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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Next Generation Networks – Security

Performance models and metrics for deep packet inspection

Recommendation ITU-T Y.2773

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Recommendation ITU-T Y.2773

Performance models and metrics for deep packet inspection

Summary

Recommendation ITU-T Y.2773 specifies the performance models and metrics for deep packet inspection in evolving networks. This Recommendation specifies deep packet inspection- (DPI-) specific performance models and measure points of DPI performance metrics, and also specifies categorization methods of DPI performance metrics. Furthermore, a DPI performance description template and DPI specific performance metrics are specified.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.2773	2017-02-17	13	11.1002/1000/13015

Keywords

Deep packet inspection, performance metric, performance model.

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FOREWORD

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Performance models and metrics for deep packet inspection

1 Scope

This Recommendation specifies performance models and metrics for deep packet inspection (DPI) in evolving networks.

The scope of this Recommendation is limited to:

– DPI-specific performance models

– DPI-specific performance metrics.

The specification of new metrics ensures specification quality as required by performance-related Recommendations.

Implementers and users of this Recommendation shall comply with all applicable national and regional laws, regulations and policies. The mechanism described in this Recommendation may not be applicable to international correspondence in order to ensure the secrecy and sovereign national legal requirements placed upon telecommunications providers, as well as the ITU Constitution and Convention.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T I.350] Recommendation ITU-T I.350 (1993), *General aspects of quality of service and network performance in digital networks, including ISDNs.*

[ITU-T Y.2770] Recommendation ITU-T Y.2770 (2012), *Requirements for deep packet inspection in next generation networks.*

[ITU-T Y.2771] Recommendation ITU-T Y.2771 (2014), *Framework for deep packet inspection.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 application [ITU-T Y.2770]: A designation of one of the following:

– an application protocol type (e.g., IP application protocols ITU-T H.264 video, or session initiation protocol (SIP));

– a served user instance (e.g., VoIP, VoLTE, VoIMS, VoNGN, and VoP2P) of an application type, e.g., "voice-over-Packet application";

– a "provider specific application" for voice-over-Packet, (e.g., 3GPP provider VoIP, Skype VoIP);

– an application embedded in another application (e.g., application content in a body element of a SIP or an HTTP message).

An application is identifiable by a particular identifier (e.g., via a bit field, pattern, signature, or regular expression as "application level conditions", see also clause 3.2.2 of [ITU-T Y.2770]), as a common characteristic of all the above listed levels of applications.

3.1.2 deep packet inspection (DPI) [ITU-T Y.2770]: Analysis, according to the layered protocol architecture OSI-BRM [b-ITU-T X.200], of:

– payload and/or packet properties (see list of potential properties in clause 3.2.11 of [ITU-T Y.2770]) deeper than protocol layer 2, 3 or 4 (L2/L3/L4) header information, and

– other packet properties

in order to identify the application unambiguously.

NOTE – The output of the DPI function, along with some extra information such as the flow information, is typically used in subsequent functions such as reporting or actions on the packet.

3.1.3 DPI engine [ITU-T Y.2770]: A subcomponent and central part of the DPI functional entity which performs all packet path processing functions (e.g., packet identification and other packet processing functions in Figure 6-1 of [ITU-T Y.2770]).

3.1.4 DPI node [ITU-T Y.2771]: A network element or device that realizes the DPI related functions. It is thus a generic term used to designate the realization of a DPI physical entity.

NOTE – Functional perspective: the DPI node function (DPI-NF) comprises the DPI policy enforcement function (DPI-PEF) and the (optional) local policy decision function (L-PDF), hence, the DPI-NF is functionally equal to the DPI functional entity.

3.1.5 DPI policy condition (also known as DPI signature) [ITU-T Y.2770]: A representation of the necessary state and/or prerequisites that identify an application and define whether a policy rule's actions should be performed. The set of DPI policy conditions associated with a policy rule specifies when the policy rule is applicable (see also [b-IETF RFC 3198]).

A DPI policy condition must contain application level conditions and may contain other options such as state conditions and/or flow level conditions:

1) State condition (optional):
   a) network grade of service conditions (e.g., experienced congestion in packet paths); or
   b) network element status (e.g., local overload condition of the DPI-FE).
2) Flow descriptor/Flow level conditions (optional):
   a) packet content (header fields);
   b) characteristics of a packet (e.g., number# of MPLS labels);
   c) packet treatment (e.g., output interface of the DPI-FE).
3) Application descriptor/application level conditions:
   a) packet content (application header fields and application payload).

NOTE – The condition relates to the "simple condition" in the formal descriptions of flow level conditions and application level conditions.

3.1.6 flow descriptor (also known as flow level conditions) [ITU-T Y.2770]: A set of rule conditions that is used to identify a specific type of flow (according to clause 3.1.3 of [ITU-T Y.2770]) from inspected traffic.

NOTE 1 – This definition of flow descriptor extends the definition in [b-ITU-T Y.2121] with additional elements as described in clause 3 of [ITU-T Y.2770].

NOTE 2 – For further normative discussion of the flow descriptor as used in [ITU-T Y.2770], see Annex A of [ITU-T Y.2770].

