INTERNATIONAL STANDARD

ISO/IEC/IEEE 8802-1Q

First edition
2016-03-15

AMENDMENT 7
2019-02

Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements —

Part 1Q: Bridges and bridged networks

AMENDMENT 7: Cyclic queuing and forwarding

Technologies de l'information — Télécommunications et échange d'information entre systèmes — Réseaux locaux et métropolitains — Exigences spécifiques —

Partie 1Q: Ponts et réseaux pontés

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Reference number
ISO/IEC/IEEE 8802-1Q:2016/Amd.7:2019(E)

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(Amendment to
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IEEE Std 802.1Qcd™-2015,
IEEE Std 802.1Q-2014/Cor 1-2015,
IEEE Std 802.1Qbv™-2015,
IEEE Std 802.1Qbu™-2016,
IEEE Std 802.1Qbz™-2016, and
IEEE Std 802.1Qci™-2017)

IEEE Standard for
Local and metropolitan area networks—

Bridges and Bridged Networks—

Amendment 29: Cyclic Queuing and Forwarding

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 18 May 2017

IEEE-SA Standards Board

Abstract: The use of traffic scheduling and per-stream filtering and policing to support cyclic queuing and forwarding are described in this amendment to IEEE Std 802.1Q-2014.

Keywords: Bridged Local Area Networks, cyclic queuing and forwarding (CQF), IEEE 802®, IEEE 802.1Q™, IEEE Std 802.1Qbu™, IEEE 802.1Qbv™, IEEE 802.1Qch™, IEEE 802.1Qci™, local area networks (LANs), MAC Bridges, metropolitan area networks, scheduled traffic, Virtual Bridged Local Area Networks (virtual LANs)

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Print: ISBN 978-1-5044-4095-0 STD22629
PDF: ISBN 978-1-5044-4096-7 STDPD22629

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Introduction

This introduction is not part of IEEE Std 802.1Qch-2017, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks—Amendment 29: Cyclic Queuing and Forwarding.

This amendment to IEEE Std 802.1Q-2014 describes the use of traffic scheduling and per-stream filtering and policing to support cyclic queuing and forwarding.

This standard contains state-of-the-art material. The area covered by this standard is undergoing evolution. Revisions are anticipated within the next few years to clarify existing material, to correct possible errors, and to incorporate new related material. Information on the current revision state of this and other IEEE 802® standards may be obtained from

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Local and metropolitan area networks—

Bridges and Bridged Networks—

Amendment 29: Cyclic Queuing and Forwarding

(This amendment is based on IEEE Std 802.1Q™-2014 as amended by IEEE Std 802.1Qca™-2015, IEEE Std 802.1Qcd™-2015, IEEE Std 802.1Q-2014/Cor 1-2015, IEEE Std 802.1Qbv™-2015, IEEE Std 802.1Qbu™-2016, IEEE Std 802.1Qbz™-2016, and IEEE Std 802.1Qbci™-2017)

NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and <u>underscore</u> (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.[1]

[1]Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

2. Normative references

Insert the following references in alphanumeric order:

IEEE Std 802.1Qbv™, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks—Amendment 25: Enhancements for Scheduled Traffic.

IEEE Std 802.1Qci™, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks—Amendment 28: Per-Stream Filtering and Policing.

NOTE—IEEE Std 802.1Qbv and IEEE Std 802.1Qci are both amendments to IEEE Std 802.1Q-2014, as is this standard. This NOTE and the references to IEEE Std 802.1Qbv and IEEE P802.1Qci will be removed when this standard is incorporated into the IEEE 802.1Q base standard in the next revision.

4. Abbreviations

Insert the following abbreviation in alphanumeric order:

CQF cyclic queuing and forwarding

5. Conformance

5.4 VLAN Bridge component requirements

5.4.1 VLAN Bridge component options

Insert new subclause 5.4.1.9 as shown, renumbering as necessary:

5.4.1.9 Cyclic queuing and forwarding (CQF) requirements

A VLAN Bridge component implementation that conforms to the provisions of this standard for CQF (see Annex T) shall

a) Support the enhancements for scheduled traffic as specified in 8.6.8.4.
b) Support the state machines for scheduled traffic as specified in 8.6.9.
c) Support the state machines for stream gate control as specified in 8.6.10.
d) Support the management entities for scheduled traffic as specified in 12.29.
e) Support the requirements for per-stream filtering and policing (PSFP) as stated in 5.4.1.8.
f) Support the management entities for PSFP as specified in 12.31.

