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

Future networks

Framework for service function chaining in information-centric networking

Recommendation ITU-T Y.3073

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Recommendation ITU-T Y.3073

Framework for service function chaining in information-centric networking

Summary

This Recommendation specifies the framework for applying information-centric networking (ICN) to edge computing and service function chaining. It describes the communication models, messages and their content, and functional components and their interactions in applying ICN to service function chaining.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.3073	2019-08-13	13	11.1002/1000/13984

Keywords

IMT-2020, ICN, information-centric networking, in-network processing, service function chaining.

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Framework for service function chaining in information-centric networking

1 Scope

This Recommendation specifies the framework including communication models and scenarios, and messages and their content to be exchanged in executing functions, in applying information-centric networking to edge computing and service function chaining.

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 Y.3001] Recommendation ITU-T Y.3001 (2011), *Future networks: Objectives and design goals.*

[ITU-T Y.3011] Recommendation ITU-T Y.3011 (2012), *Framework of network virtualization for future networks.*

[ITU-T Y.3031] Recommendation ITU-T Y.3031 (2012), *Identification framework in future networks.*

[ITU-T Y.3032] Recommendation ITU-T Y.3032 (2014), *Configurations of node identifiers and their mapping with locators in future networks.*

[ITU-T Y.3033] Recommendation ITU-T Y.3033 (2014), *Framework of data aware networking for future networks.*

[ITU-T Y.3071] Recommendation ITU-T Y.3071 (2017), *Data aware networking (information centric networking) – Requirements and capabilities.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 DAN element [ITU-T Y.3071]: A network component that forwards messages to producers, consumers, and other data aware networking (DAN) elements.

3.1.2 DAN realm [ITU-T Y.3071]: A set of data aware networking (DAN) elements operated under one DAN realization and managed by an organization. Different DAN realms may adopt different DAN realizations such as naming convention, communication models including push and pull models and name resolution mechanisms.

3.1.3 identifier [b-ITU-T Y.2091]: An identifier is a series of digits, characters and symbols or any other form of data used to identify subscriber(s), user(s), network element(s), function(s), network entity(ies) providing services/applications, or other entities (e.g., physical or logical objects). Identifiers can be used for registration or authorization. They can be either public to all networks, shared between a limited number of networks or private to a specific network (private IDs are normally not disclosed to third parties).

3.1.4 IMT-2020 [ITU-T Y.3100]: Systems, system components, and related aspects that provide far more enhanced capabilities than those described in [b-ITU-R M.1645].

NOTE – [b-ITU-R M.1645] defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000 for the radio access network.

3.1.5 name [b-ITU-T Y.2091]: A name is the identifier of an entity (e.g., subscriber, network element) that may be resolved/translated into an address.

3.1.6 named data object (NDO) [b-ITU-T Y.Sup. 35]: A data object that is identifiable by a name.

3.1.7 NDO consumer [ITU-T Y.3071]: A component that makes requests on named data objects (NDOs).

3.1.8 NDO producer [ITU-T Y.3071]: A component holding named data objects (NDOs) and make them reachable by corresponding requests. An NDO producer may be an actual owner of the NDO or a delegate of the actual owner.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 data-aware networking [based on ITU-T Y.3001]: This refers to an architecture of future networks optimized to handle large amounts of data in a distributed environment, and to enable users to access desired data safely, easily, quickly and accurately, regardless of their location.

3.2.2 edge computing: This refers to a strategy to deploy processing capability at network edge where end terminals are connected, and to perform the processing of data which is derived from and fed to the end terminals.

3.2.3 explicit processing allocation function [based on ITU-T Y.3071]: This is a capability to allocate data processing function to a specified location.

3.2.4 ICN service function: This refers to the execution of a computer program that implements a unit of functionality initiated and utilized by the protocol of ICN.

3.2.5 information-centric networking [based on ITU-T Y.3033]: Information-centric networking is equivalent to data-aware networking.

3.2.6 in-network processing: This refers to executing computer programs in network nodes such as routers instead of in-host computers connected at the end of the network.

3.2.7 ISF provider: This is a component that prepares an ISF description, registers the ISF description to the system, and manages the chain of ISFs made of a series of ISF descriptions.

