ITUPublications
Recommendations

International Telecommunication Union
Standardization Sector

Recommendation

ITU-T Y.4489 (11/2023)

SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

Internet of things and smart cities and communities – Frameworks, architectures and protocols

Reference architecture of digital twin federation in smart cities and communities

ITU-T Y-SERIES RECOMMENDATIONS

Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

GLOBAL INFORMATION INFRASTRUCTURE	Y.100-Y.999
INTERNET PROTOCOL ASPECTS	Y.1000-Y.1999
NEXT GENERATION NETWORKS	Y.2000-Y.2999
FUTURE NETWORKS	Y.3000-Y.3499
CLOUD COMPUTING	Y.3500-Y.3599
BIG DATA	Y.3600-Y.3799
QUANTUM KEY DISTRIBUTION NETWORKS	Y.3800-Y.3999
INTERNET OF THINGS AND SMART CITIES AND COMMUNITIES	Y.4000-Y.4999
General	Y.4000-Y.4049
Definitions and terminologies	Y.4050-Y.4099
Requirements and use cases	Y.4100-Y.4249
Infrastructure, connectivity and networks	Y.4250-Y.4399
Frameworks, architectures and protocols	**Y.4400-Y.4549**
Services, applications, computation and data processing	Y.4550-Y.4699
Management, control and performance	Y.4700-Y.4799
Identification and security	Y.4800-Y.4899
Evaluation and assessment	Y.4900-Y.4999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T Y.4489

Reference architecture of digital twin federation in smart cities and communities

Summary

As the digital representation of an object of interest with data connections enables convergence between the physical and digital states at an appropriate rate of synchronization. Digital twin federation is an operation among one or more digital twin initiated to solve the problem of crossing the boundaries of multiple domains. Recommendation ITU-T Y.4224 defines the requirements for digital twin federation. Based on the requirements, Recommendation ITU-T Y.4489 addresses the reference architecture of digital twin federation. It defines the functionalities of each entity and the interfaces among the entities. In addition, it also addresses the operational flows of digital twin federation in different scenarios.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T Y.4489	2023-11-29	20	11.1002/1000/15683

Keywords

Digital twin, federation, reference architecture.

* To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, 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 appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

© ITU 2024

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without the prior written permission of ITU.

Table of Contents

Recommendation ITU-T Y.4489

Reference architecture of digital twin federation in smart cities and communities

1 Scope

This Recommendation defines the reference architecture of digital twin federation in smart cities and communities. The scope of this Recommendation includes the following:

– Components of digital twin federation;

– Reference architecture of digital twin federation;

– Operation flows of digital twin federation.

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.4224] Recommendation ITU-T Y.4224 (2023), *Requirements for digital twin federation in smart cities and communities*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 candidate digital twin [ITU-T Y.4224]: A set of digital twins with the possibility of being participating digital twins.

3.1.2 connection information [ITU-T Y.4224]: Information used for establishing the connection between digital twins. The example components of connection information are protocols, URI, IP address and port number, etc.

3.1.3 digital twin [b-ITU-T Y.4600]: A digital representation of an object of interest.

NOTE – A digital twin may require different capabilities (e.g., synchronization, real-time support) according to the specific domain of the application.

3.1.4 digital twin federation [ITU-T Y.4224]: Sharing an application context for collaboration across different digital twins.

3.1.5 feature information [ITU-T Y.4224]: Description of digital twin including the data and functions which can be provided, the access rights to the data and functions, semantic information for each data and function, and connection information for the digital twin.

3.1.6 federated digital twin [ITU-T Y.4224]: Digital twin created as a result of digital twin federation.

NOTE – A digital twin is an extension of an initiating digital twin.

3.1.7 initiating digital twin [ITU-T Y.4224]: A digital twin that initiates digital twin federation.

3.1.8 participating digital twin [ITU-T Y.4224]: A digital twin that participates in digital twin federation according to the request from an initiating digital twin.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AP-FE Adaptation Process Functional Entity

CASF Communication Adaptation Support Functions

CFIM-FE Candidate Feature Information Management Functional Entity

CM-REQ Connection Management Requirements

CSIM-FE Communication Status Information Management Functional Entity

DFA-FE Data Format Adaptation Functional Entity

DTD-FE Digital Twin Discovery Functional Entity

DTR-FE Digital Twin Registration Functional Entity

FC-FE Federation Communication Functional Entity

FCSF Federation Communication Support Functions

FIM-FE Feature Information Management Functional Entity

FI-REQ Feature Information Requirements for digital twins

FM-FE Federation Management Functional Entity

FOF Federation Orchestration Functions

FSIM-FE Federation Status Information Management Functional Entity

FS-REQ Digital twin Requirement for Federation Support

GF General Functions

PA-FE Protocol Adaptation Functional Entity

SA-FE Semantic Adaptation Functional Entity

SD-FE Semantic Dictionary Functional Entity

SE-REQ Security requirements

5 Conventions

The following conventions apply:

1) This Recommendation uses the following conventions which are specific to this Recommendation and are used to facilitate referencing different relationships:

FO-A: This term is used to indicate the relationship between functional entities in the federation orchestration functions (FOF) and federated application;

FO-G: This term is used to indicate the relationship between functional entities in the federation orchestration functions and general functions;

FO-CAS: This term is used to indicate the relationship between a functional entity in the federation orchestration functions and a functional entity in communication adaptation support functions;

FO-FCS*n*: This term is used to indicate the relationship between functional entities in the federation orchestration functions and functional entities in federation configuration support functions;

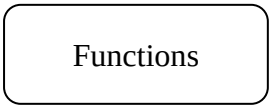
FO-FO: This term is used to indicate the relationship between a functional entity in the federation orchestration functions of a digital twin and a functional entity in the federation orchestration functions of another digital twin;

G-A: This term is used to indicate the relationship between general functions and standalone applications;

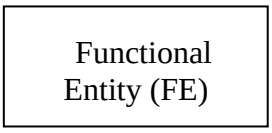
G-O: This term is used to indicate the relationship between general functions and objects of interest.

2) In this Recommendation:

The keyword "functions" is defined as a collection of functionalities. It is represented by the following symbol in this Recommendation:



The keyword "functional entity" (FE) is defined as a representation of functionality that has not been further subdivided at the level of detail described in this Recommendation. It is represented by the following symbol in this Recommendation:



6 Components for digital twin federation

The components for digital twin federation are shown in Figure 1.

NOTE – Applications and objects of interests in Figure 1 are not under the scope of this Recommendation.