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3GPP	Third Generation Partnership Project
DNNF	Determining Next Node Function
DPI	Deep Packet Inspection
DPI-AcIF	DPI Action Information Function
DPI-AnF	DPI Analyser Function
DPI-FE	DPI Functional Entity
DPI-NF	DPI Node Function
DPI PD-FE	DPI Policy Decision Functional Entity
DPI-PEF	DPI Policy Enforcement Function
DPI-PIB	DPI Policy Information Base
DPI-ScF	DPI Scan Function
FIB	Forwarding Information Base
HTTP	Hypertext Transfer Protocol
IP	Internet Protocol
KPI	Key Performance Indicator
L-PDF	Local Policy Decision Function
MP	Measurement Point
MPLS	Multi-Protocol Label Switching
NMS	Network Management System
OSI-BRM	Open System Interconnection-Basic Reference Model
PIB	Policy Information Base
QoE	Quality of Experience
QoS	Quality of Service
SD-PDF	Session-Dependent Policy Decision Function
SIP	Session Initiation Protocol
SI-PDF	Session-Independent Policy Decision Function
TCP	Transmission Control Protocol
VoIMS	Voice over Integrated Media System
VoIP	Voice over Internet Protocol
VoLTE	Voice over Long Term Evolution
VoNGN	Voice over Next Generation Network
VoP2P	Voice over Peer to Peer

Table 4-1 – Mathematical symbols for DPI metrics

ε_{DPI}	(DPI) error rate	-
ε_{f-n}	(DPI) false-negative error rate	-
ε_{f-p}	(DPI) false-positive error rate	-
$\phi_{P,In}$	(DPI) processing rate of incoming packets	$[s^{-1}]$
$\phi_{P,Out}$	(DPI) packet rate in outgoing direction	$[s^{-1}]$
$\phi_{P,Node,Out.}$	packet node throughput	-
$\phi_{P,Identified}$	rate of successfully identified packets	-
$P_{Hit,BloomFilter}$	estimated information certainty of probability	-
N_{db}	the number of DPI policy rules	-
S_p	the packet size	-
N_{DPIeng}	the number of DPI engines	-
τ_{TD}	node-internal transfer delay (of DPI node)	[ns]
D_{dpi}	DPI inspection depth	-
$\lambda_{TCP,con,est}$	TCP successful connection establishment rate	-
$N_{TCP,concur}$	Number of concurrent TCP connections	-
$\lambda_{TCP,succ}$	TCP connection establishment success rate	-
$\lambda_{HTTP,trf,rate}$	HTTP application transaction identification rate	-
N_{Tags}	Number of supported application tags	-
T_{rule}	Rule take effect time	-
$T_{failover}$	Failover time	-
T_{deploy}	DPI node deployment time	-
T_{syn}	Redundancy data synchronization time	-
T_{NMS}	NMS response time	
N_{NMS}	Concurrent NMS number supported by a DPI entity	-
$N_{rulewrite}$	NMS DPI rule number written per second	-
$T_{agereport}$	NMS DPI rule age report time	-
E_{bit}	Energy per bit	-
E_{packet}	Energy per packet	-

5 Conventions

None.

6 DPI performance model and categorizations

6.1 DPI performance model

The DPI performance metrics are specified on the basis of DPI functions and events that may be observed at measurement points (MPs). An example of a DPI performance model is illustrated in Figure 6-1.

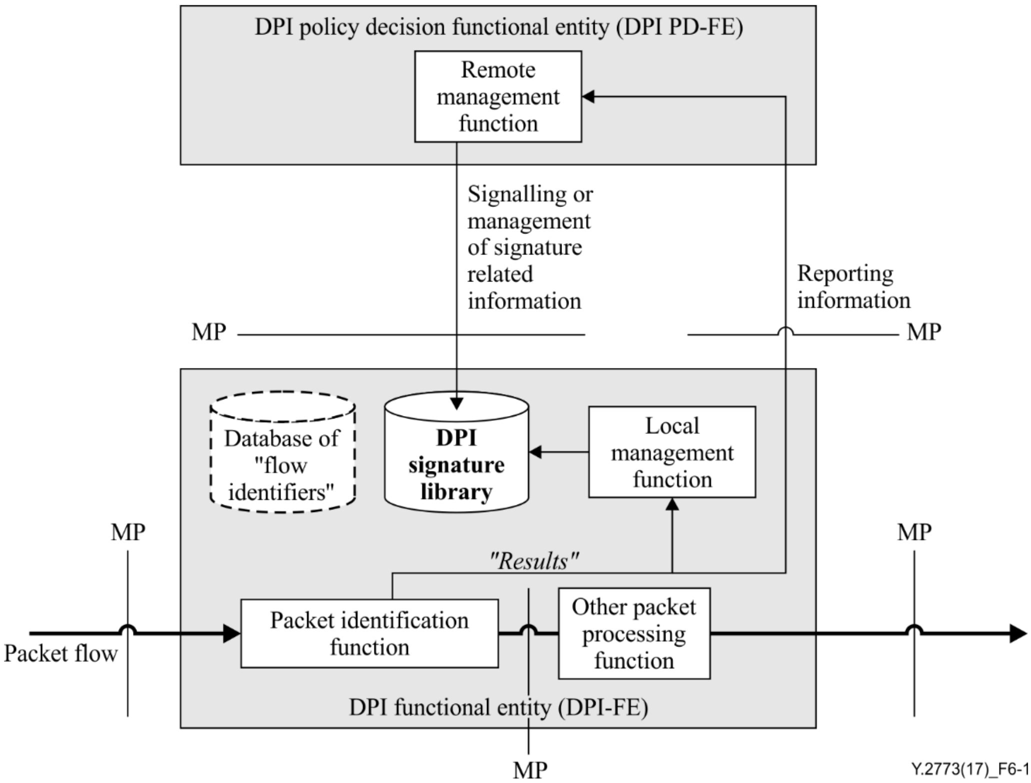

Figure 6-1 – An example of a DPI performance model

6.2 Categorization based on the type of performance metric

For comparability and completeness, DPI performance is considered in the context of the m × n (m and n are integers greater than 1) performance matrix specified in [ITU-T I.350]. Three DPI functions are identified in the matrix: application identification, policy information base (PIB) maintenance and system status. Each function is considered with respect to four general performance concerns: speed, accuracy, dependability and resources.