3.2.8 NDO and processing description retrieval function [based on ITU-T Y.3071]: This is a capability to retrieve data processing descriptions and the NDOs to be processed by the requested processing.

3.2.9 processing function [based on ITU-T Y.3071]: This is the capability to process NDOs before transmitting them in order to adapt the NDOs to the capability of the receiving consumer or to aggregate information.

3.2.10 process registration function [based on ITU-T Y.3071]: This is a mechanism to register the description of the processing function.

3.2.11 process scheduling and coordination function [based on ITU-T Y.3071]: This is a capability to recognize data processing requests, coordinate the requested processing placed at appropriate DAN elements and schedule the processing.

3.2.12 publish/subscribe: This refers to a communication model between information sources and information-requesting parties. The information-requesting parties express their interest to receive information which is characterized with features. The feature may be described in terms of keywords, identifiers, names, etc. The information source transmits information accompanied with its features and the system supporting the publish/subscribe communication model delivers the information to all the information-requesting parties expressing matching features. The function to implement publish/subscribe is called the publish/subscribe function.

3.2.13 service function chaining: This is the placing execution of ICN service functions in a sequence so that the sequence of ICN service functions is executed one after another to form a network service or an application as a whole.

NOTE – Service function chaining, as defined in this Recommendation, covers only ICN service functions.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

DAN Data Aware Networking

EPAF Explicit Processing Allocation Function

ICN Information-centric Networking

IoT Internet of Things

ISF ICN Service Function

NPDRF NDO and Processing Description Retrieval Function

PRF Process Registration Function

PSCF Process Scheduling and Coordination Function

5 Conventions

This Recommendation uses "is required" to indicate the main points to be taken into account in the framework for service function chaining in ICN.

6 Justification

IMT-2020 networks are expected to connect large number of terminals and devices. Also, in some applications of IMT-2020 networks, a short response time is required. Edge computing and in-network processing technology which equips network nodes, such as routers and switches, data processing capability, is considered to be an effective solution to handle the data from a large number of terminals and devices, and to provide short response times.

On the other hand, information-centric networking (ICN) technology is expected to be incorporated into IMT-2020 networks. Name-based routing is effective to handle the large number of terminals and devices. Combining ICN and service function chaining is essential to providing the IMT-2020 capability to handle a large number of devices and a short response time.

This Recommendation specifies the framework utilizing edge computing and service function chaining in conjunction with ICN.

7 Communication and in-network processing models and scenarios

7.1 Service function chaining scenarios

Service function chaining may potentially be used in a variety of scenarios. In the context of this Recommendation, the following three scenarios are assumed:

- A user initiates the collection of data: The request is propagated to many producers of the corresponding data. On the way back to the requesting user, the collected data is preprocessed and delivered to the requesting user.
- Sensor readings are pushed to a nearby computer to detect certain information from the readings. The processing result initiates additional processing and eventually results in controlling an actuator. This communication is necessary for the applications with low latency in control loop.
- Sensor readings are pushed to an intermediate repository. Pushing is necessary to save energy consumption of sensors. The readings are later requested by users or application programs.

Use cases of the scenarios described above can be found in Appendix I.

7.2 Architecture for ICN service function chaining

[ITU-T Y.3071] defines the components of ICN and also required functions for in-network processing. Those components and functions are almost sufficient to support ICN service function chaining and make up the basis of the architecture for ICN service function chaining as shown in Figure 1.