NOTE—The enhancements for scheduled traffic are defined in IEEE Std 802.1Qbv, and PSFP is defined in IEEE Std 802.1Qci, both of which are amendments to IEEE Std 802.1Q-2014, as is this standard. This NOTE will be removed when this standard is incorporated into the IEEE 802.1Q base standard in the next revision.

5.13 MAC Bridge component requirements

5.13.1 MAC Bridge component options

Insert new subclause 5.13.1.2 as shown, renumbering as necessary:

5.13.1.2 Cyclic queuing and forwarding requirements

A MAC Bridge component implementation that conforms to the provisions of this standard for CQF (see Annex T) shall

a) Support the enhancements for scheduled traffic as specified in 8.6.8.4.
b) Support the state machines for scheduled traffic as specified in 8.6.9.
c) Support the state machines for stream gate control as specified in 8.6.10.
d) Support the management entities for scheduled traffic as specified in 12.29.
e) Support the requirements for PSFP as stated in 5.13.1.1.
f) Support the management entities for PSFP as specified in 12.31.

Insert the following new subclause at the end of Clause 5, renumbering as necessary:

5.28 End station requirements—Cyclic queuing and forwarding

An end station implementation that conforms to the provisions of this standard for CQF (see Annex T) shall

a) Support the enhancements for scheduled traffic as specified in 8.6.8.4.
b) Support the state machines for scheduled traffic as specified in 8.6.9.
c) Support the state machines for stream gate control as specified in 8.6.10.

d) Support the management entities for scheduled traffic as specified in 12.29.
e) Support the requirements for PSFP as stated in 5.27.
f) Support the management entities for PSFP as specified in 12.31.

Annex A

(normative)

PICS proforma—Bridge implementations[2]

A.5 Major capabilities

Insert the following row at the end of Table A.5:

CQF	Does the implementation support cyclic queuing and forwarding?	O	5.4.1.9, 5.13.1.2	Yes [ ]	No [ ]

A.14 Bridge management

Change MGT-248 and MGT-249 in Table A.14 as shown:

Item	Feature	Status	References	Support
MGT-248	Does the implementation support the management entities defined in 12.29?	SCHED OR CQF: M	5.4.1 item ad), 5.4.1.9 item c), 5.13.1.2 item c), 12.29	Yes [ ] N/A [ ]
MGT-249	Does the implementation support the management entities defined in 12.31?	PSFP OR CQF: M	5.4.1.9 item e), 5.13.1.2 item e), 8.6.5.1, 8.6.6.1, 8.6.10, 12.31	Yes [ ] N/A [ ]

A.24 Management Information Base (MIB)

Change MIB-42 and MIB-43 in Table A.24 as shown:

Item	Feature	Status	References	Support
MIB-42	Is the IEEE8021-ST-MIB module fully supported (per its MODULE-COMPLIANCE)?	MIB AND (SCHED OR CQF): O	5.4.1 item ad), 5.4.1.9 item c), 5.13.1.2 item c), 12.29, 17.7.22	Yes [ ] N/A [ ] No [ ]
MIB-43	Is the IEEE8021-PSFP-MIB module fully supported (per its MODULE-COMPLIANCE)?	PSFP OR CQF: O	5.4.1.9 item e), 5.13.1.2 item e), 8.6.5.1, 8.6.6.1, 8.6.10, 12.31, 17.7.24	Yes [ ] N/A [ ]

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Change Table A.44 as shown:

A.44 Scheduled traffic

Item	Feature	Status	References	Support
	If neither scheduled traffic (SCHED in Table A.5) nor cyclic queuing and forwarding (CQF in Table A.5) ~~is not~~ are supported, mark N/A and ignore the remainder of this table.		5.4.1, 5.13.1, 8.6.8, 8.6.9, 12.29, 17.7.22	N/A[ ]
SCHED1	Support the state machines and associated definitions as specified in 8.6.9	SCHED OR CQF:M	5.4.1, 5.13.1, 8.6.8, 8.6.9	Yes [ ] N/A [ ]
SCHED2	Does the implementation support the management entities defined in 12.29?	SCHED OR CQF:M	5.4.1 item ad), 5.4.1.9 item c), 5.13.1.2 item c), 12.29	Yes [ ] N/A [ ]
SCHED3	Is the IEEE8021-ST-MIB module fully supported (per its MODULE-COMPLIANCE)?	MIB AND (SCHED OR CQF):O	5.4.1 item ad), 5.4.1.9 item c), 5.13.1.2 item c), 12.29, 17.7.22	Yes [ ] N/A [ ] No [ ]

