced in the event that the available bandwidth is reduced, and in the event of a large reduction of the available bandwidth from 100 Mbps to 50 Mbps, the third CoS 11 is accorded a WFQ weight of 0.
25
30

The above mention solution can not be realized by using static WFQ setting, even if rate limiters are used.

In order to apply WFQ weights dynamically according to the Adaptive Modulation, the scheduler 5 needs to be aware of the state of the link and the available bandwidth.
35

This requires the scheduler to receive information about Adaptive Modulation from a transmitter over which the data packets are being sent.

Figure 4 is a flow diagram illustrating steps of an embodiment of the invention, with the following numbering corresponding to that of Figure 4:

- 5 S1. Each CoS is accorded a weight for use in packet scheduling, and the scheduler 5 sends the data packets over the communication link according to the weight for each CoS;
- 10 S2. Adaptive modulation causes a change in the available bandwidth over the communication link. This change is communicated to the scheduler 5.
- 15 S3. The scheduler 5 looks up the new bandwidth in a database and obtains new weights for each CoS from the database.
- S4. A timer is started.
- S5. The new weights obtained from the database are accorded to each CoS.
- 20 S6. A further change in bandwidth is detected.
- S7. If the timer is still running, then no changes are made to the weights. If the timer is no longer running, then new weights are obtained from the database and the method reverts to step S3.
- 25

As mentioned above, per-Bearer level information (e.g. #ongoing Bearers) can be taken into account when dynamically adjusting the weight settings. Considering the number of ongoing Bearers allows more sophisticated resource sharing policies to be supported by the scheduler 5. This also allows bandwidth guarantee to be provided at the bearer level, which gives finer control than simply providing bandwidth guarantee for a particular CoS. Figure 5 shows the steps of an embodiment that uses per-Bearer level information, with the following numbering corresponding to that of Figure 4:

S8. A determination is made of the number of ongoing Bearers per CoS. This determination may be made using, for example, header information such as a Tunnel End-point Identifier (TEID), or parsing signalling messages.

5 S9. The WFQ weights for each CoS are recalculated in the event of a change in the capacity of the link owing to Adaptive Modulation, and/or in the event of a change in the number of Bearers used by a CoS. For example:

- $w_1 = \text{\#Bearer1} \times 4$;
- 10 • $w_2 = \text{\#Bearer2} \times 2$ and
- if $C > 20$ Mbps then
 - $w_3 = \text{\#Bearer3}$
- else
 - $w_3 = 0$.

15

In this example, the settings are used when the first CoS 9 is a gold class service with a weight of 4, the second CoS 10 is a silver class service with a weight of 2 and the third CoS 11 is a bronze class service with a weight of 1, but at lowest modulation it is down-prioritized.

20

Note that modifying the WFQ weights for each CoS on the basis of per-Bearer information may be performed separately from modifying the WFQ weights for each CoS on the basis of Adaptive Modulation changing the conditions of the link. However, this has certain drawbacks. For example, frequent changes in the number of bearers
 25 cause frequent changes in WFQ weights. Furthermore, a single bearer arrival/termination would only lead to a negligible changing of WFQ weights. However, it is advantageous to change WFQ weights on the basis of both the per-Bearer information and Adaptive Modulation changing the conditions of the link, as it allows the current link conditions and traffic situation to be considered.

30

The number of number of bearers in each traffic class may be considered when setting new WFQ weights when the link capacity changes.

Figure 6 illustrates a scheduler 5 according to an embodiment of the invention. The
 35 scheduler is provided with a processor 12 and a computer readable medium in the form

of a memory 13. The processor 12 receives data packets from a packet source 14 in order to perform scheduling. In order to do this, a weight function 15 and a scheduling function 16 are provided, typically provided by the same processor 12, although it will be appreciated that these functions may be performed by different processors. A transmitter 17 is provided for sending scheduled data packets according to their assigned weights over a communication link. The transmitter 17 may feed information back to the processor about the available bandwidth and the state of adaptive modulation. The processor 12 is arranged to dynamically adjust the scheduling weight for each set of data packets. The processor 12 may also be used to determine the number of bearers of a set of data packets by, for example, of parsing signalling messages or analysing header information.

The memory 13 stores a program 17 which, when executed by the processor 12, causes the scheduler 5 to behave as described above. The memory 13 may also include a database 18 which stores information correlating available bandwidth, weights and CoSs. It will be appreciated that the database 18 may be located remotely from the scheduler 5.

As described above, a timer 19 may also be provided to ensure that weights are not dynamically adjusted too rapidly.