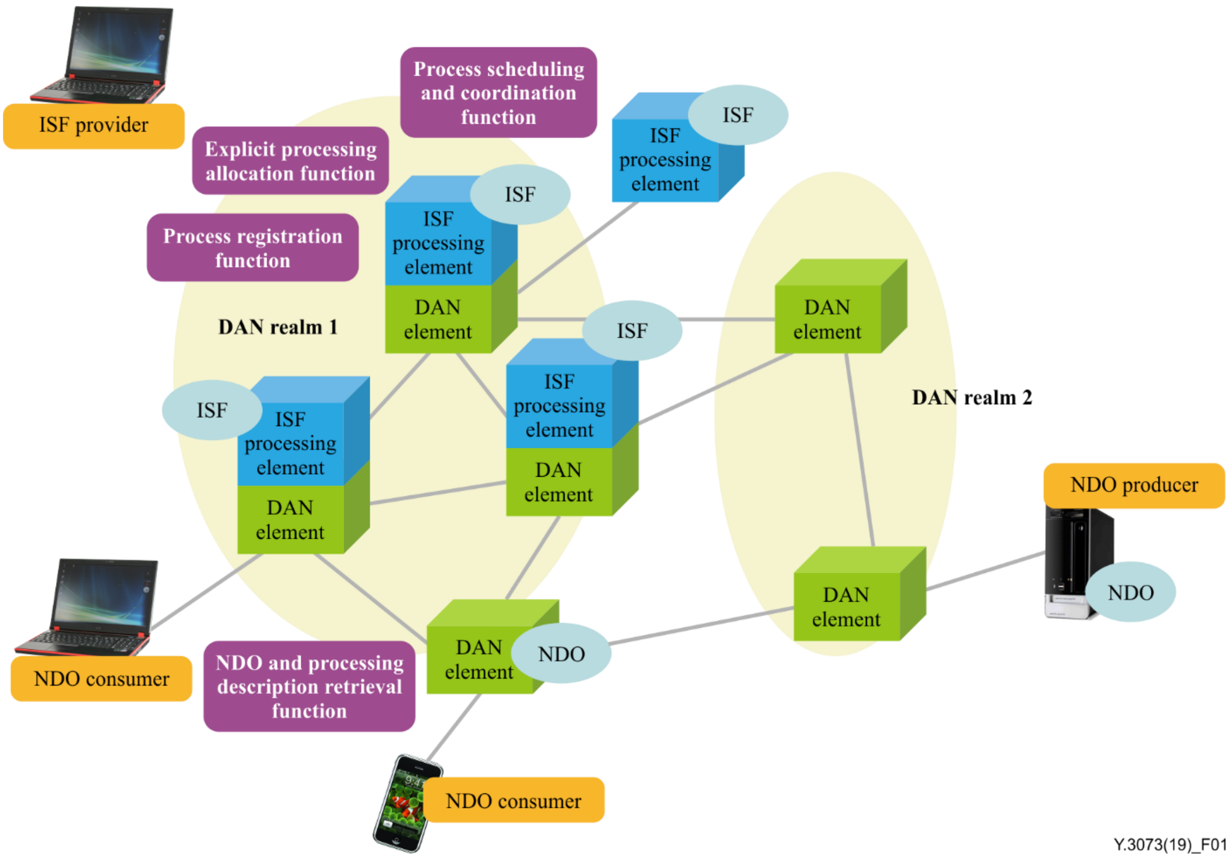

Figure 1 – Architecture for ICN service function chaining

To define communication models and interaction among components and functions in ICN service function chaining in the following clauses two additional components are defined in addition to what is defined in [ITU-T Y.3071]. The two additional components are:

- ISF and
- ISF provider.

When a DAN realm provides ISF chaining as its capability, the process scheduling and coordination function (PSCF), process registration function (PRF), NDO and processing description retrieval function (NPDRF), and explicit processing allocation functions (EPAF), as well as the ISF processing element (processing function in [ITU-T Y.3071]) are required and are supported by the DAN realm as defined in [ITU-T Y.3071]. The PSCF chooses the appropriate ISF processing elements and instructs them to retrieve specified ISF descriptions from the PRF by means of the NPDRF, and execute the ISF descriptions. The PSCF also instructs ISF processing elements where to send the outcome of the execution of ISF descriptions. ISF providers define ISF descriptions and register them at PRF.

The EPAF may explicitly deploy the registered ISF descriptions at certain ISF processing elements specified by the ISF providers or the organization managing the DAN realm. ISF processing elements either retrieve ISF descriptions from the PRF according to the instruction provided by the PSCF or the EPAF, and execute the ISF descriptions.

7.3 Function-initiation models

In ICN, NDOs are typically requested by NDO consumers sending request messages. In this context, functions provided by the network is initiated by the NDO consumer. Initiation of functions may be triggered by both request message reception and reply message reception. In some cases, retrieving information may be required to execute certain functions. In other cases, retrieved data carried by response messages is processed by a chain of functions.