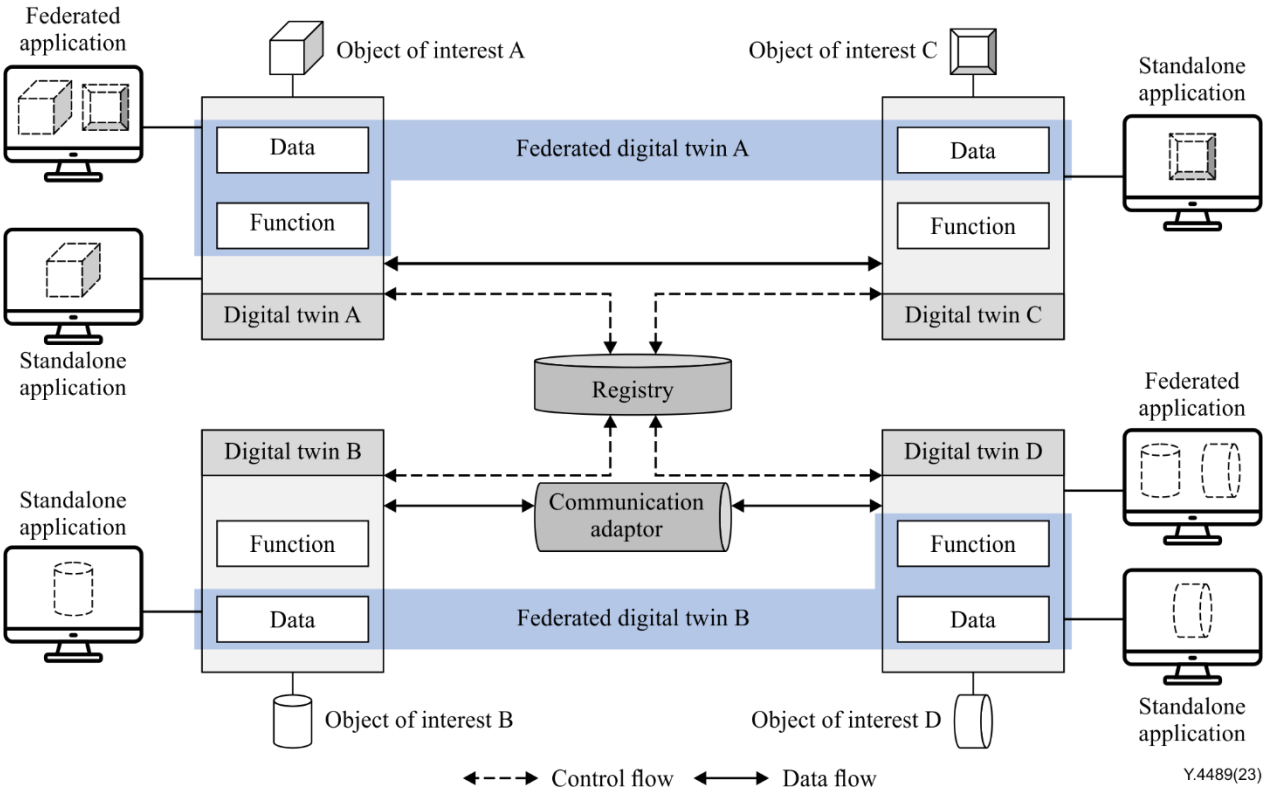


Figure 1 – Components of digital twin federation

6.1 Registry

Registry is a component registering the feature information of each digital twin and providing the registered feature information according to the request from a digital twin.

NOTE – Registration and discovery using registry may not be involved in digital twin federation if predefined members of the digital twin federation have shared their feature information with a certain method which is not under the scope of this Recommendation.

6.2 Communication adaptor

Communication adaptor is a component providing indirect communication in between digital twins. The indirect communication which the communication adaptor offers, is used in the case when the digital twins cannot establish direct communication because of, for instance, protocol, data format, semantics, etc.

6.3 Digital twin

Digital twin is the main component of the digital twin federation which mainly offers a standalone application and is capable of offering a federated application.

6.4 Federated digital twin

Federated digital twin is a logical digital twin generated as the result of a digital twin federation and it is an extended version of an initiating digital twin. For instance, federated digital twin A in Figure 1 is an extended version of digital twin A with data possessed by digital twin C.

6.5 Application

Application is composed of a standalone application, which digital twin offers without a digital twin federation, and a federated application in which multiple digital twins are involved. The application is implementation-specific, and it is not under the scope of this Recommendation.

6.6 Object of interest

Object of interest is a specific object which has the corresponding digital twin. This Recommendation does not address the function of the object of interest, as it is not under the scope of this Recommendation.

7 Reference architecture of digital twin federation

Figure 2 shows the reference architecture of the digital twin federation including functions and functional entities of each component depicted in Figure 1 and reference points among the functions or functional entities. Note that federation orchestration functions (FOF) of other digital twin in Figure 2 shows the functional entities with external reference points for information exchange only, but the functions shall have entire functional entities described in clause 10.3.

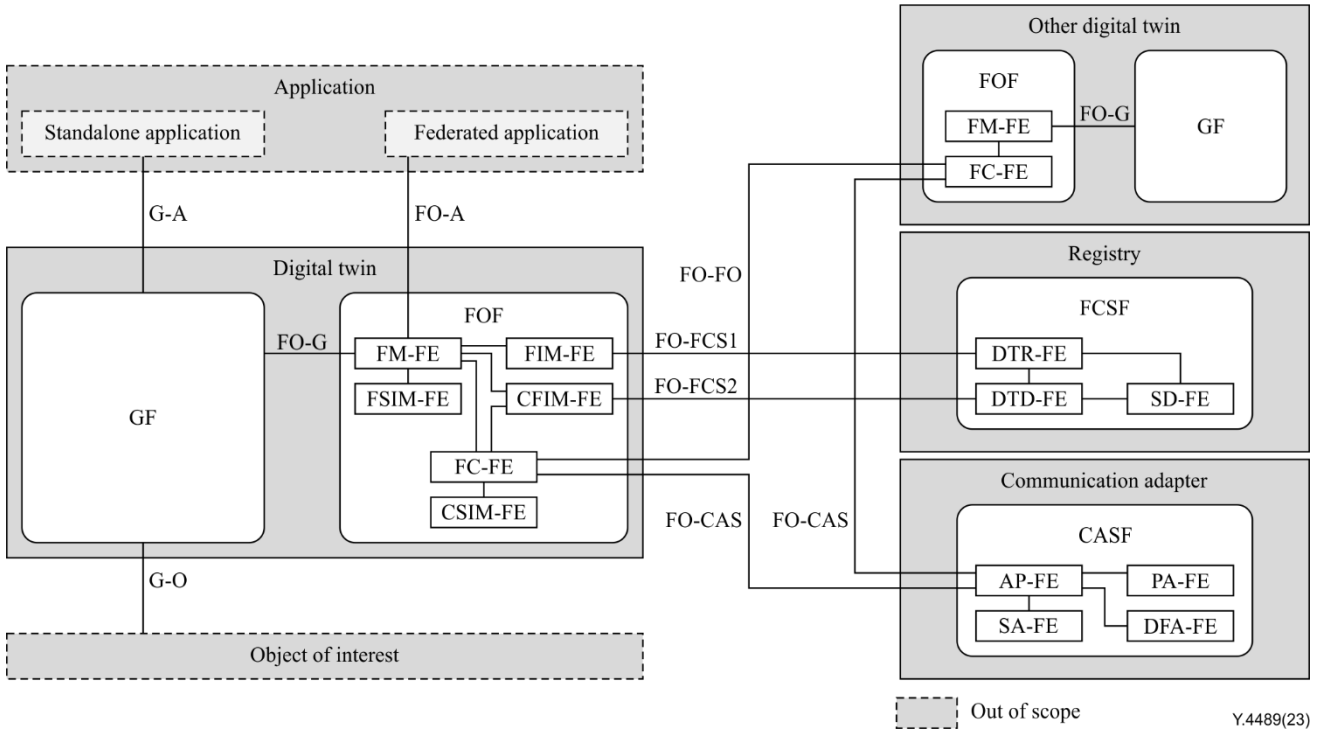


Figure 2 – Reference architecture of digital twin federation

8 Functions and functional entities of registry

8.1 Functions of the registry

Figure 3 shows the functions and functional entities of the registry. The registry is composed of FCSF.

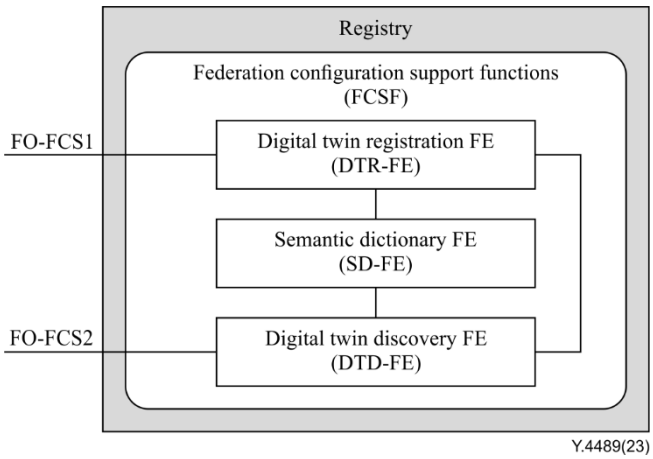


Figure 3 – Functions and functional entities of registry

NOTE 1 – FO-FCS1 is the reference point between digital twin registration functional entity (DTR-FE) and feature information management FE (FIM-FE), defined in clause 10.3.3, in federation orchestration functions (FOF) in the digital twin.