Change Table A.45 as shown:

A.45 Per-stream filtering and policing

Item	Feature	Status	References	Support
	If neither per-stream filtering and policing (PSFP in Table A.5) nor cyclic queuing and forwarding (CQF in Table A.5) ~~is not~~ are supported, mark N/A and ignore the remainder of this table.		5.4.1.9, 5.13.1.2, 8.6.5.1, 8.6.6.1, 8.6.10, 12.31, 17.7.24	N/A[ ]
PSFP1	Does the implementation support the state machines and associated definitions as specified in 8.6.10?	PSFP OR CQF:M	5.4.1.9 item b), 5.13.1.2 item b), 8.6.5, 8.6.10	Yes [ ] N/A [ ]
PSFP2	Does the implementation support the management entities defined in 12.31?	PSFP OR CQF:M	5.4.1.9 item e), 5.13.1.2 item e), 8.6.5.1, 8.6.6.1, 8.6.10, 12.31	Yes [ ] N/A [ ]
PSFP3	Is the IEEE8021-PSFP-MIB module fully supported (per its MODULE-COMPLIANCE)?	MIB AND (PSFP OR CQF):O	5.4.1.9 item e), 5.13.1.2 item e), 12.31, 17.7.24	Yes [ ] N/A [ ] No [ ]

Annex B

(normative)

PICS proforma—End station implementations[3]

B.5 Major capabilities

Insert the following row at the end of Table B.5:

CQF	Does the implementation support cyclic queuing and forwarding?	O	5.25, 5.28	Yes [ ]	No [ ]

Change Table B.15 as shown:

B.15 Scheduled traffic

Item	Feature	Status	References	Support
	If neither scheduled traffic (SCHED in Table B.5) nor cyclic queuing and forwarding (CQF in Table B.5) ~~is not~~ are supported, mark N/A and ignore the remainder of this table.		~~5.4.1, 5.13.1,~~5.25, 5.28, 8.6.8, 8.6.9, 12.29, 17.7.22	N/A[ ]
SCHED1	Support the state machines and associated definitions as specified in 8.6.9	SCHED OR CQF:M	~~5.4.1, 5.13.1,~~5.28 item b)~~,~~ 8.6.8, 8.6.9	Yes [ ] N/A [ ]
SCHED2	Does the implementation support the management entities defined in 12.29?	SCHED OR CQF:M	~~5.4.1 item ad)~~5.28 item c), 12.29	Yes [ ] N/A [ ]
SCHED3	Is the IEEE8021-ST-MIB module fully supported (per its MODULE-COMPLIANCE)?	MIB AND (SCHED OR CQF):O	~~5.4.1 item ad)~~5.28 item c), 12.29, 17.7.22	Yes [ ] N/A [ ] No [ ]

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Change Table B.16 as shown:

B.16 Per-stream filtering and policing

Item	Feature	Status	References	Support
	If neither per-stream filtering and policing (PSFP in Table B.5) nor cyclic queuing and forwarding (CQF in Table B.5) ~~is not~~ are supported, mark N/A and ignore the remainder of this table.		5.28 items d) and e), 8.6.5.1, 8.6.6.1, 8.6.10, 12.31, 17.7.24	N/A[ ]
PSFP1	Does the implementation support the state machines and associated definitions as specified in 8.6.10?	PSFP OR CQF:M	5.28 items b) and d), 8.6.5, 8.6.10	Yes [ ] N/A [ ]
PSFP2	Does the implementation support the management entities defined in 12.31?	PSFP OR CQF:M	5.28 item e), 8.6.5.1, 8.6.6.1, 8.6.10, 12.31	Yes [ ] N/A [ ]
PSFP3	Is the IEEE8021-PSFP-MIB module fully supported (per its MODULE-COMPLIANCE)?	MIB AND (PSFP OR CQF):O	12.31, 17.7.24	Yes [ ] N/A [ ] No [ ]