Edge computing for IoT networks is one of the application areas for service function chaining. IoT devices are energy constrained. Keeping their power on consumes their precious energy while it is necessary if IoT devices need to wait for request arrival. It is preferable for sensor devices to send their readings to the nearby DAN elements while their power is on and to go to sleep after sending the data to save energy. In turn, the DAN elements accumulating readings from surrounding IoT devices aggregate the readings after accumulating enough readings. In this case, a chain of functions is triggered by delivery of data from IoT devices or NDO producers.

From the above discussion, both consumer-initiated and producer-initiated models are required for ICN service function chaining.

The following function-initiation models are required to be supported by ICN:

- Consumer-initiated model:

A chain of functions is initiated by the NDO consumer's request. The chain is specified by a name or names. The name can be the name of a predefined service, which is composed of a sequence of ISFs, or a series of ISF names and NDO names. The ISF execution order can be in both the order of request traversal and the order of response traversal. In order to execute ISFs, some NDOs may be retrieved to provide parameter values for the ISF execution or values directly taken from arguments fields. Both NDO names and values can appear in argument fields. An argument field can be either ISF specific or global. ISF specific arguments are only applicable to an ISF identified by an associated ISF name. Global arguments are applicable to all ISFs invoked by the request message.

An example is given in Appendix II.

- Producer-initiated model:

A chain of functions is initiated by the NDO producer's request. The NDO producer autonomously transmits NDOs without the NDO consumers' requests. The destination of the request may not be NDO consumers in this case and can be other DAN elements. The DAN elements may implement the publish/subscribe function or cache the NDOs and/or the NDOs derived from the transmitted NDOs.

Examples are given in Appendix II.

8 Messages exchanged for in-network processing

8.1 Specification scheme for in-network functions

Messages are delivered to the destinations addressed by names in ICN. Functions to which request messages are to be delivered are specified by names as well. Service chaining of the ISF is specified either by a sequence of names of ISFs or by ISF description. The latter case simply means one ISF calls another ISF from the program of the ISF or ISF description.

8.2 Message content in function request

It is required that the messages to be used to request ISFs are equipped with the field to specify a sequence of ISF names or an ISF name to accommodate the function-initiation models described in clause 7.3. In addition, the request messages for ISFs may have fields to specify arguments to the ISFs. The specification of the arguments may be expressed by names of NDOs. The values of named NDOs can be derived from the network. Otherwise, argument values can be provided directly in the argument field. Consequently, the request messages to initiate the execution of ISFs include the following message fields to implement the function-initiation models described in clause 7.3. Examples of the message format are given in Appendix III:

- a sequence of ISF names or an ISF name (mandatory)
- arguments to ISF(s) which may be either NDO names or values (optional)

8.3 Message content in response

The response messages may contain the field to specify a sequence of ISF names to accommodate the consumer-initiated model described in clause 7.3 where some ISFs are executed on the arrival of response messages. It is required, therefore, for the response messages to be equipped with the field to specify a sequence of ISF names or an ISF name. In addition, the response messages with ISF names may have fields to specify arguments to the ISFs like function request messages. The response messages to execute ISFs include the following message fields:

- a sequence of ISF names or an ISF name (mandatory)
- arguments to ISF(s) which may be either NDO names or values (optional)

9 Service function chaining mechanisms

9.1 Service creation mechanism

ICN service function chaining has four stakeholders (Figure 2): DAN realm, ISF provider, NDO producer and NDO consumer. In the following description, the numbers of items correspond with the numbers of the message flows in Figure 2.

1) An ISF provider, who intends to provide a certain network service, creates ISF descriptions and registers them to the PRF. The registration may be accompanied with the description of precedence relations among ISFs.
2) The PRF stores the registered ISF descriptions and
3) asks the PSCF to properly allocate ISFs to certain ISF processing elements.
4) The PSCF informs the allocation to the corresponding ISF processing elements.
5) The informed ISF processing element retrieves the corresponding ISF description by asking the NPDRF and executes it. The PSCF additionally configures the routing of service function chaining.

9.2 Service usage mechanism

An NDO consumer transmits a request message with ISF names to use the service function chaining in consumer-initiated mode as expressed with red arrows in Figure 2. The request message is forwarded following the route established by the PSCF and goes through the ISFs specified by their names. When the request message reaches to the specified NDO producer the message is changed to a response message with the appropriate NDO in it. The ISFs apply their execution on the contents carried by the request and response messages.