NOTE 2 – FO-FCS2 is the reference point between digital twin discovery functional entity (DTD-FE) and candidate feature information management functional entity (CFIM-FE) in FOF in the digital twin.

Table 1 lists the requirements relevant to the functionalities of the registry defined in [ITU-T Y.4224].

Table 1 – Requirements of registry's functionalities and related functional entities

Requirement ID	Relevant functional entities
FS-REQ-01	Digital twin registration functional entity, digital twin discovery functional entity
FS-REQ-02	Digital twin registration functional entity, digital twin discovery functional entity
FI-REQ-05	Digital twin registration functional entity, digital twin discovery functional entity
FI-REQ-06	Digital twin registration functional entity, digital twin discovery functional entity, semantic dictionary functional entities

8.2 Functional entities of federation configuration support functions

Federation configuration support functions (FCSF) interact with the federation orchestration functions (FOF) in a digital twin and provide the functionalities to find the digital twins for a digital twin federation.

8.2.1 Digital twin registration functional entity (DTR-FE)

Digital twin registration functional entity (DTR-FE) provides the functionalities related to digital twin registration as follows:

– Register feature information of a digital twin based on the registration request from the digital twin;

– Maintain the registered feature information;

– Provide semantic information in the feature information to the semantic dictionary functional entity (SD-FE).

8.2.2 Semantic dictionary functional entity (SD-FE)

Semantic dictionary functional entity (SD-FE) provides the functionalities related to the semantic dictionary which has the mapping among synonyms or words in different languages as follows:

– Generate a semantic dictionary by using semantic information provided by DTR-FE;

– Provide semantic information to digital twin discovery functional entity (DTD-FE);

– Maintain the generated semantic dictionary.

8.2.3 Digital twin discovery functional entity (DTD-FE)

Digital twin discovery functional entity (DTD-FE) provides the functionalities related to digital twin discovery as follows:

– Find digital twins matched on a specific condition provided by a digital twin starting the federation;

– Interact with SD-FE to find the proper digital twin;

– Provide the feature information of digital twins found to the digital twin which requested for digital twin discovery.

9 Functions and functional entities of communication adaptor

9.1 Functions of communication adaptor

Figure 4 shows the functions and functional entities of the communication adaptor. The communication adaptor is composed of communication adaptation support functions (CASF).

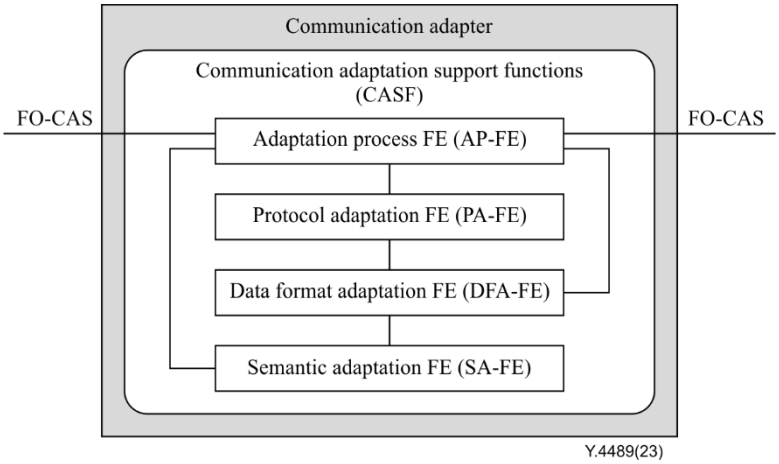


Figure 4 – Functions and functional entities of communication adaptor

NOTE – FO-CAS is the reference point between the adaptation process functional entity (AP-FE) and FC-FE in the FOF in the digital twin.

Table 2 lists the requirements relevant to the functionalities of the communication adaptor defined in [ITU-T Y.4224].

Table 2 – Requirements of communication adaptor's functionalities and relevant functional entities

Requirement ID	Relevant functional entities
FS-REQ-03	Adaptation process functional entity, protocol adaptation functional entity (PA-FE), data format adaptation functional entity (DFA-FE), semantic adaptation functional entity (SA-FE)
CM-REQ-01	Adaptation process functional entity, protocol adaptation functional entity, data format adaptation functional entity, semantic adaptation functional entity

9.2 Functional entities of communication adaptation support functions

Communication adaptation support functions (CASF) interact with the federation orchestration functions (FOF) in a digital twin and provide the functionalities to establish communication among the digital twins which cannot communicate directly caused by using different communication protocols, or different data formats or different semantics.

9.2.1 Adaptation process functional entity (AP-FE)

Adaptation process functional entity (AP-FE) provides the functionalities related to the adaptation process as follows:

– Determine whether the adaptation request from a digital twin is acceptable;

– Process the requested adaptation by interaction with protocol adaptation functional entity (PA-FE), data format adaptation functional entity (DFA-FE), and semantic adaptation functional entity (SA-FE);

– Generate the adaptation status information being activated;

– Maintain the adaptation status information of adaptation including the mapping between the digital twins which will communicate via the communication adaptor, the type of adaptation, etc.

NOTE – The mapping may include the identifier of both digital twins, and the connection information of both digital twins such as the IP address and port number, etc.

– Send the adapted message to the digital twin which is the recipient of the message.

9.2.2 Protocol adaptation functional entity (PA-FE)

Protocol adaptation functional entity (PA-FE) provides the functionality related to the protocol adaptation as follows:

– Conduct the protocol adaptation under the control of AP-FE.

NOTE – The protocol adaptation means that 1) the conversion of the message format of the protocol used by the initiating digital twin to the message format of the protocol used by the digital twin, which is the recipient of the message, and 2) performing the operation of the protocol which each digital twin uses.

9.2.3 Data format adaptation functional entity (DFA-FE)

Data format adaptation functional entity (DFA-FE) provides the functionality related to the data format adaptation as follows:

– Conducts the data format adaptation under the control of AP-FE.

NOTE – The data format adaptation means the conversion of the data format used by the initiating digital twin such as XML to the data format used by the digital twin, which is the recipient of the message, such as JSON.

9.2.4 Semantic adaptation functional entity (SA-FE)

Semantic adaptation functional entity (SA-FE) provides the functionality related to the semantic adaptation as follows:

– Conducts the semantic adaptation under the control of AP-FE.

NOTE – The semantic adaptation is used to align the representations of the initiating digital twin and participating digital twins in order to understand the terminologies used by each other.

10 Functions and functional entities of digital twin

10.1 Functions of digital twin

Figure 5 shows the functions and functional entities of the digital twin. Digital twin is composed of general functions (GF) and federation orchestration functions (FOF).