Annex T

(informative)

Cyclic queuing and forwarding[4]

T.1 Overview of CQF

Cyclic queuing and forwarding (CQF) is a method of traffic shaping that can deliver deterministic, and easily calculated, latency for time-sensitive traffic streams. As the name implies, the principle underlying CQF is that stream traffic is transmitted and queued for transmission along a network path in a cyclic manner. Time is divided into numbered time intervals i, i+1, i+2, ... i+N, each of duration d. Frames transmitted by a Bridge, *Alice*, during time interval i are received by a downstream Bridge, *Bob*, during time interval i and are transmitted onwards by *Bob* towards Bridge *Charlie* during time interval i+1, and so on. A starting assumption is that, for a given traffic class, all Bridges and all end stations connected to a given bridge have a common understanding (to a known accuracy) of the start time of cycle i, and the cycle duration, d.

Frames transmitted by *Alice* during interval i are transmitted by *Bob* in interval i+1; the maximum possible delay experienced by a given frame is from the beginning of i to the end of i+1, or twice d. Similarly, the minimum possible delay experienced is from the end of i to the beginning of i+1, which is zero. More generally, the maximum delay experienced by a given frame is

$$(h+1) \times d$$

and the minimum delay experienced by a given frame is

$$(h-1) \times d$$

where h is the number of hops.

This illustrates the attraction of CQF as a technique for handling time-sensitive traffic; the latency introduced as a frame transits the network is completely described by the cycle time and the number of hops, and is unaffected by any other topology considerations, including interference from other non time-sensitive traffic. This only holds, however, if frames are kept to their allotted cycles; if, for example, some of the frames that were expected to be received by *Bob* during cycle i do not appear until cycle i+1 has started, then the stated assumptions about maximum latency calculation no longer hold. Careful choice of cycle times, alignment of cycle times among the Bridges in the network, and the timing of first and last transmissions within a cycle are required in order to ensure that the desired latency bounds are achieved.

Any delays through a particular intermediate relay (for example, *Bob*) do not affect the end-to-end delay so long as *Bob's* performance does not affect the correct assignment of frames to time intervals.

Since one of the goals for the handling of time-sensitive streams is zero frame loss (assuming that no unrecognizable non-conformant traffic is present), it is prudent to assume that reception is continuous—a frame received by a downstream system will always be assigned to one interval or another. This places most of the burden of correct interval assignment on the transmitting system; frames should not be transmitted if incorrect interval assignment is possible upon reception. It is therefore necessary to define the anticipated (and accommodated) errors in reception assignment with respect to the point in interval time, t,

[4]In early discussions, CQF was known as the "Peristaltic Shaper" [B52].

where interval *i*–1 becomes interval *i*. A relay (such as *Bob*) can of course choose when to start reception assignment to *i* in relation to *t*; it is assumed that *Bob's* intent is that the earliest frame to be assigned to *i* is the first whose very last octet (or other frame transmission encoding symbol) is still on the transmission medium (or other definable external event to what is considered to be *Bob* reference point) at *t*, thus placing any accommodation of known implementation dependent delays within *Bob* under *Bob's* control.

While *Bob* attempts to start *i* reception with a frame coming off the medium at *i*, and may factor known and repeatable internal delays into the way he goes about that intent, his actual start time depends on:

a) The error in *Bob's* time sync (i.e., the error in his determination as to when *t* actually occurs).
b) The maximum deviation (jitter) in *Bob's* use of that time.
c) Additional delays that *Bob* does not account for, such as delays in selecting the output queue to be used for *i*.

Alice has to stop transmitting frames for *i*–1 before *t*, by a time that is the sum of *Bob's* possible early start of *i* as a consequence of a) through c), and the following:

d) The error in *Alice's* time sync (i.e., the error in her determination as to when *t* occurs).
e) The maximum deviation (jitter) in *Alice's* use of that time.
f) The time between *Alice* deciding to commit a frame for transmission and the appearance of the last octet/symbol "on the medium" at *Alice's* end.
g) The length of "the medium" in transmission time, i.e., the time for the last octet/symbol to leave *Alice* and reach *Bob*, including any consideration of the effect of interfering frames or fragments.