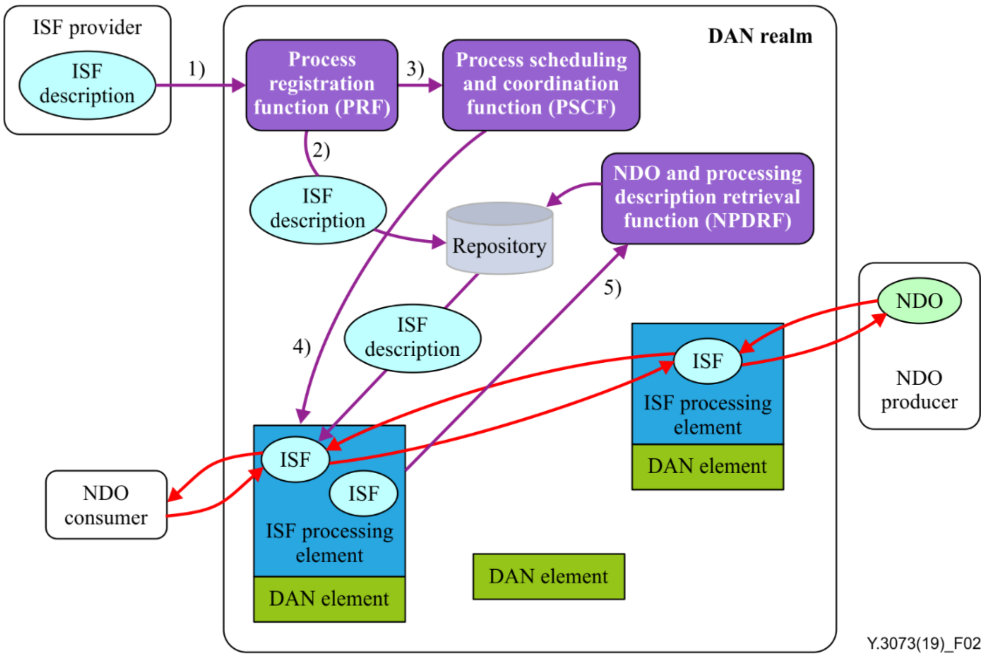

Figure 2 – Service function chaining mechanism

In the case of the producer-initiated mode, the producer generates a request message carrying NDOs in addition to ISF names. The request message is routed through the network following the specified in the sequence of ISF names. The routes are preconfigured by the PSCF.

10 Security considerations

ICN provides mechanisms to guarantee secrecy, integrity and availability of NDOs, as well as verifying the owners of NDOs. To operate the mechanisms properly, an additional mechanism to distribute cryptographic keys may be required.

Revealing the NDO access history by NDO consumers is an intrinsic problem in ICN where NDO names are expected to be long-lived. Even if the name itself does not reveal the content of the NDO, the name can be used to retrieve the NDO and the content may be known.

The capability for ISF providers to create their designed ISF descriptions and embed them into the network poses a serious security risk. The process registration function is required to impose access control on the registration of ISF descriptions. The process registration function may be required to perform a sanity test on the registered ISF descriptions.

Also, the capability to perform ISFs with requests from NDO consumers and NDO producers poses security risk. It is required to place an access control mechanism at every DAN node where ISFs are performed. An access control mechanism requires the identification of the requesting party, either the NDO consumer or NDO producer.

11 Environmental considerations

The environmental considerations in this Recommendation are mainly subject to those provided by DAN, or ICN, as specified in [ITU-T Y.3033]. Additional energy reduction by ICN may come from the processing capability provided by ISFs. ISFs can be used to reduce the amount of data and the number of messages to be transferred over ICN. Although the processing increases energy consumption at one DAN element, a reduction in the number of messages being exchanged lowers energy consumption in the other DAN elements, which results in energy reduction in the entire ICN network.

Appendix I

Use cases of service function chaining

(This appendix does not form an integral part of the Recommendation.)

I.1 User-initiated data collection

A user sends a request containing a keyword or keywords to the network and receives NDOs relevant to the specified keyword(s). The nodes in the network gather relevant NDOs by forwarding the request and sending back a response message to originating nodes. This use case is further described in [b-Kurita]. ICN service functions can be used to realize this use case.