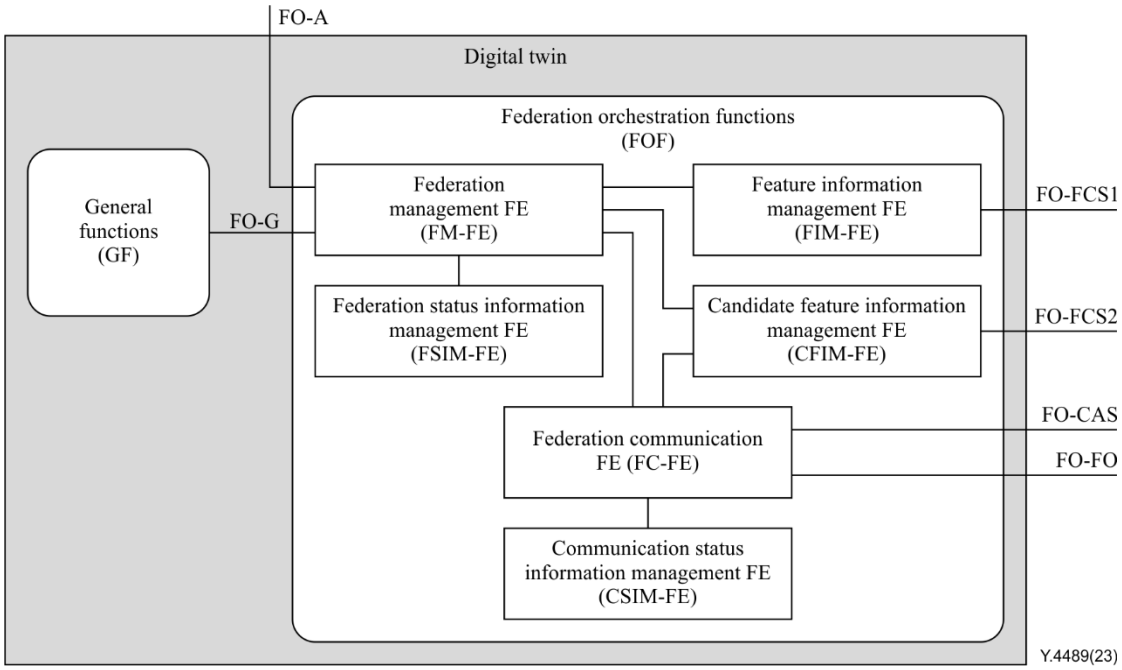


Figure 5 – Functions and functional entities of digital twin

NOTE 1 – FO-A is the reference point between the federation management FE (FM-FE) and a certain functional entity of federated application. FM-FE may have multiple FO-A reference points, if the federated application has multiple functional entities interacting with FM-FE.

NOTE 2 – FO-G is the reference point between FM-FE and general functions. FM-FE may have multiple FO-G reference points, if the general functions have multiple functional entities interacting with FM-FE.

NOTE 3 – FO-FO is the reference point between federation communication FEs (FC-FEs) of digital twins federating.

NOTE 4 – FO-FCS 1 is the reference point between feature information management FE (FIM-FE) and digital twin registration FE (DTR-FE) of the registry, while FO-FCS2 is the reference point between candidate feature information management FE (CFIM-FE) and digital twin discovery FE (DTD-FE), defined in clause 8.2.3, of the registry.

NOTE 5 FO-CAS is the reference point between FC-FE and adaptation process FE (AP-FE) of the communication adaptor.

Table 3 lists the requirements relevant to the functionalities of the digital twin defined in [ITU-T Y.4224].

Table 3 – Requirements of digital twin's functionalities and relevant functional entities

Requirement ID	Relevant functional entities
FS-REQ-01	Feature information management functional entity, candidate feature information management functional entity
FS-REQ-02	Federation management functional entity, feature information management functional entity, candidate feature information management functional entity
FS-REQ-03	Federation management functional entity, federation status information management functional entity (FSIM-FE), Feature information management functional entity, candidate feature information management functional entity, federation communication functional entity, communication status information management functional entity (CSIM-FE)
FS-REQ-04	Federation management functional entity, federation status information management functional entity, federation communication functional entity
FS-REQ-05	Federation management functional entity
FI-REQ-01	Federation management functional entity, feature information management functional entity, candidate feature information management functional entity
FI-REQ-02	Federation management functional entity, feature information management functional entity, candidate feature information management functional entity
FI-REQ-03	Federation management functional entity, feature information management functional entity, candidate feature information management functional entity, federation communication functional entity
FI-REQ-04	Federation management functional entity, feature information management functional entity, candidate feature information management functional entity
FI-REQ-05	Feature information management functional entity, candidate feature information management functional entity
CM-REQ-01	Candidate feature information management functional entity, federation communication functional entity, communication status information management functional entity
SE-REQ-01	Federation management functional entity, feature information management functional entity
SE-REQ-02	Federation management functional entity, feature information management functional entity, candidate feature information management functional entity

10.2 General functions

General functions (GF) are the functions required to offer standalone service which a digital twin is supposed to offer. Thus, this Recommendation does not define any functional entity in the general functions. However, general functions are required to have one or more functionalities to offer their resources, which are data and functions of the digital twin, for the digital twin federation under the control of federation orchestration functions (FOF).

10.3 Functional entities of federation orchestration functions

Federation orchestration functions (FOF) orchestrate digital twin federation from the beginning to the end.

10.3.1 Federation management FE (FM-FE)

To start and orchestrate digital twin federation, the federation management functional entity (FM-FE) provides the functionalities related to federation management as follows:

– Interact with candidate feature information management functional entity (CFIM-FE) in order to discover candidate digital twins to be federated;

NOTE 1 – FM-FE does not need to interact with CFIM-FE, if the predefined members have shared their feature information through some other methods, which is not under the scope of this Recommendation.

– Interact with candidate feature information management functional entity (CFIM-FE) in order to select one or more candidate digital twins discovered;

– Interact with the federation communication functional entity (FC-FE) in order to start communication with the selected candidate digital twins;

– Interact with FC-FE in order to exchange information with the digital twins in the federation;

– Use own data or functions by interacting with general functions (GF) and utilize the data or the result of the functions of other digital twins obtained by exchanging information via FC-FE;

– Provide meaningful data to the federated application;

– Interact with the federation status information management functional entity (FSIM-FE) in order to manage the federation status information including the identifier of the participating digital twins, the data and functions provided by them, and so on.

To participate in a digital twin federation as a participating digital twin and provide data and functions, FM-FE provides the functionalities related to the federation management as follows:

– Interact with FIM-FE in order to register own feature information;

NOTE 2 – FM-FE does not need to interact with FIM-FE, if the predefined members have shared their feature information through some other methods, which is not under the scope of this Recommendation.

– Process the request for data or functions which is received via FC-FE;

– Interact with the GF in order to get the requested data or the result of the requested functions;

– Interact with FC-FE in order to send the requested data or the result of the requested functions to the digital twin that requested the data or function;

– Interact with FSIM-FE in order to manage the federation status including the identifier of the participating digital twins, the data and functions which the digital twin provides, etc.

For both cases, FM-FE provides the functionality related to the federation management as follows:

– Interact with feature information management functional entity (FIM-FE) in order to generate or modify own feature information based on the information obtained from the GF or the federated application.

10.3.2 Federation status information management FE (FSIM-FE)

Federation status information management functional entity (FSIM-FE) provides the functionality related to the federation status as follows:

– Generate the federation status being activated through interaction with FM-FE;

– Maintain the federation status including the identifier of the participating digital twins, the data and functions provided by each digital twin, etc;

– Remove the federation status upon the termination of the digital twin federation.

10.3.3 Feature information management FE (FIM-FE)

Feature information management FE (FIM-FE) provides the functionalities related to feature information management as follows:

– Generate the feature information through interaction with FM-FE;

– Maintain the generated feature information;

– Modify the feature information under the control of FM-FE.

– Interact with the registry in order to register the own feature information of a digital twin under the control of FM-FE.

10.3.4 Candidate feature information management FE (CFIM-FE)

Candidate feature information management functional entity (CFIM-FE) provides the functionalities related to feature information obtained from the registry as follows:

– Interact with the registry in order to discover appropriate candidate digital twins for digital twin federation under the control of FM-FE;

– Maintain the feature information of the candidate digital twins obtained from the registry;

– Interact with FM-FE and FC-FE in order to provide feature information and connection information in feature information, respectively.

10.3.5 Federation communication FE (FC-FE)

Federation communication FE (FC-FE) provides the functionalities related to communication as follows:

– Establish the communication between itself and FC-FE in another digital twin based on the orchestration of FM-FE;

– Interact with CFIM-FE in order to obtain the connection information of the digital twin to be linked;

– Establish indirect communication by interacting with a communication adaptor, if direct communication is not possible;

– Exchange information including data and the result of functions through either direct communication or indirect communication;

– Interact with the communication status information management functional entity (CSIM-FE) in order to maintain or remove the communication status information.