Table 6-1 – Categorization of DPI performance metrics

DPI function	Performance concern			
	Speed	Accuracy	Dependability	Resources
Application identification	×	×	×	×
PIB maintenance	×	×	×	×
System status	×	×	×	×

6.3 Categorization based on functional planes and DPI node

A description of performance metrics is logically clear if the metrics are classified based on functional planes and entities. Specifications of functional planes and entities can be seen in Figure 7-6 and Figure 7-7 of [ITU-T Y.2771], which are used as a basis for the specification of the classification method in this Recommendation (see Figure 6-2).

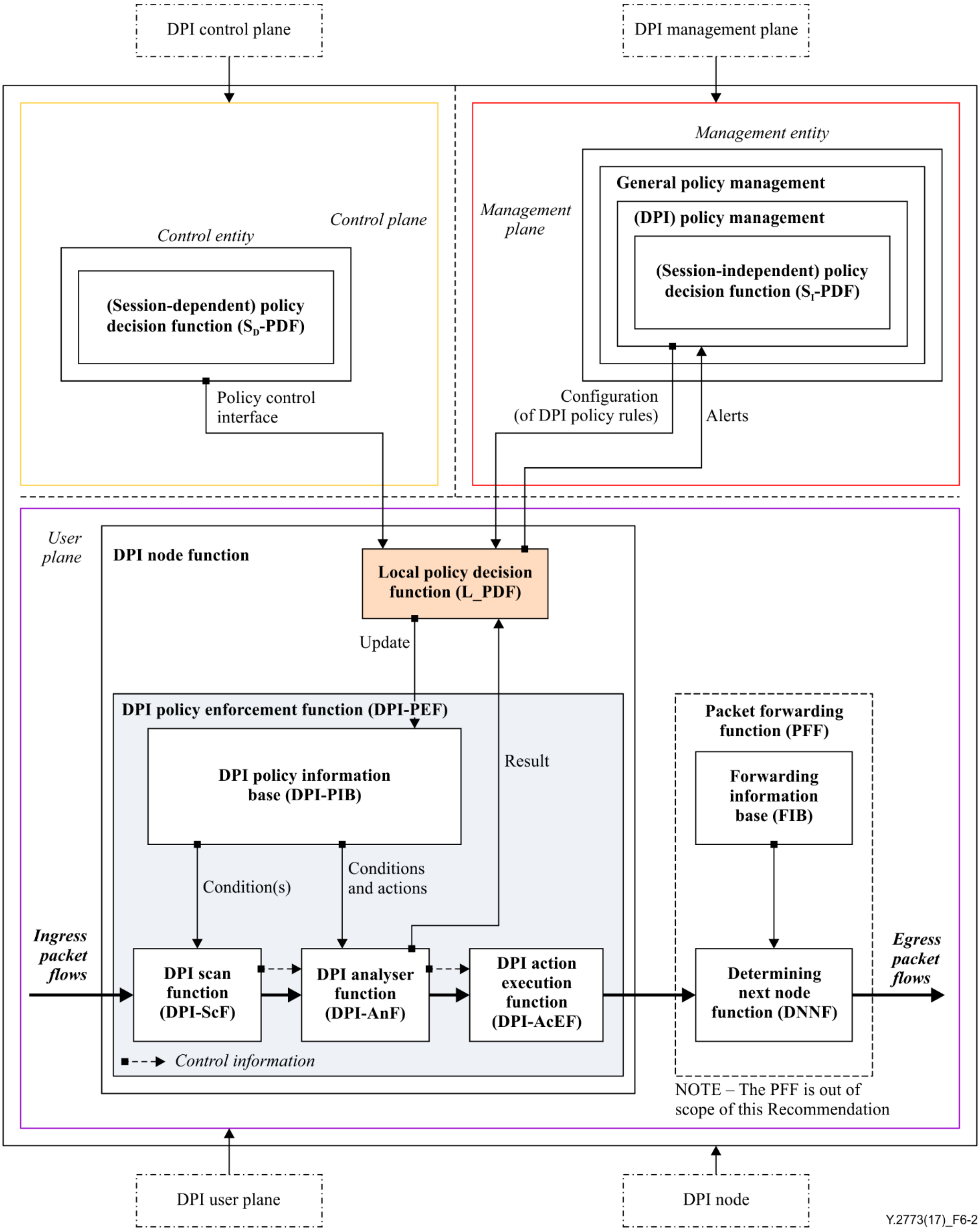

Figure 6-2 – Categorization of DPI performance metrics based on the functional plane and DPI node

7 Summary and formal template for performance metric specifications

7.1 Summary of performance metrics

Performance metrics are summarized in Table 7-1.