NDO producers advertise keywords that represent characteristics of the NDO to the routers. The keywords are stored in a dedicated forward information base in the service function in each router. More than one NDO can advertise the same keywords.

Each router provides a service function that forwards a request it received to all nodes listed in the forwarding information base and aggregates all data it receives from those nodes to compose a response data. The request message specifies a keyword or keywords as a parameter to the service function.

If a request contains "X" as the keyword parameter, all NDOs associated with the keyword "X" receive the request and response data (NDOs) is aggregated at each router as one response data.

The service function can also perform elementary AND / OR operations as shown in Figure I.1. If a request contains "X&Y" as the keyword parameter, the service function composes of an intersection of X and Y.

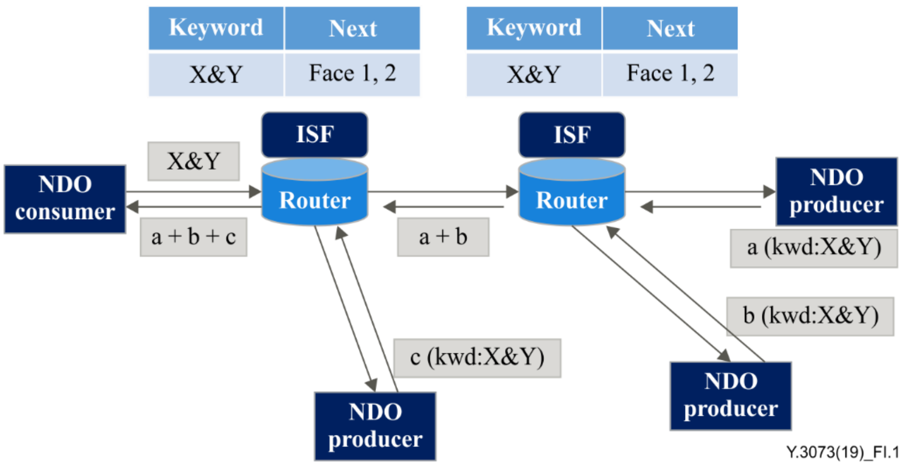

Figure I.1 – ISF forwarding requests and aggregating data

I.2 Sensor-initiated data transmission for low latency (Figure I.2)

An infrared sensor or a motion detector initiates the operation of a wildlife management system. Such a sensor transmits the NDO of detected information to a nearby computer whose names are known by the sensor. The computer analyses the NDO to detect the existence of wildlife. The computer may request additional data from other sensors to come to the final decision. Once the decision is made on the existence of a certain wild animal, the system may respond with closing a cage door or simply operating a robot to expel the wild animal depending on the type of animal.

To implement the real-time response to wild animals, the chain of functions needs to be triggered right after the creation of the initial NDO by one of the sensors.

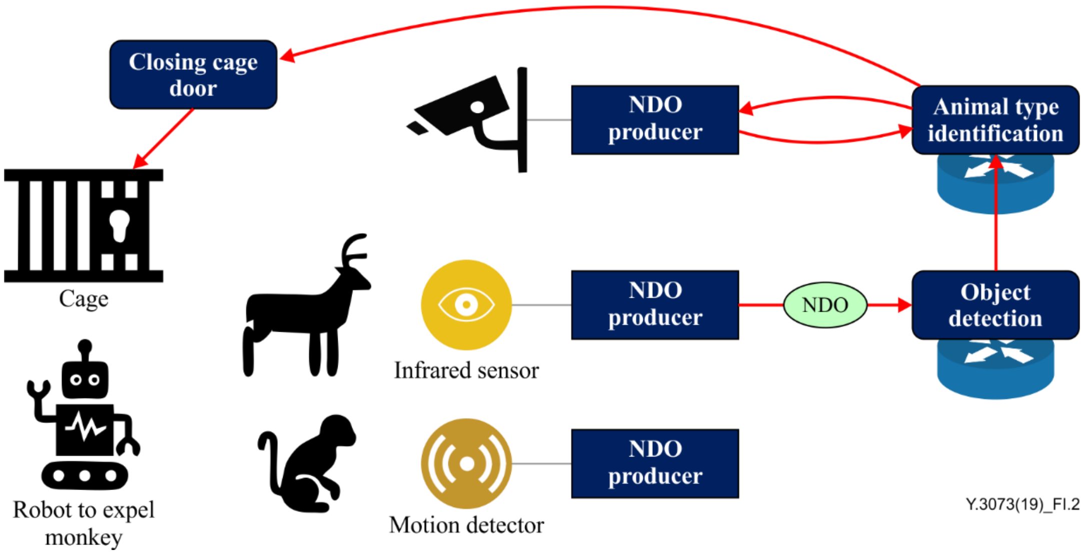

Figure I.2 – Wildlife management system

I.3 Publish/subscribe communication for energy saving (Figure I.3)