10.3.6 Communication status information management FE (CSIM-FE)

Communication status information management functional entity (CSIM-FE) provides the functionalities related to communication status management as follows:

– Generate the communication status information being activated through interaction with FC-FE;

– Maintain the status information including the identifier of the digital twins communicating with, communication type whether the communication is directly or supported by a communication adaptor, etc.;

– Remove the status information under the control of FC-FE.

Annex A

Operation flows of digital twin federation

(This annex forms an integral part of this Recommendation.)

Annex A describes the operation flows of the digital twin federation in each procedure.

A.1 Feature information registration between digital twin and registry

As the first procedure to participate in the digital twin federation, each digital twin registers its feature information at the registry. Figure A.1 shows the procedure for feature information registration.

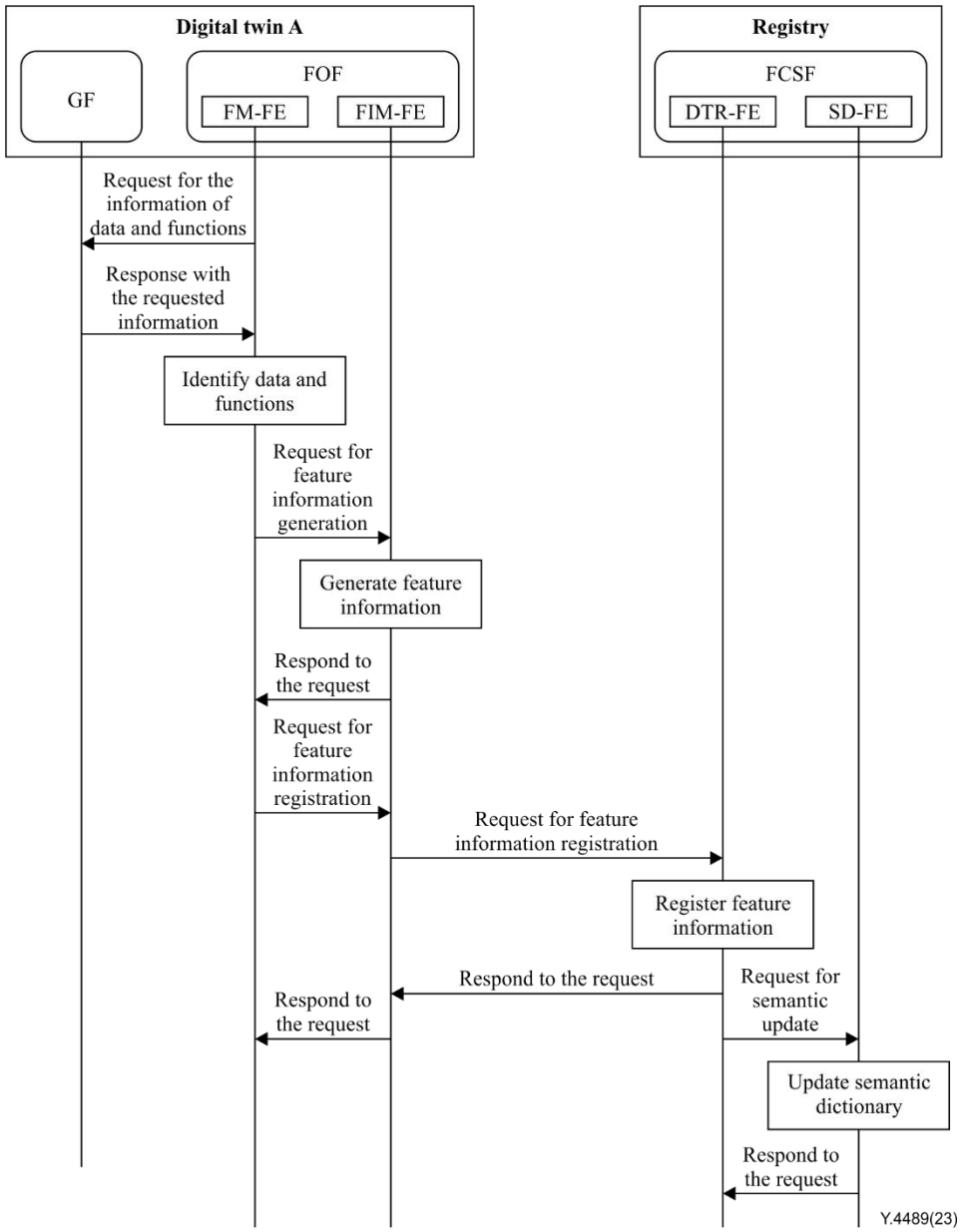


Figure A.1 – Procedure for feature information registration

The description about each step of the procedure is as follows:

1) To register feature information of a digital twin, federation orchestration functions (FOF) generates the feature information by interacting with general functions (GF). FOF requests

GF through FO-G reference point to provide the information of data and functions to be open for digital twin federation. Upon receiving the response, FOF gives the received information to feature information management functional entity (FIM-FE);

2) FIM-FE generates under the control of a federation management functional entity (FM-FE). During the feature information generation, FIM-FE also generates semantic information of data based on the information of the data and it includes the generated semantic information into the feature information. Upon the generation, FIM-FE notifies FM-FE that feature information has been generated;

3) FM-FE interacts with FIM-FE to register the generated feature information;

4) FIM-FE requests a registry to register the feature information through the FO-FCS1 reference point;

5) Digital twin registration functional entity (DTR-FE) of the registry receives the request including feature information;

6) DTR-FE maintains the feature information of the registered digital twin;

7) DTR-FE gives the semantic information in the feature information to the semantic dictionary functional entity (SD-FE);

8) SD-FE updates semantic dictionary;

9) DTR-FE responds to FIM-FE that the requested registration is successfully done;

10) FIM-FE notifies FM-FE of successful registration.

A.2 Feature information registration between digital twins

Different from a digital twin federation using a registry, static digital twin federation can happen with predefined members. In such cases, feature information does not need to be registered in the registry. However, each digital twin needs to generate its feature information and shares the generated feature information through some method which is not under the scope of this Recommendation.

A.3 Candidate digital twin discovery

Before starting the digital twin federation, the digital twin starting the federation needs to discover the candidate digital twins. Figure A.2 shows the procedure for candidate digital twin discovery.

NOTE – If the registry is not used for feature information registration because of having predefined members, the candidate digital twin discovery is not needed.