In practice, the scheduler 5 is typically embodied at a function provided at an existing transport node, examples of which include switches, routers, and microwave transmission nodes.

The techniques described above give improved resource sharing control and resource guarantees during adaptive modulation at both CoS and Bearer level. The dynamic adjustment of weights means that the scheduler reconfigures weights whenever the modulation level is changed.

It will be appreciated by the person of skill in the art that various modifications may be made to the above described embodiments without departing from the scope of the present invention as defined in the appended claims.

The following abbreviations have been used in this specification:

	CoS	Class of Service
	GBR	Guaranteed Bit Rate
	OTT	Over the Top
5	p2p	Peer to peer
	PDN GW	Packet Data Network
	Serving GW	Serving Gateway
	TCP	Transmission Control Protocol
	TEID	Tunnel Endpoint Identifier
10	WFQ	Weighted Fair Queuing

CLAIMS

1. A method of packet scheduling over a communication link in a communication network, the method comprising, at a data packet scheduler:
5 according (S1) scheduling weights to at least two sets of data packets and scheduling data packets in accordance with the scheduling weights;
determining (S2) that a change in available bandwidth over the communication link has occurred; and
dynamically adjusting the scheduling weight for each set of data packets on the
10 basis of the available bandwidth.
2. The method according to claim 1, further comprising:
dynamically adjusting the scheduling weights for each set of data packets by obtaining (S3), for each set of data packets, scheduling weights stored at a database.
15
3. The method according to claim 1 or 2, further comprising:
determining that a change in a number of bearers of a set of data packets has occurred; and
dynamically adjusting the scheduling weight for each set of data packets on the
20 basis of the change in the number of bearers.
4. The method according to claim 3, wherein the scheduling weight for each set of data packets are dynamically adjusted using an algorithm taking into account the number of bearers of a set of data packets.
25
5. The method according to any of claims 1 to 4, wherein each set of data packets is identified by a Class of Service.
6. The method according to any of claims 1 to 5, wherein a change in available
30 bandwidth is caused by adaptive modulation of the communication link.
7. The method according to any of claims 1 to 6, further comprising:
after dynamically adjusting the scheduling weights, starting (S4) a timer and performing no further scheduling weight adjustments for the duration of the timer.
35

8. The method according to any of claims 1 to 7, further comprising:
determining (S8) a number of bearers of a set of data packets by any of parsing signalling messages and analysing header information.
- 5 9. A data packet scheduler (5) for scheduling data packets to be sent via a communication link in a communication network, the data packet scheduler comprising:
a weight function (15) for according scheduling weights to at least two sets of data packets
a scheduling function (16) for scheduling data packets in accordance with the
10 scheduling weights;
a processor (12) for determining that a change in available bandwidth over the communication link has occurred; and wherein
the processor (12) is arranged to dynamically adjust the scheduling weight for each set of data packets on the basis of the available bandwidth.
- 15 10. The data packet scheduler (5) according to claim 9, further comprising:
a database (18) for storing scheduling weights to be accorded to each set of data packets.
- 20 11. The data packet scheduler (5) according to claim 9 or 10, wherein the processor is further arranged to determine that a change in a number of bearers of a set of data packets has occurred and dynamically adjust the scheduling weight for each set of data packets on the basis of the change in the number of bearers.
- 25 12. The data packet scheduler (5) according to claim 11, wherein processor is further arranged to dynamically adjust the scheduling weight for each set of data packets taking into account the number of bearers of a set of data packets.
- 30 13. The data packet scheduler (5) according to any of claims 9 to 12, further comprising:
a timer (19) for starting a time after an adjustment in scheduling weights, during which no further scheduling weight adjustments are performed by the processor (12).

14. The data packet scheduler according to an of claims 9 to 13, wherein the processor (12) is arranged to determine a number of bearers of a set of data packets by any of parsing signalling messages and analysing header information.
- 5 15. A computer program (17), comprising computer readable code which, when run on a data packet scheduler, causes the data packet scheduler to perform the method of any of claims 1 to 8.
- 10 16. A computer program product comprising a computer readable medium (13) and a computer program (17) according to claim 15, wherein the computer program is stored on the computer readable medium.