A farmland management system may involve thermometers, hygrometers, anemometers, surveillance cameras, etc. These devices are battery powered and their power consumption must be suppressed to prolong battery life. Devices should be kept at sleep state as much as possible to save energy. For this purpose, it is preferable for devices to wake up with a certain interval, perform their tasks such as retrieving sensor readings, and transmit the readings, and go to sleep immediately.

In order for devices to go to sleep immediately, the data derived at the devices must be stored in the system to make it ready to be used by applications while the devices are sleeping. In addition, some of the applications may be ready for processing the device data. The device data is to be delivered to these applications immediately. For example, all readings from thermometers, hygrometers, and anemometers may be stored by a server in the farmland management system for later analysis of the effect of control factors to the production level and also for the real-time control of the temperature, humidity, etc.

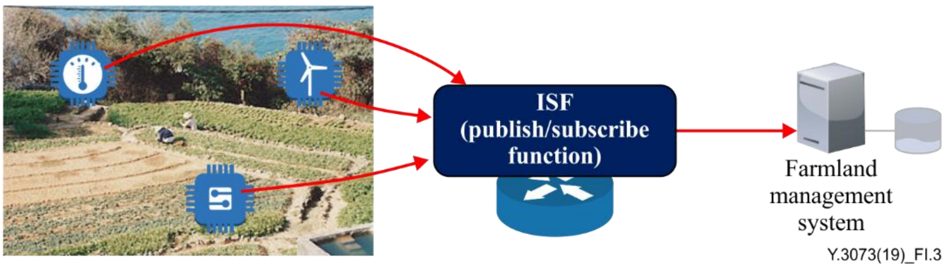

Figure I.3 – Farmland management system

Appendix II

Examples of function-initiation models

(This appendix does not form an integral part of the Recommendation.)

This appendix is intended to help readers better understand the function-initial models. The communications explained in this appendix are just examples and are not meant to indicate any particular protocol.

II.1 An example of consumer-initiated model

In the example shown in Figure II.1, the NDO consumer sends a request to initiate a service. The request passes through Router 1 and execute ISF 2 at Router 2. To execute ISF 2, NDO 1 is derived. Then the request is further forwarded to Router 3 where ISF 3 is executed with another NDO 2 as its parameter. After executing ISF 3 a response is returned with the value calculated by ISF 3. The response passed through Router 2 and at Router 1, ISF 1 is executed with the value carried by the response. The result of ISF 1 is finally returned to the NDO consumer.