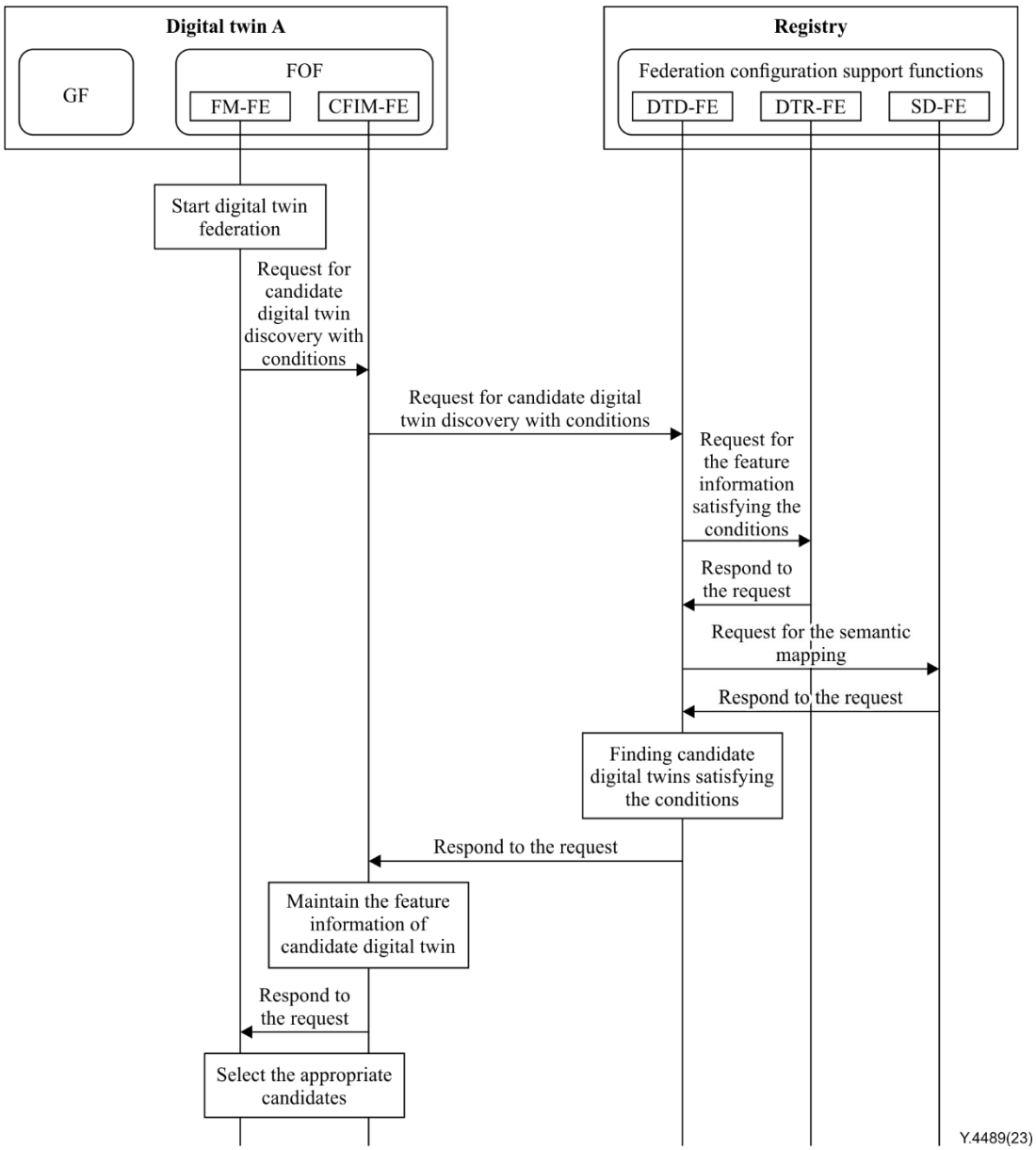


Figure A.2 – Procedure for candidate digital twin discovery

The description about each step of the procedure is as follows:

1) FM-FE starts the digital twin federation under the control of the federated application interacting through the FO-A reference point;

2) FM-FE interacts with CFIM-FE to discover candidate digital twins;

3) CFIM-FE sends a request with certain conditions to the digital twin discovery functional entity (DTD-FE) for candidate digital twins discovery;

4) DTD-FE finds candidate digital twins which matches the conditions by referring to both the registered feature information and semantic discovery which are maintained by DTR-FE and SD-FE respectively;

5) DTD-FE responds with the feature information of candidate digital twins;

6) CFIM-FE notifies FM-FE of the result of the candidate digital twin discovery;

7) FM-FE interacts with the CFIM-FE to select the appropriate candidates. To select the candidates, FM-FE may interact with the federated application through the FO-A reference point.

A.4 Direct communication establishment

The digital twin starting the digital twin federation can establish direct communication with the selected federation members if they use the same communication protocol, the same data format and the common semantic, which is described in the feature information of each digital twin. Figure A.3 shows the procedure for direct communication establishment.

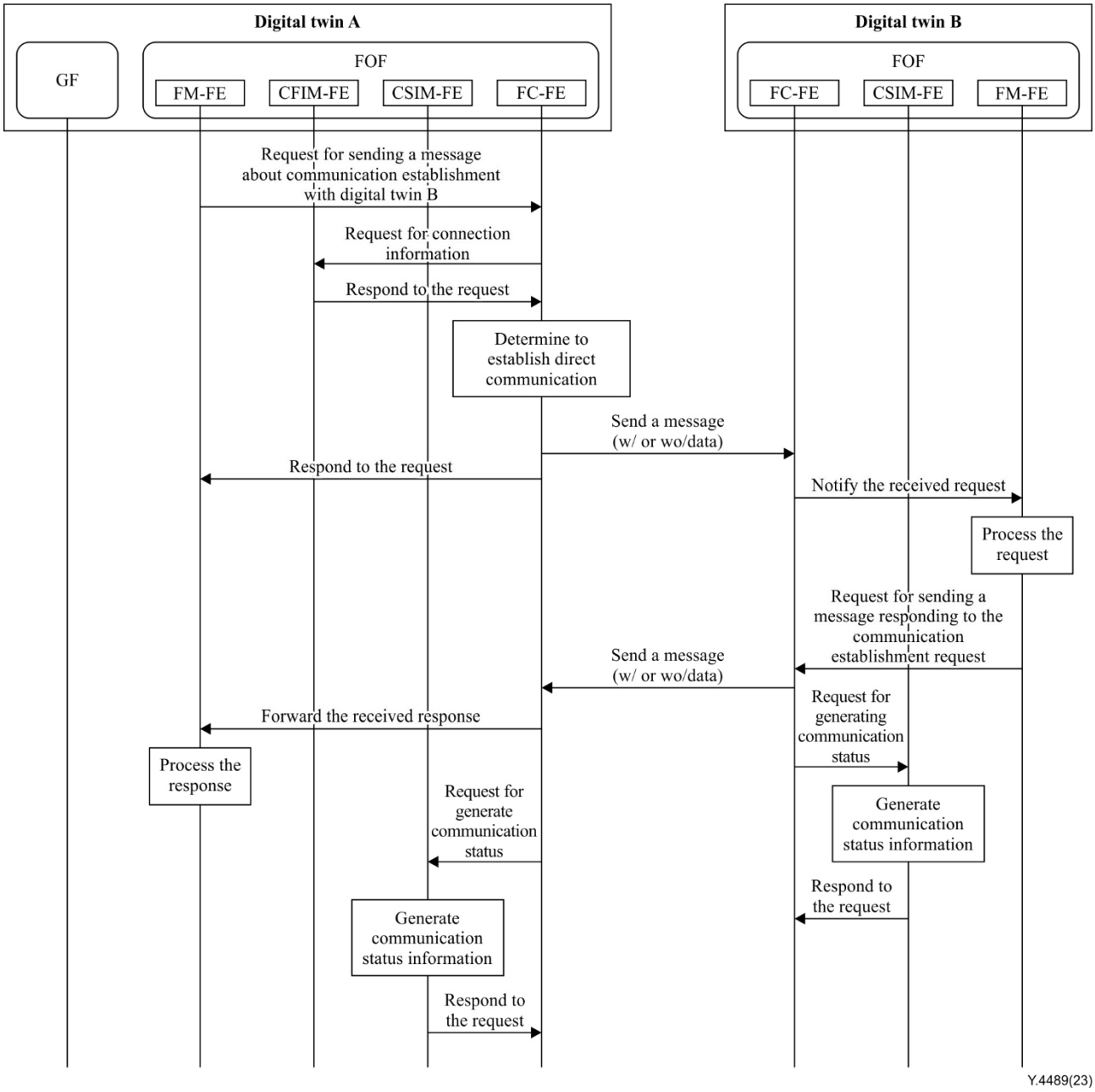


Figure A.3 – Procedure for direct communication establishment

The description about each step of the procedure is as follows:

1) FM-FE sends a federation communication functional entity (FC-FE) request with the identifier of a specific member for communication establishment with the member;

2) Based on the received identifier, FC-FE interacts with CFIM-FE to get the connection information of the corresponding digital twin;

3) FC-FE decides to contact FC-FE of the target digital twin if it confirms that two digital twins use the same communication protocol and data format and the common semantic;

4) Two FC-FEs establish communication by exchanging requests and responses for communication establishment.