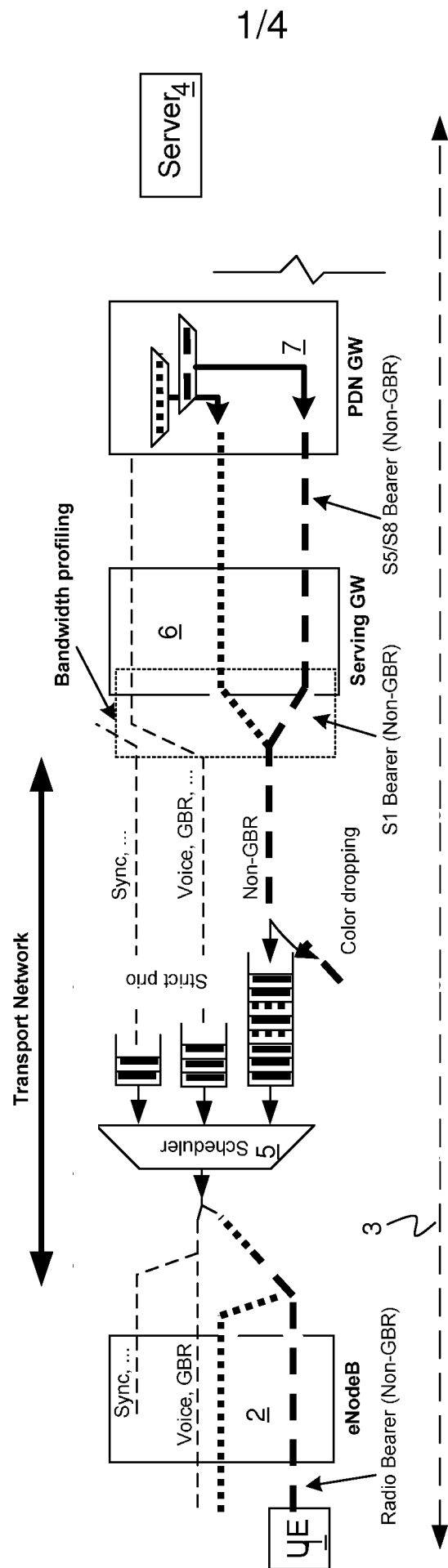


Figure 1 (Prior Art)

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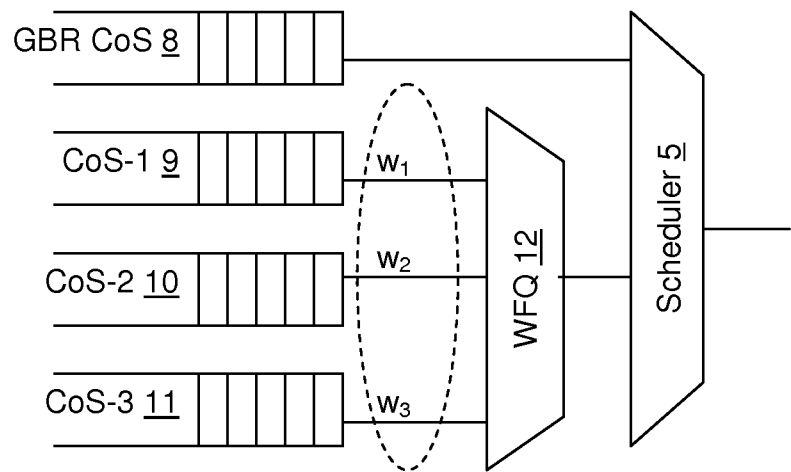