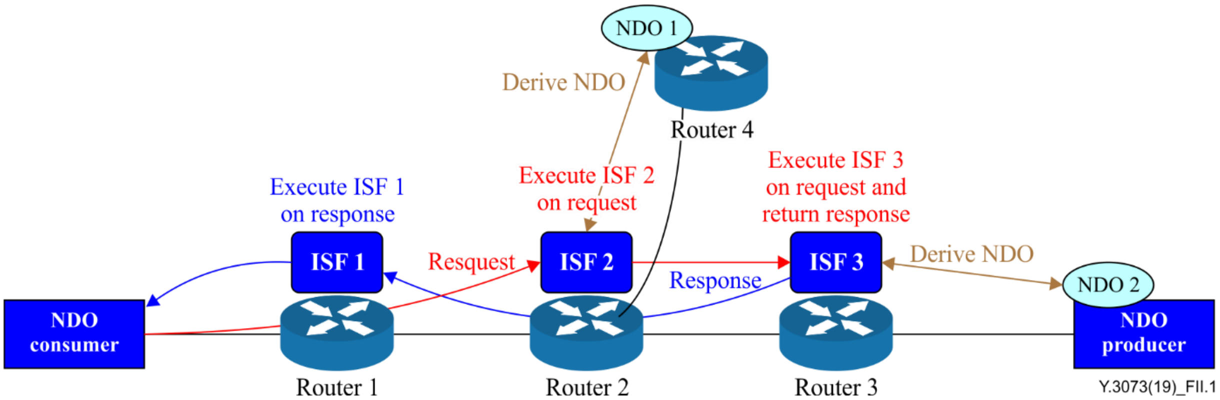

Figure II.1 – Consumer-initiated model

II.2 An example of producer-initiated model

In the producer-initiated model, only request messages trigger execution of the ISFs as shown in Figure II.2. Three ISFs: ISF 1, ISF 2 and ISF 3 are specified in the request message in that order and they are executed in sequence on the NDO provided by the NDO producer. The response from the NDO consumer is used only for acknowledgement purposes.

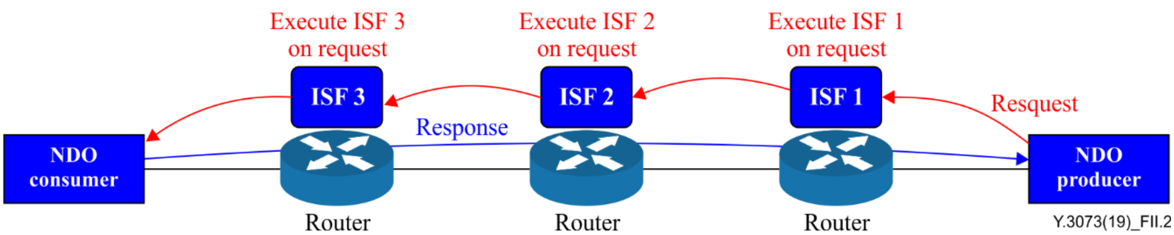

Figure II.2 – Producer-initiated model

II.3 A publish/subscribe example of producer-initiated model

Figure II.3 shows an example of the publish/subscribe function. Here the publish/subscribe function is one of the ISFs. NDO consumers register their intention to subscribe NDOs at the publish/subscribe function in advance (orange arrow). Upon creation of NDOs, the NDO producer transmits a request (publish) with the NDOs to Router 3 where the NDO is used to perform ISF 1. The result NDO of

ISF 1 is further forwarded to the publish/subscribe function. If the request (publish) matches the preregistered subscription, the NDO is forwarded to the registered NDO consumers.

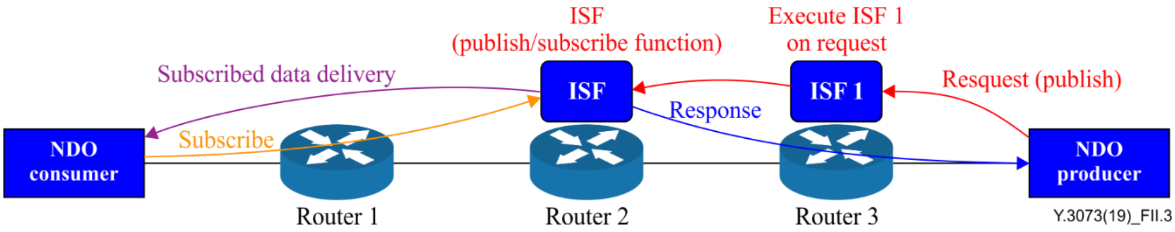

Figure II.3 – Producer-initiated model (publish/subscribe)

Appendix III

Examples of message format

(This appendix does not form an integral part of the Recommendation.)

III.1 An example message format for function request

A function request message can contain both a sequence of ISF names and arguments to ISF(s). Argument fields can be either local or global. The local argument fields are used by specific functions while the global argument field is shared among all the ISFs specified in the function request messages. Figure III.1 shows an example of request message fields.

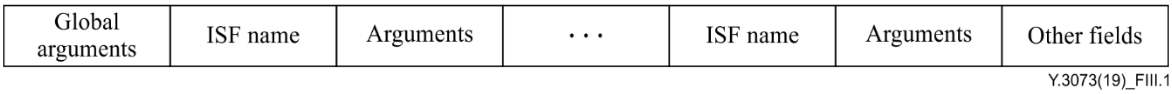

Figure III.1 – Example request message fields

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