Table 7-1 – Summary of performance metric specifications

Sequence number	Performance metric	Type	Functional category	Functional plane/entity
1	Node-internal transfer delay	Speed	Application identification	User plane
2	Packet processing rate	Speed	Application identification	User plane
3	Error rate	Accuracy	Application identification	User plane
4	False-positive error rate	Accuracy	Application identification	User plane
5	False-negative error rate	Accuracy	Application identification	User plane
6	Rate of successfully identified packets	Speed	Application identification	User plane
7	DPI inspection depth	Resources	System status	User plane
8	TCP successful connection establishment rate	Speed	System status	User plane
9	Number of concurrent TCP connections	Resources	System status	User plane
10	TCP connection establishment success rate	Speed	System status	User plane
11	Number of supported application types	Dependability	PIB maintenance	User plane
12	DPI PIB size at the line rate	Resources	PIB maintenance	User plane
13	Packet loss rate	Accuracy	System status	User plane
14	Rule take effect time	Speed	PIB maintenance	Control plane
15	Failover time	Speed	System status	Control plane
16	Network management system (NMS) response time	Speed	System status	Management plane
17	NMS DPI rule age report time	Resources	PIB maintenance	Control plane
18	Supported concurrent NMS number	Dependability	System status	Management plane
19	Energy per bit	Resources	System status	DPI node
20	Energy per packet	Resources	System status	DPI node

7.2 Formal template for performance metric specifications

Performance metric specifications in this Recommendation use the template given in Table 7-2, which itself is derived from the template of clause 5.4.4 of [b-IETF RFC 6390].

Table 7-2 – Formal template for performance metric specifications

Metric	Normative/informative	Comment
Metric name	N	
Symbol	I	
Metric description	N	
Method of measurement or calculation	N	
Unit of measurement	N	
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	e.g., "realtime DPI", "non-realtime DPI"
Reporting model	I	
Is this a KPI: Yes/No?	I	i.e., "KPI", "non-KPI" or "unclassified"
Categorization of speed, accuracy, dependability or resources	I	
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

The template is used to ensure a minimum specification quality for the metrics introduced in this Recommendation. However, primarily the normative description elements are provided due to the "framework character" of this Recommendation. Empty (informative) description elements are an indicator that the usage of such a metric in a real performance specification would firstly need further specification work in order to get complete, applicable metrics. For instance, an "implementation" description lies outside the scope of a "framework" Recommendation, or a metric specification without "verification" information is useless (because it is required, for example, for the calibration of the measurement function).

8 DPI specific user plane performance metrics

8.1 DPI node-internal transfer delay metric

Table 8-1 provides the metric specification.

Table 8-1 – DPI node-internal transfer delay metric

Metric	Normative/informative	Comment
Metric name	N	Node-internal transfer delay
Symbol	I	τ_{TD}
Metric description	N	The accumulated waiting and service times of a packet through a DPI node.
Method of measurement or calculation	N	This value is calculated by measuring the entry and exit times of individual packets at the packet interfaces of a physical or logical representation of a DPI node function.

Table 8-1 – DPI node-internal transfer delay metric

Metric	Normative/informative	Comment
		Precondition: the measurement entity must be able to identify individual packets. Warning: this metric is typically load-dependent.
Unit of measurement	N	nanoseconds
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	This metric can be used over a wide range of time intervals.
Implementation	I	–
Verification	I	–
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI? Yes/No	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

The performance metric is also specified in clause 8.2.3.1 of [ITU-T Y.2771] and depicted in Table 8-2 of [ITU-T Y.2771].

8.2 DPI packet processing rate metric

Table 8-2 provides the metric specification.

Table 8-2 – DPI packet processing rate metric

Metric	Normative/informative	Comment
Metric name	N	Packet processing rate
Symbol	I	$\phi_{P,in}$
Metric description	N	The rate of packets, processed by the DPI policy enforcement function (DPI-PEF). This is the ingress packet rate because DPI policy rules are performed for every incoming packet. The egress rate is equal to or smaller than the ingress rate (due to possible packet discard actions). $\phi_{P,in} \leq \phi_{P,out}$
Method of measurement or calculation	N	Counting all packets observed at the ingress interface over a time period. The value is then calculated by dividing the observed number by the time period.
Unit of measurement	N	packets per second
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).

Table 8-2 – DPI packet processing rate metric

Metric	Normative/informative	Comment
Measurement timing	N	This metric can principally be used over a wide range of time intervals. Typically a time scale is of the order of seconds.
Implementation	I	–
Verification	I	–
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

The performance metric is also specified in clause 8.2.3.2 of [ITU-T Y.2771] and depicted in Table 8-3 of [ITU-T Y.2771].

8.3 DPI error rate metric

Table 8-3 provides the metric specification.

Table 8-3 – DPI error rate metric

Metric	Normative/informative (Note 1)	Comment
Metric name	N	Error rate
Symbol	I	ε_{DPI}
Metric description	N	The sum of false-negative (see clause 8.3.2) and false-positive (see clause 8.3.1) results of the DPI node.
Method of measurement or calculation	N	Direct measurement: not possible (Note 2). Indirect measurement (calculation): $\varepsilon_{DPI} = \varepsilon_{f-n} + \varepsilon_{f-p}$
Unit of measurement	N	–
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	The measurement interval is dependent on the time scale from the perspective of the served user instance (Note 3).
Implementation	I	e
Verification	I	–
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No? (Note 1)	I	Yes

Table 8-3 – DPI error rate metric

Metric	Normative/informative (Note 1)	Comment
NOTE 1 – Normative (N) and informative (I) description elements; KPI: key performance indicator. NOTE 2 – This performance metric is a so-called *composed* metric, i.e., it may not be measured directly, but can be composed from *base* metrics that have been measured (see clause 5.3.1 of [b-IETF RFC 6390]). NOTE 3 – The served user instance in general represents a remote entity ("the user"), interested in the measurements. Examples: performance management system, DPI policy decision functional entity (DPI PD-FE).		