Figure 2

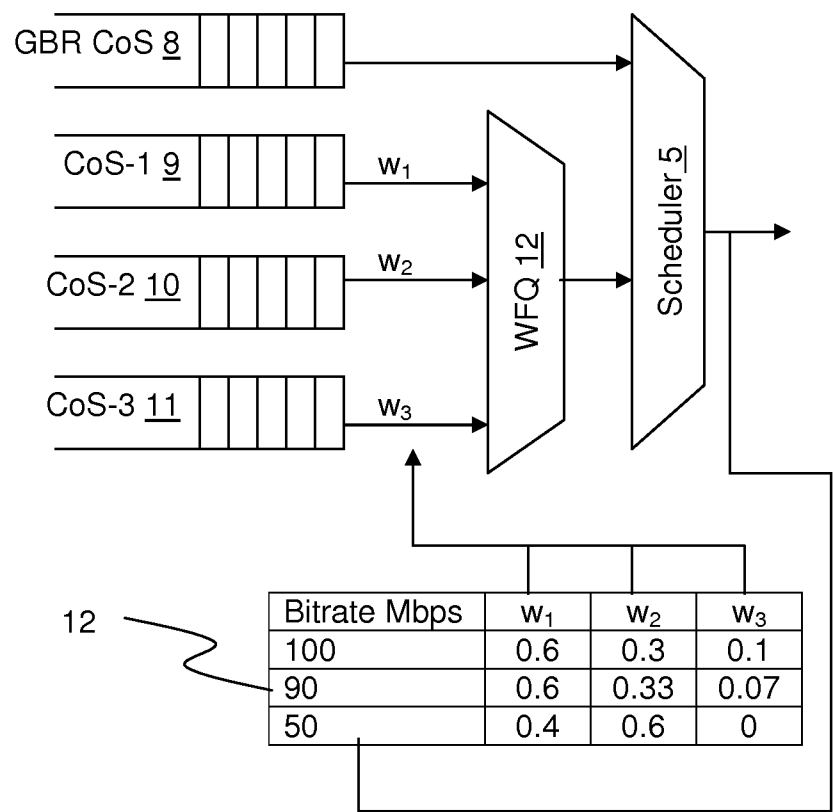


Figure 3

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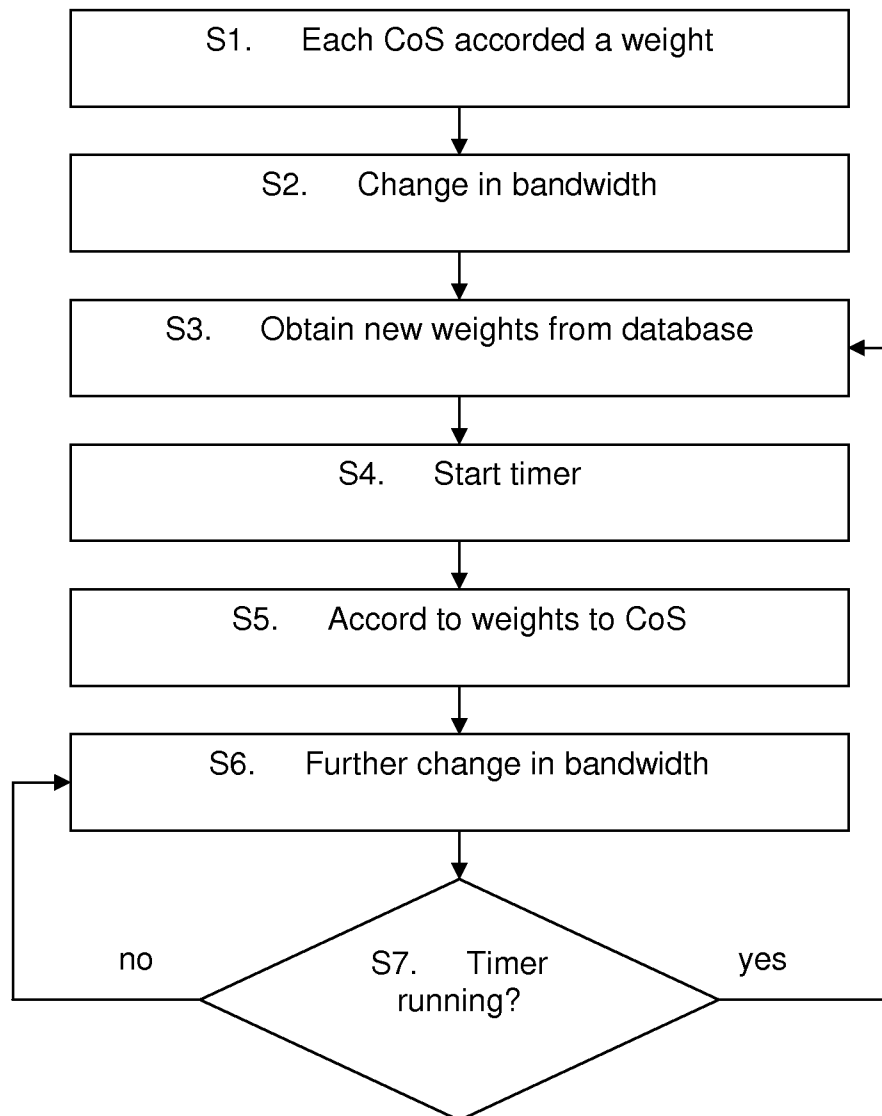