The description of CQF in terms of a number of consecutive intervals (as opposed to their support by "odd/even" queues, as discussed in T.2 onwards) gives easy answers to what to do with traffic still queued when its selected transmission interval has expired—discard it, or mark it down (discard eligible or priority change) and generate an alarm. In an environment where the stream bandwidth is allocated appropriately (i.e., the bandwidth allocated per time interval is less than can be received/transmitted in the chosen interval duration), this will be a rare occurrence, the traffic that follows will be conformant, and the overall system performance will be recoverable.

The discussion so far has assumed that all link speeds are the same; however, the situation becomes more complicated when links of different speeds are considered. One typical arrangement might comprise low speed links at the start and end of the path (network periphery to periphery), another with the high speed towards one end (periphery to core or vice versa). Taking the first of these, and placing *Alice* at the first transition from slow to fast, *Bob* as her fast neighbor, *Charlie* as his fast neighbor, and *Donald* at the transition from fast to slow, the important thing (treating the fast core of the network as a CQF black box) is that all conformant traffic received by *Alice* in interval *i* (say) is transmitted by *Donald* in a later interval *i*+*n*. A number of internal arrangements might be made between *Alice*, *Bob*, *Charlie*, and *Donald* to make this happen and would be valid from an external CQF perspective. It is also possible to consider fractional *n*, where *n* is still > 1, as *Alice* may need to collect the entirety of any slow cycle before transmitting that in a more compressed burst into the rest of the fast network. More complex possibilities are equivalent to redefining the slow cycle time. Some of the less elaborate possibilities for the use of links of different speeds are discussed in T.5.

T.2 An approach to CQF implementation

In essence, the approach involves the use of two transmission queues and a cycle timer. During even numbered cycles (intervals), queue 1 accumulates received frames from the Bridge's reception Ports (and does not transmit them), while queue 2 transmits any queued frames from the previous odd-numbered cycle (and does not receive any frames). During odd-numbered cycles, queue 2 accumulates received frames from the Bridge's reception Ports (and does not transmit them), while queue 1 transmits any queued frames from the previous even-numbered cycle (and does not receive any frames). With appropriate choice of receive and transmit cycle times (see T.5), such that, for any given stream, the cycle is at least long enough to accommodate all of the time-sensitive traffic that will need to be transmitted on the Bridge Port during the class measurement interval for that stream (see 34.6.1, also known as the observation interval in IEEE Std 802.1BA™ [B51]), plus a maximum-sized interfering frame (or frame fragment, if preemption is supported), then all of the stream's traffic will be accumulated during the cycle time in queues that are in receive mode, and it will all be transmitted during the cycle time when the queues switch to transmit mode.

CQF is implemented by configuring a combination of the stream gate control mechanisms defined for per-stream filtering and policing (PSFP, IEEE Std 802.1Qci) and the traffic scheduling mechanisms defined in 8.6.8.4 and 8.6.9 of IEEE Std 802.1Qbv. Per-stream filtering is used to direct received frames to one of a pair of outbound queues on a timed basis, determined by the cycle time of the per-stream filter, and traffic scheduling is used to ensure that frames are transmitted from the appropriate queue using the same cycle time, as described in the rest of this annex.

T.3 Use of per-stream filtering and policing for CQF

The first step in establishing the filtering and queuing structures needed for CQF is to set up one or more stream filters (8.6.5.1.1) and a stream gate instance (8.6.5.1.2) that will be receiving incoming time-sensitive frames. The stream filter(s) are configured so that all time-sensitive frames received on a given Port are directed to the same stream gate instance; in turn, the stream gate instance is configured so that the internal priority value (IPV) associated with the time-sensitive frames will direct them to one of two outbound queues on a timed basis. The use of the IPV allows this direction of frames to outbound queues to be independent of the received priority, and also does not affect the priority associated with the frame on transmission.

T.3.1 Stream filter configuration

The simplest stream filter configuration would be achieved where the same priority is used for all time-sensitive frames (and this priority is not used for any other frames); for example, the default priority assigned to SR class A (see Clause 34) could be used, in which case, the priority associated with the time-sensitive frames would be 3. The parameters that would define the stream filter for the time-sensitive frames would then be as follows:

a) The *stream_identifier specification* would take the wild-card value.

b) The *priority specification* would take the priority value 3.

c) The *stream gate instance identifier* would take the value of the instance identifier for the stream gate (T.3.2).

d) In the simplest case, there would be no filter specifications; however, these could be added as appropriate, for example if the maximum SDU size for the time-sensitive traffic is bounded at a value less than the maximum SDU size for the medium.