The performance metric is also specified in clause 8.2.3.3 of [ITU-T Y.2771] and depicted in Table 8-4 of [ITU-T Y.2771].

8.3.1 DPI false-positive error rate metric

Table 8-4 provides the metric specification.

Table 8-4 – DPI false-positive error rate metric

Metric	Normative/informative	Comment
Metric name	N	False-positive error rate
Symbol	I	$\varepsilon_{f\text{-}p}$
Metric description	N	The proportion of negative instances that were erroneously reported as being positive.
Method of measurement or calculation	N	Measurements of this metric are inherently challenging, hence only indications may be given by this Recommendation: Typically a well-known pattern of a sufficiently large series of packets would be sent to the DPI entity. The *expected* result (as given by the applied DPI policy rules) is compared against the *measured* results from the DPI process. The measurement may be done in intrusive or non-intrusive test types.
Unit of measurement	N	–
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	The measurement interval is dependent on the time scale from the perspective of the served user instance.
Implementation	I	–
Verification	I	–
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

The performance metric is also specified in clause 8.2.3.3.1 of [ITU-T Y.2771] and depicted in Table 8-5 of [ITU-T Y.2771].

8.3.2 DPI false-negative error rate metric

Table 8-5 provides the metric specification.

Table 8-5 – DPI false-negative error rate metric

Metric	Normative/informative	Comment
Metric name	N	False-negative error rate
Symbol	I	$\varepsilon_{f\text{-}n}$
Metric description	N	The proportion of positive instances that were erroneously reported as negative.
Method of measurement or calculation	N	See corresponding entry in Table 8-4.
Unit of measurement	N	–
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	The measurement interval is dependent on the time scale from the perspective of the served user instance.
Implementation	I	–
Verification	I	–
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

The performance metric is also specified in 8.2.3.3.2 of [ITU-T Y.2771] and depicted in Table 8-6 of [ITU-T Y.2771].

8.4 DPI rate of successfully identified packets metric

Table 8-6 provides the metric specification.

Table 8-6 – DPI rate of successfully identified packets metric

Metric	Normative/informative	Comment
Metric name	N	Rate of successfully identified packets
Symbol	I	$\phi_{P,identified}$
Metric description	N	An incoming packet is "successfully identified" (by the packet identification function) when the DPI policy rule conditions (from at least one DPI policy rule) "match" the inspected packet. The type of "match" (such as full, partial, deterministic, with probability …, etc.) is not further qualified.

Table 8-6 – DPI rate of successfully identified packets metric

Metric	Normative/informative	Comment
		The "rate" relates to the number of successfully identified packets per time unit.
Method of measurement or calculation	N	1. Direct measurement: For instance: enforcement of a known DPI policy rule and the generation of a packet flow with known characteristics (i.e., the ratio of traffic which should match (or not) is known in advance). The measured value is then compared against the nominal value. 2. Indirect measurement (calculation): $\phi_{P,identified} = \phi_{P,in} \cdot (1 - \varepsilon_{DPI})$
Unit of measurement	N	packets per second
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	The measurement interval is dependent on the time scale from the perspective of the served user instance.
Implementation	I	–
Verification	I	See "direct measurement" against "Method of measurement or calculation" in row 4.
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

The performance metric is also specified in clause 8.2.3.4 of [ITU-T Y.2771] and depicted in Table 8-7 of [ITU-T Y.2771].

8.5 DPI inspection depth metric

Table 8-7 provides the metric specification.

Table 8-7 – DPI inspection depth metric

Metric	Normative/informative	Comment
Metric name	N	DPI inspection depth
Symbol	I	D_{DPI}
Metric description	N	This metric represents the capability of a DPI entity to process a packet. It depends on protocol. Without losing generality, Internet protocol (IP) is used when measuring the metric.

Table 8-7 – DPI inspection depth metric

Metric	Normative/informative	Comment
Method of measurement or calculation	N	1) Configure a rule with the maximum designed inspection depth of a DPI entity. 2) Send the packet corresponding to the rule through the test device. 3) Receive the packet and verify whether the rule has taken effect.
Unit of measurement	N	
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

Although the DPI functional entity (DPI-FE) can inspect the packet up to L7, different applications have different packet header lengths, so the maximum DPI inspection depth is an important characteristic of a DPI-FE.

The following is the specification of the maximum DPI inspection depth (DDPI):

Max D_DPI is the maximum number of bytes of a data packet that can be handled by a DPI-FE. In other words, Max D_DPI is the maximum length (bytes) of a protocol data unit that can be processed by the DPI scan function within a DPI-FE.

It is notable that the DDPI counts all data from L2 to L7, including both the protocol header and payload.