Figure 4

4/4

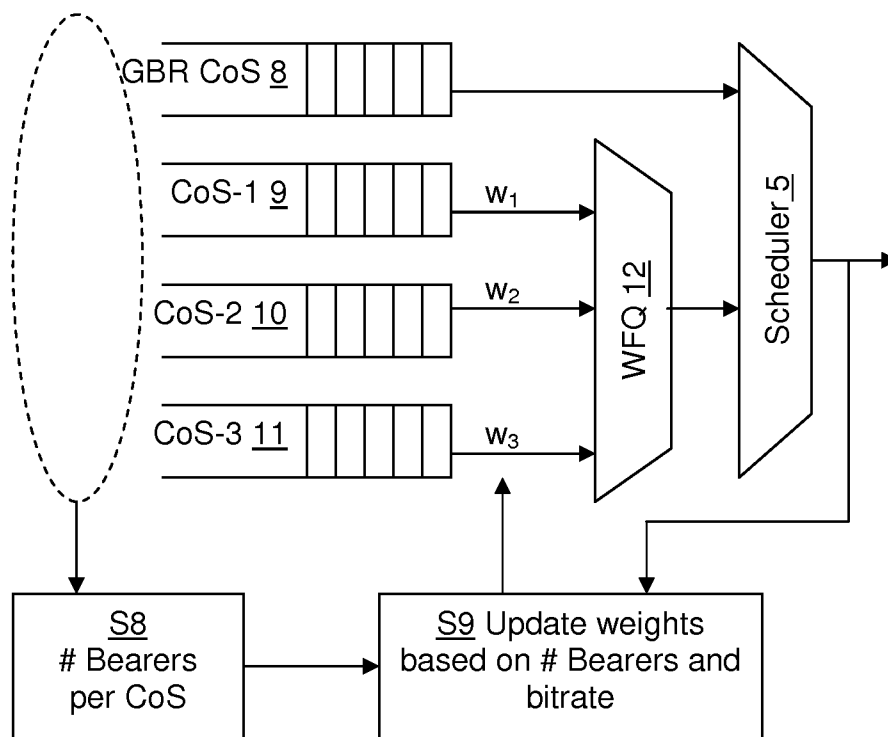


Figure 5

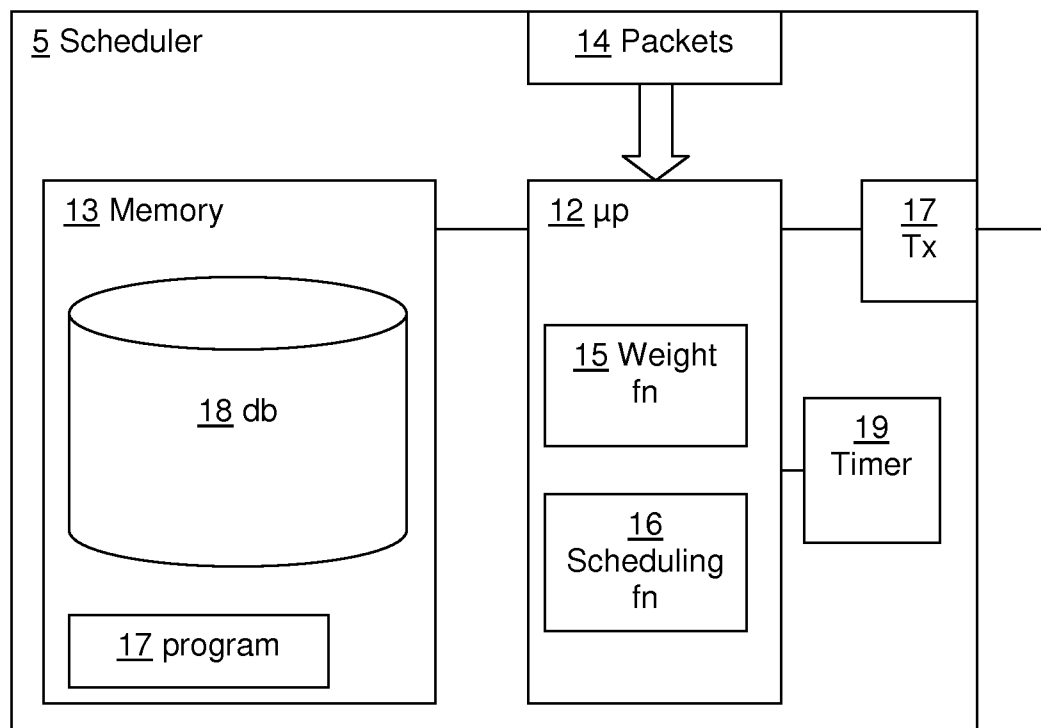


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/057347

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W72/12 H04L12/863
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 981 052 B1 (CHERITON DAVID R [US]) 27 December 2005 (2005-12-27) claims 1, 5, 8 abstract column 3, line 32 - column 4, line 11 -----	1-16
X	WO 03/043273 A1 (NORTEL NETWORKS LTD [CA]) 22 May 2003 (2003-05-22) paragraph [0006] paragraph [0019] - paragraph [0024] claims 1, 4, 6 ----- -/--	1-16



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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INTERNATIONAL SEARCH REPORT

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