A.5 Indirect communication establishment

The digital twin starting the digital twin federation needs to establish indirect communication with the selected federation members if they use different communication protocols or different data formats, which is described in the feature information of each digital twin. Figure A.4 shows the procedure for indirect communication establishment.

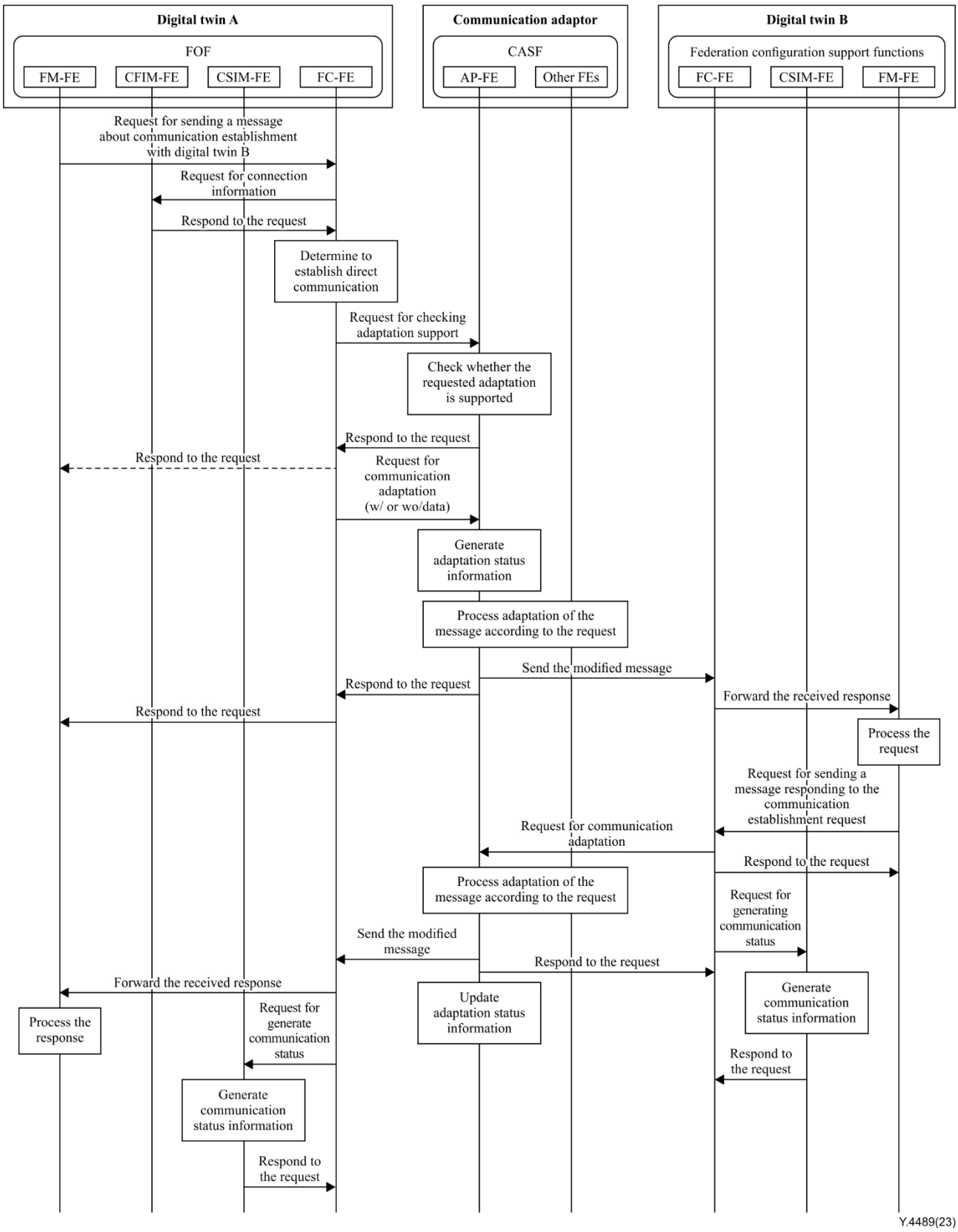


Figure A.4 – Procedure for indirect communication establishment

The description about each step of the procedure is as follows:

1) FM-FE of digital twin A sends a request with the identifier of a specific member to the federation communication functional entity (FC-FE) for communication establishment with the member;

2) Based on the received identifier, FC-FE interacts with CFIM-FE to get the connection information of the corresponding digital twin;

3) FC-FE decides to use a communication adaptor since it confirms that two digital twins use different communication protocols or data formats, or semantics;

4) FC-FE sends the adaptation process functional entity (AP-FE) of the communication adaptor an adaptation request with the information of protocol or data format or semantic which need adaptation;

5) AP-FE checks whether the communication adaptor supports the requested adaptation and responds based on the result;

6) FC-FE sends AP-FE a request for connection establishment;

7) AP-FE processes the requested adaptation and sends FC-FE of digital twin B a processed request for communication establishment;

8) FC-FE of digital twin B receives the request and responds to AP-FE;

9) AP-FE processes the received response and sends the processed response to FC-FE of the digital twin;

10) Two FC-FEs establish communication.

A.6 Direct information exchange

After communication establishment, the digital twin starting the digital twin federation can send its data or request for sending data or the result of the functions. Figure A.5 shows the procedure for direct information exchange.