8.6 Protocol-specific performance metrics

8.6.1 Metrics for TCP

8.6.1.1 Background to connection-oriented communication

Transmission control protocol (TCP) belongs to the "connection-oriented" protocol category. The concept of a "connection" relates just to a particular setting of a flow descriptor (see clause 3.2.16 in [ITU-T Y.2770]) from the DPI-FE perspective. Such a connection might be generally at L2, L3 or L4 or others. Some examples are: at L2, an Ethernet connection or Ethernet virtual connection; at L3, a unidirectional or bidirectional IP connection; at L4, an IP transport connection. The performance indicators in this area are thus related to flow-dependent DPI.

8.6.1.2 Packet flow types for TCP traffic

A DPI entity basically does not provide the role of a TCP client, TCP server, TCP proxy or others, but rather behaves transparently to the end-to-end TCP entities. A "constitution of a TCP connection" from a DPI entity perspective implies that the:

– DPI flow descriptor contains at least policy conditions with the 5-tuple for an IP transport connection with a TCP; and
– conditions are specified for TCP connection state tracking (i.e., a stateful DPI scenario).

8.6.1.3 DPI TCP successful connection establishment rate metric

Table 8-8 provides the metric specification.

Table 8-8 – DPI TCP successful connection establishment rate metric

Metric	Normative/informative	Comment
Metric name	N	TCP successful connection establishment rate
Symbol	I	$\lambda_{TCP,con,est}$
Metric description	N	Number of TCP connections per second through the DPI node that have been successfully established. A TCP connection has been successfully established when a TCP three-way handshake is completed (and then the assumption is made by the DPI-FE that both remote TCP endpoints have reached the TCP connection state ESTABLISHED). To measure this metric, the DPI node needs to track the TCP state machine.
Method of measurement or calculation	N	The result can be calculated based on counting the number of TCP three-way handshakes in an observation period.
Unit of measurement	N	reciprocal seconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	The timing accuracy should basically allow measurements on a time scale of seconds.
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

Example:

A measurement of $\lambda_{TCPcon,est}$ equal to 100 means that 100 TCP connections through the DPI node have been successfully established in 1 s (by the remote pair of TCP client and TCP server entities).

8.6.1.4 DPI number of concurrent TCP connections metric

Table 8-9 provides the metric specification.

Table 8-9 – DPI Number of concurrent TCP connections metric

Metric	Normative/informative	Comment
Metric name	N	Number of concurrent TCP connections
Symbol	I	$N_{\text{TCP,concur}}$
Metric description	N	The number of TCP connections that have been successfully established concurrently in the DPI node in an observation period. This metric is dependent on the number of parallel TCP connections that have been successfully established during the observation period *T* (e.g., per second).
Method of measurement or calculation	N	given by equation: $N_{\text{TCP,concur}} = \lambda_{\text{TCP,con,est}} \cdot T$
Unit of measurement	N	– (Integer)
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

Example:

If the reported 2-tuple ($N_{\text{TCPconcur}}$, T) is equal to (100, 10), then the number of TCP connections that have been successfully established concurrently in the DPI node in 10 s is equal to 100.

8.6.1.5 DPI TCP connection establishment success rate metric

Table 8-10 provides the metric specification.

Table 8-10 – DPI TCP connection establishment success rate metric

Metric	Normative/informative	Comment
Metric name	N	TCP connection establishment success rate
Symbol	I	$\lambda_{\text{TCP,succ}}$
Metric description	N	This metric specifies the number of TCP connections through the DPI node that have been successfully established compared to the total number of TCP connection attempts. The metric is dependent on the TCP connection attempts $N_{\text{TCP,con,att}}$, the TCP connections that have been successfully established $N_{\text{TCP,succ}}$ and the testing time period *T* (in seconds).
Method of measurement or calculation	N	See following equations: $\lambda_{\text{TCP,succ}} = \frac{\lambda_{\text{TCP,con,est}}}{\lambda_{\text{TCP,con,att}}}$

Table 8-10 – DPI TCP connection establishment success rate metric

Metric	Normative/informative	Comment
		with $\lambda_{\text{TCP,con,est}} = \frac{N_{\text{TCP,con,est}}}{T}$ [s^{-1}] and $\lambda_{\text{TCP,con,att}} = \frac{N_{\text{TCP,con,att}}}{T}$ [s^{-1}]
Unit of measurement	N	–
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	Yes
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

Example:

If the reported 3-tuple ($N_{\text{TCP,att}}$, $N_{\text{TCP,succ}}$, T) is equal to (100,10,5), then there would be an observation period of 5 s, 100 TCP connection attempts in overall inclusive 10 successfully established TCP connections, leading to a figure of $\lambda_{\text{TCP,succ}}$ equal to 10%.

8.6.2 DPI metrics for IP application layer

One of the key function requirements of deep packet inspection is application identification and transfer to ensure the quality of service (QoS) and quality of experience (QoE). The most common IP applications include HTTP, FTP, P2P, e-mail and video. Table 8-11 illustrates the HTTP application transaction identification rate metric.

Table 8-11 – DPI HTTP application transaction identification rate metric

Metric	Normative/informative	Comment
Metric name	N	HTTP application transaction identification rate
Symbol	I	$\lambda_{\text{HTTP,trf,rate}}$
Metric description	N	Number of HTTP transactions per second through the DPI node that have been successfully established and identified by the DPI node. An HTTP connection has been successfully established when an HTTPGET/POST-RESPONSE handshake is completed. To measure this metric, the DPI node needs to track the HTTP message and status code.