This stream filter specification results in all frames that carry a priority value of 3 being submitted to the stream gate. As the operation of PSFP is such that received frames that do not match a stream filter are handled as if PSFP is not implemented, there is no need for further stream filter specifications to handle frames that carry priorities other than 3 unless there are other filtering or gating decisions that need to be taken for such frames.

T.3.2 Stream gate configuration

The *stream gate instance* (8.6.5.1.1) needed to support the stream filter described in T.3.1 has a *stream gate control list* that contains two entries, each containing a SetGateAndIPS operation, with parameters as follows:

1) StreamGateState = *open*, IPV = 7, TimeInterval = T
2) StreamGateState = *open*, IPV = 6, TimeInterval = T

This control list has the effect of directing any traffic that passes the stream filter specified in T.3.1 to one of two different outbound queues (assuming that the outbound Ports support 8 queues, and that the default assignments for priorities to traffic classes follows the recommendation shown in Table 34-1); in the first time interval T, traffic is directed to queue 7, in the second time interval T, to queue 6, in the third time interval to queue 7, in the fourth time interval, to queue 6, and so on. The choice of time interval T is discussed in T.5; the cycle time (OperCycleTime, see 8.6.9.4.20) for the stream gate state machines would need to be set to 2T in order to accommodate the sum of the time intervals for the two gate operations. See Figure T-1

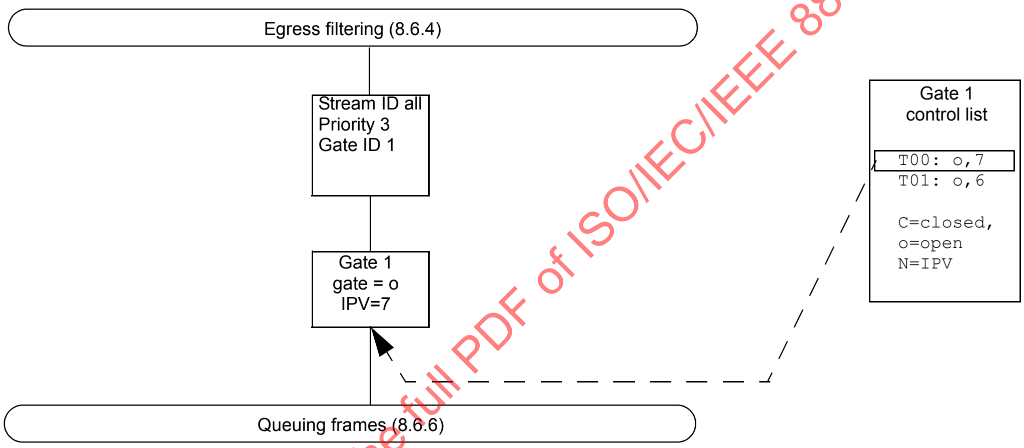

Figure T-1—Example PSFP configuration for QCF

T.4 Use of traffic scheduling for CQF

The traffic scheduling support needed on each outbound Port in order to support the PSFP configuration described in T.3 is to execute a gate control list that will set the GateState to *open* for queue 6 and *closed* for queue 7 for a TimeInterval of T, and then set the GateState to *open* for queue 7 and *closed* for queue 6 for a TimeInterval of T, repeating ad infinitum. If there are no other traffic scheduling considerations, this can be achieved with a gate control list that contains just two SetGateStates gate operations, with parameters as follows:

1) GateState: 0, 1, 2, 3, 4, 5, 6 *open*, 7 *closed*, TimeInterval = T
2) GateState: 0, 1, 2, 3, 4, 5, 7 *open*, 6 *closed*, TimeInterval = T

This sequence of gate operations has the effect that during the initial time period T, the GateState for queue 7 is closed while queue 7 is being filled, and queue 6 is open to allow any queued frames to be transmitted; during the second time period T, the GateState for queue 6 is closed while queue 6 is being filled, and queue 7 is open to allow any queued frames to be transmitted. The gates for all other queues are open. The choice of time interval T is discussed in T.5; the cycle time (OperCycleTime; see 8.6.9.4.20) for the