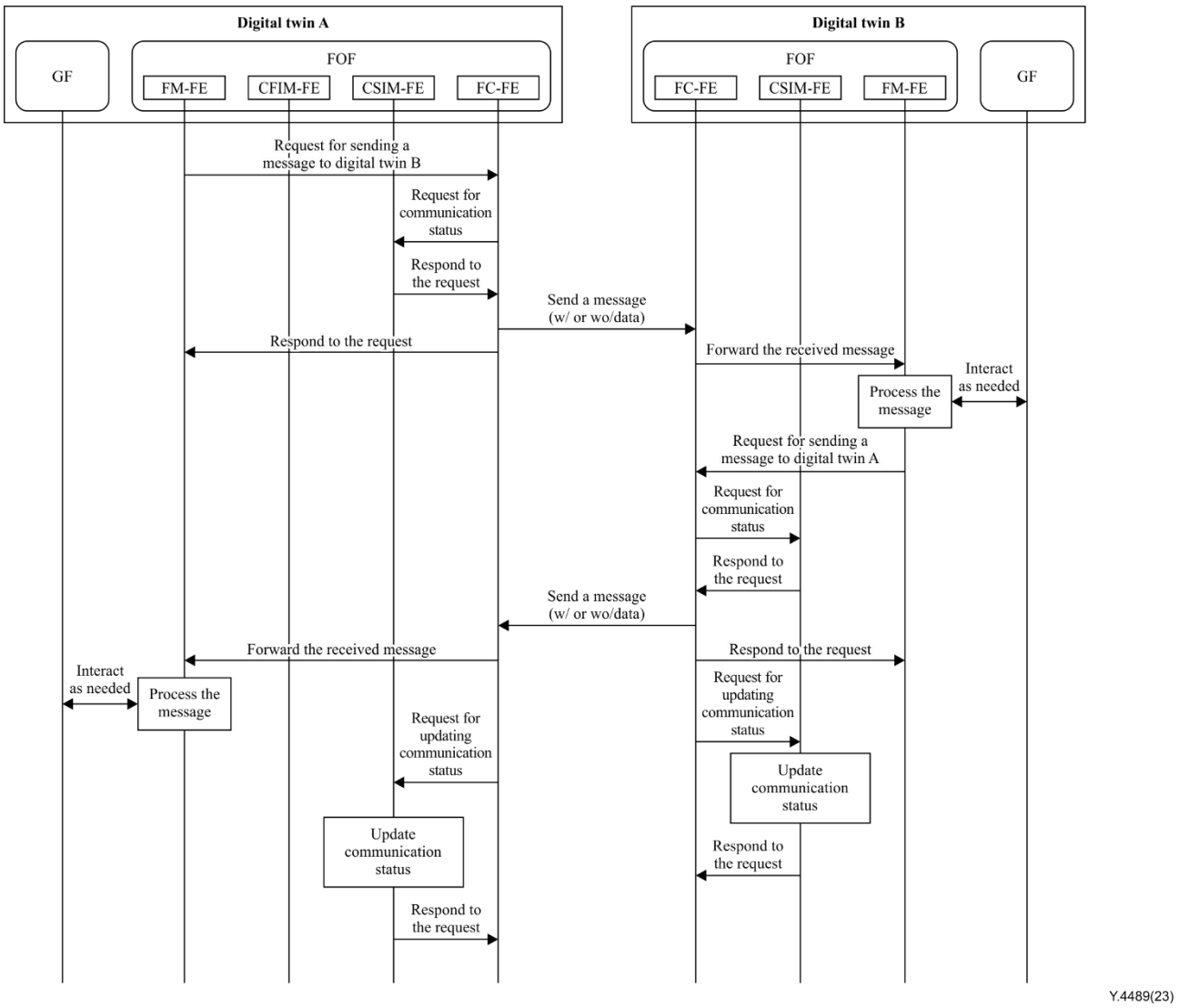


Figure A.5 – Procedure for direct information exchange

The description about each step of the procedure is as follows:

1) FM-FE of digital twin A needs data in digital twin B and it interacts with FC-FE to get the data;
2) FC-FE of digital twin A sends FC-FE of digital twin B a request for the data;
3) FC-FE of digital twin B sends FM-FE the received request;
4) FM-FE of digital twin B interacts with general functions (GF) through FO-G reference point to get the requested data;
5) FM-FE of digital twin B sends FC-FE the requested data;
6) FC-FE of digital twin B sends FC-FE of the digital twin A the requested data;
7) FC-FE of digital twin A sends FM-FE the requested data;
8) FM-FE of digital twin A needs the result of functions in digital twin B and it interacts with FC-FE to get the result;
9) FC-FE of digital twin A sends FC-FE of digital twin B a request for the result of functions in digital twin B. At this step, the request may include input data of the functions to be used;
10) FC-FE of digital twin B sends FM-FE the received request;
11) FM-FE of digital twin B interacts with GF to get the requested result;

12) FM-FE of digital twin B sends FC-FE the requested result;

13) FC-FE of digital twin B sends FC-FE of digital twin A the requested result;

14) FC-FE of digital twin A sends FM-FE the requested result.

A.7 Indirect information exchange

After communication establishment via a communication adaptor, the digital twin starting the digital twin federation can send its data or request for sending data or the result of functions. Figure A.6 shows the procedure for indirect information exchange.

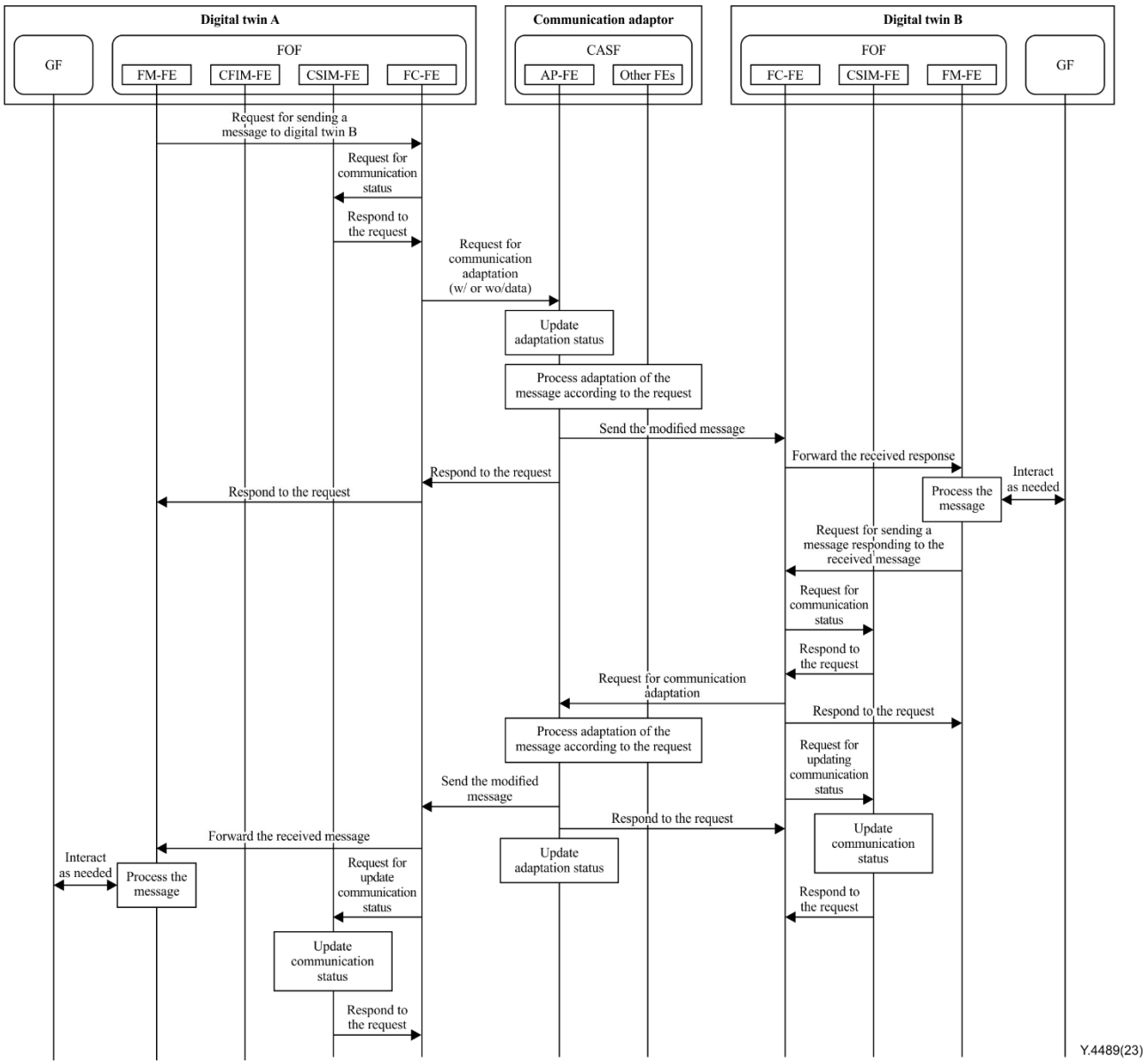


Figure A.6 – Procedure for indirect information exchange

The description about each step of the procedure is as follows:

1) FM-FE of digital twin A needs data in digital twin B and it interacts with FC-FE to get the data;

2) FC-FE sends AP-FE a request for data;

3) AP-FE processes the requested adaptation and sends FC-FE of digital twin B a processed request for data;

4) FC-FE of digital twin B receives the request and sends FM-FE the received request;

5) FM-FE of digital twin B interacts with general functions (GF) through FO-G reference point to get the requested data;

6) FC-FE of digital twin B receives the requested data and responds to AP-FE;

7) AP-FE processes the received response and sends AP-FE to FC-FE of digital twin A;

8) FC-FE of digital twin A sends FM-FE the requested data.

NOTE – The procedure for retrieving the result of functions is very similar to the procedure in clause A.6 except the communication adaptor is involved in the communication between two digital twins. Thus, the procedure is omitted.

Bibliography

[b-ITU-T Y.4600] Recommendation ITU-T Y.4600 (2022), *Requirements and capabilities of a digital twin system for smart cities.*

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	**Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities**
Series Z	Languages and general software aspects for telecommunication systems

Published in Switzerland
Geneva, 2024