Table 8-11 – DPI HTTP application transaction identification rate metric

Metric	Normative/informative	Comment
Method of measurement or calculation	N	Configure a DPI policy rule for HTTP transactions. Launch the HTTP session traffic between the HTTP client and HTTP server. Check the number of HTTP transactions successfully established and identified by the DPI node in a specified time period.
Unit of measurement	N	reciprocal seconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	The timing accuracy should basically allow measurements on a time scale of seconds.
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

Example:

A measurement of $\lambda_{HTTP,trf,rate}$ equal to 100 means that 100 HTTPGET/POST-RESPONSE transactions with the status code "HTTP 200 OK" through the DPI node have been successfully established in 1 s between the HTTP client and HTTP server entities).

8.7 DPI number of supported application tags metric

Table 8-12 provides the metric specification.

Table 8-12 – DPI number of supported application types metric

Metric	Normative/informative	Comment
Metric name	N	Number of supported application tags
Symbol	I	N_{Tags}
Metric description	N	The maximum number of application types that the DPI node can support. When an application is identified, the DPI node reports the application tag via e2 (e.g., to an NMS) or via e1 (e.g., to PD-FEs).
Method of measurement or calculation	N	Vendor declares the list of applications that they can support. Counting the number of recognized application types by sending corresponding application packets according to the declared application list.
Unit of measurement	N	(Integer)

Table 8-12 – DPI number of supported application types metric

Metric	Normative/informative	Comment
Measurement point(s) with potential measurement domain	N	e2 (e.g., to an NMS) or e1 (e.g., to PD-FEs)
Measurement timing	N	The measurement interval is dependent on the time scale from the perspective of the served user instance.
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

Example:

$N_{\text{Tags, max}} = 5$, if five applications (e.g., HTTP, FTP, TFTP, NetBIOS and DB2) are supported by a DPI node, i.e., the maximum number of supported application tags of this DPI node is 5.

8.8 DPI DPI-PIB size at the line rate metric

Table 8-13 provides the metric specification.

Table 8-13 – DPI DPI-PIB size at the line rate metric

Metric	Normative/informative	Comment
Metric name	N	DPI-PIB size at the line rate
Symbol	I	N_{db}
Metric description	N	The capacity of DPI-PIB measured by rule number when input traffic equates to the ingress port rate and no packet loss caused by DPI processing occurs with the egress port.
Method of measurement or calculation	N	Configure DPI rules of a DPI node in order to all physical PIB entries in the DPI node are occupied. Choose two physical ports of the DPI node with the same line rate and connect the ports to the test device. Test device starts sending line rate traffic that does not match the configured rules to one of the above ports, while receiving traffic from another port. If no packet loss occurs, then the current physical PIB entry number is the measured result. Otherwise, one or more entry is/are removed from the PIB, then the process goes to step 3.
Units of measurement	N	

Table 8-13 – DPI DPI-PIB size at the line rate metric

Metric	Normative/informative	Comment
Measurement point(s) with potential measurement domain	N	See Figure 6-1 (traffic model).
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	"realtime DPI"
Reporting model	I	Typically as part of performance management
Is this a KPI: Yes/No?	I	No
NOTE 1 – Normative (N) and informative (I) description elements; KPI: key performance indicator. NOTE 2 – 1) The measurement method is typical, but other methods can also be applied; 2) In step 4, the entry number to be removed lies in the test accuracy. E.g., if the test accuracy is 10, then entry number to be removed is also 10; 3) Other factors such as rule length can influence the measured result.		

Since the capacity of a link and the minimum packet size are invariable in most DPI nodes on installations, it is simple to specify the maximum number of rules or DPI-PIB size that can be supported at the line rate and any packet size, including the minimum packet size and maximum packet size.

The following is the specification of the DPI policy information base (DPI-PIB) size at the line rate (N_{db}).

$N_{\text{DPI-PIB,max}}$ is the maximum number of the DPI policy rules that can be supported when

− incoming packets can be any size, including minimum size and maximum size (in terms of L2 frame);
− the probability of hitting an arbitrary condition is independently uniform; and
− the incoming packets enter DPI-FE at the full line rate.

9 DPI specific performance metrics for the control plane

9.1 DPI rule take effect time metric

Table 9-1 provides the metric specification.

Table 9-1 – DPI rule take effect time metric

Metric	Normative/informative	Comment
Metric name	N	Rule take effect time
Symbol	I	T_{rule}
Metric description	N	Time between the moment a DPI rule is set up and the moment it is applied in a DPI node.
Method of measurement or calculation	N	Configure data flows corresponding to the DPI rules in the test instrument, start sending data flows when setting up the DPI rules, compute the times when the new rules take effect through the statistics

Table 9-1 – DPI rule take effect time metric

Metric	Normative/informative	Comment
		of the test instrument.
Units of measurement	N	milliseconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

9.2 DPI failover time metric

Table 9-2 provides the metric specification.

Table 9-2 – DPI failover time metric

Metric	Normative/informative	Comment
Metric name	N	Failover time
Symbol	I	$T_{failover}$
Metric description	N	When using the 1 + *N* protection model, the time between the active component failing and the standby component taking over the function of the failed component.
Method of measurement or calculation	N	Configure data flows corresponding to DPI rules in the test instrument, start sending the data flows and disable the active component, compute the times through the received data statistics of the test instrument.
Units of measurement	N	milliseconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

9.3 DPI node deployment time metric

Table 9-3 provides the metric specification.

Table 9-3 – DPI node deployment time metric

Metric	Normative/informative	Comment
Metric name	N	DPI node deployment time
Symbol	I	T_{deploy}
Metric description	N	The performance of the current network can be influenced when deploying a DPI node to it. The shorter the deployment time, the less is the influence on the network.
Method of measurement or calculation	N	Configure end-to-end data flows corresponding to the current network, start sending data flows on deployment of a DPI node; when the deployment is completed, compute the time between the dispatch of an NMS command to a DPI node and the response of the DPI node reaching the NMS.
Units of measurement	N	milliseconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

9.4 DPI redundancy data synchronization time metric

Table 9-4 provides the metric specification.

Table 9-4 – DPI redundancy data synchronization time metric

Metric	Normative/informative	Comment
Metric name	N	Redundancy data synchronization time
Symbol	I	T_{syn}
Metric description	N	When using the 1 + *N* protection model, the time between writing DPI rules in the active component and reception of the same DPI rules by the standby component.
Method of measurement or calculation	N	Control entity configures DPI rules in the active component; the DPI rules are then read by the standby components every 100 ms until the standby component DPI rules are the same as those in the active component; the time taken for this process is the measured value.
Units of measurement	N	milliseconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

10 DPI specific performance metrics for management plane

10.1 DPI NMS response time metric

Table 10-1 provides the metric specification.

Table 10-1 – DPI NMS response time metric

Metric	Normative/informative	Comment
Metric name	N	NMS response time
Symbol	I	T_{NMS}
Metric description	N	The time between the dispatch of an NMS command to a DPI node and the reception response of the DPI node reaching the NMS.

Table 10-1 – DPI NMS response time metric

Metric	Normative/informative	Comment
Method of measurement or calculation	N	There are two measurement methods: 1) by NMS; 2) through the test instrument.
Units of measurement	N	milliseconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

10.2 DPI supported concurrent NMS number metric

Table 10-2 provides the metric specification.

Table 10-2 – DPI supported concurrent NMS number metric

Metric	Normative/informative	Comment
Metric name	N	Concurrent NMS number supported by a DPI entity
Symbol	I	N_{NMS}
Metric description	N	The maximum number of NMSs that can be concurrently supported by a DPI entity.
Method of measurement or calculation	N	Gradually add NMS instances relative to a DPI entity until the status of an NMS or the DPI entity is not normal.
Units of measurement	N	none
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

10.3 DPI NMS DPI rule number written per second metric

Table 10-3 provides the metric specification.

Table 10-3 – NMS DPI rule number written per second metric

Metric	Normative/informative	Comment
Metric name	N	NMS DPI rule number written per second
Symbol	I	$N_{\text{rulewrite}}$
Metric description	N	When using an NMS system to manage a DPI rule, the time taken to modify the rule table influences the forwarding performance of the corresponding DPI node.
Method of measurement or calculation	N	Configure data flows corresponding to a group of DPI rules to be written in the DPI rule table in the test instrument, start to write the rules into the DPI rule table while initiating sending data flow, compute the number of rules written per second through the received data statistics of the test instrument.
Units of measurement	N	
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

10.4 NMS DPI rule age report time metric

Table 10-4 provides the metric specification.

Table 10-4 – NMS DPI rule age report time metric

Metric	Normative/informative	Comment
Metric name	N	NMS DPI rule age report time
Symbol	I	$T_{\text{agereport}}$
Metric description	N	When one or more DPI rule expires, the NMS needs to know the event, to synchronize its data base and to take other actions. The DPI node then reports the rule expiry event to the NMS as soon as possible.
Method of measurement or	N	Configure data flows corresponding to a DPI rule with expiry time in the test instrument, start sending

Table 10-4 – NMS DPI rule age report time metric

Metric	Normative/informative	Comment
calculation		data flows, when NMS receives the expiry report message, stop sending the data, compute the times through the received data statistics of the test instrument.
Units of measurement	N	seconds
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

11 DPI specific performance metrics for DPI nodes

11.1 DPI power per bit metric

Table 11-1 provides the metric specification.

Table 11-1 – DPI power per bit metric

Metric	Normative/informative	Comment
Metric name	N	Power per bit
Symbol	I	E_{bit}
Metric description	N	Unit bit power dissipation (in other words, average power dissipation while handling a data bit) of the DPI entities of a node.
Method of measurement or calculation	N	General power dissipation (joule)/general data traffic (bit)
Units of measurement	N	picojoule per bit
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE – Normative (N) and informative (I) description elements; KPI: key performance indicator.		

11.2 DPI power per packet metric

Table 11-2 provides the metric specification.

Table 11-2 – DPI power per packet metric

Metric	Normative/informative	Comment
Metric name	N	Power per packet
Symbol	I	ϕ_{power}
Metric description	N	Unit packet power dissipation (in other words, average power dissipation while handling a data packet) of the DPI entities of a node.
Method of measurement or calculation	N	General power dissipation (joule)/general data traffic (packet)
Units of measurement	N	picojoule per packet
Measurement point(s) with potential measurement domain	N	
Measurement timing	N	
Implementation	I	
Verification	I	
Use and applications	I	
Reporting model	I	
Is this a KPI: Yes/No?	I	No
NOTE 1 – Normative (N) and informative (I) description elements; KPI: key performance indicator. NOTE 2 – This performance indicator is used to evaluate power dissipation of a DPI entity or node. Because it is dependent on packet length, a certain packet length can be chosen when testing and evaluating a DPI entity or node.		

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