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SERIES F: NON-TELEPHONE TELECOMMUNICATION SERVICES

Audiovisual services

Requirements and functional model for a ubiquitous network robot platform that supports ubiquitous sensor network applications and services

Recommendation ITU-T F.747.3

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Recommendation ITU-T F.747.3

Requirements and functional model for a ubiquitous network robot platform that supports ubiquitous sensor network applications and services

Summary

Recommendation ITU-T F.747.3 describes the concept, use cases, requirements and functional model of a ubiquitous network robot platform that supports ubiquitous sensor network (USN) applications and services.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T F.747.3	2013-03-16	16

Keywords

Middleware, network robot system, ubiquitous network robot platform, USN.

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.

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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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Requirements and functional model for a ubiquitous network robot platform that supports ubiquitous sensor network applications and services

1 Scope

The objective of this Recommendation is to define a ubiquitous network robot platform, and to identify its requirements and functional model. The use of standard interfaces for the ubiquitous network robot platform will ensure network robot service reusability, portability across several network robot services, and network accessibility and interoperability by the ubiquitous sensor network (USN).

The scope of this Recommendation includes:

– the concept of ubiquitous network robot platform;

– requirements of the ubiquitous network robot platform;

– functional model of the ubiquitous network robot platform.

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 F.744] Recommendation ITU-T F.744 (2009), *Service description and requirements for ubiquitous sensor network middleware*.

[ITU-T Y.2221] Recommendation ITU-T Y.2221 (2010), *Requirements for support of ubiquitous sensor network (USN) applications and services in the NGN environment*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 sensor [ITU-T Y.2221]: An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic.

3.1.2 sensor network [ITU-T Y.2221]: A network comprised of inter-connected sensor nodes exchanging sensed data by wired or wireless communication.

3.1.3 sensor node [ITU-T Y.2221]: A device consisting of sensor(s) and optional actuator(s) with capabilities of sensed data processing and networking.

3.1.4 service [ITU-T Y.2221]: A set of functions and facilities offered to a user by a provider.

3.1.5 ubiquitous sensor network (USN) [ITU-T Y.2221]: A conceptual network built over existing physical networks which makes use of sensed data and provides knowledge services to anyone, anywhere and at any time, and where the information is generated by using context awareness.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 robot: A device with a processing unit often accompanied by sensors and actuators that can work with real-world phenomena and entities. Robots can be roughly classified into the following three types: visible-type robot, virtual-type robot and unconscious-type robot.

3.2.2 ubiquitous network robot platform: Middleware that enables applications to perform services continuously by combining multiple robotic devices effectively across multiple areas.

3.2.3 unconscious-type robot: A type of robot that mainly senses real-world phenomena and processes measurement results into high-level abstractions. An example of this type of robot is a camera equipped with a processing unit used for detecting people. Unconscious-type robots are often embedded in environments such as roads, towns or rooms, or are hidden in clothes or accessories.

3.2.4 virtual-type robot: A type of robot that mainly processes and utilizes information via a network. Smartphones are examples of this type of robot. Virtual-type robots typically interact with people through audio and visual modalities.

3.2.5 visible-type robot: A type of robot that can be seen and which can take one of several forms such as a humanoid, a pet or a stuffed animal. Visible-type robots interact with people in a combination of verbal and nonverbal modalities such as through a conversation augmented by gestures.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

FDML	Field Data Mark-up Language
FE	Functional Entity
GPF	Global Platform
ID	Identifier
LOD	Linked Open Data
LPF	Local Platform
NGN	Next Generation Network
NRS	Network Robot System
PF	Platform
SOA	Service-Oriented Architecture
UNR	Ubiquitous Network Robot
UNR-PF	Ubiquitous Network Robot Platform
USN	Ubiquitous Sensor Network

5 Conventions

None.

6 Overview of UNR-PF in terms of USN applications and services

6.1 General overview of UNR-PF

Demands for assistance robots are quickly emerging with the increase in elderly population. In recent decades, researchers have been focusing on constructing robots that can interactively support daily human activities. As the structure and functionality of robots grow large and complicated, constructing robots now requires more time, cost and effort. As with traditional software engineering, developers have started to seek modularity and reusability of basic functional components, which has led to research and development of common libraries and middleware. Reusable and modular components allow developers to utilize existing functional modules in combination with their own software and to rapidly develop working robots. This modularized development process has accelerated the development of stand-alone robots as well as individual functional components. At the same time, however, variations in both hardware and software have decreased the reusability of robotic applications.

Another approach to enhance capabilities of robots is the concept called network robot system (NRS) or networked robots [b-Sanfeliu2008]. The main goal of NRS was to integrate various types of devices such as robots, sensor networks and smartphones, so that the whole system could act as an integrated system with enhanced capabilities that cannot be attained by a single robot or multiple uniform robots. Since its introduction in 2002, many research projects have been carried out accompanied with real-world field experiments. These have successfully shown that the concept is effective ([b-Jung2007], [b-Nakamura2008], [b-Tezuka2006], [b-Sanfeliu2010], [b-Shiomi2011] and [b-Salvini2011]).

However, customers need robots to support them in a much wider range of daily activities. Robots for individual household tasks such as cleaning floors or folding laundry are not sufficient. Support for the elderly and disabled in a variety of daily activities is in great demand. Such support requires robots to accompany people to many different places (e.g., homes, shopping malls, hospitals) and to assist people for various activities (e.g., checking health, showing routes, carrying luggage) in ways that differ depending on place and the physical demands of an individual (e.g., wheelchair user). At the same time, these sequences of activities shall be well integrated to provide comfortable and seamless support throughout our daily lives.

Existing robotic systems cannot yet provide such continuous support in various aspects of our daily lives. Although they have had success in enriching capabilities of individual robotic applications, a general framework is missing for adapting behaviours of robots and composing them to form an integrated sequence of applications. Similar concepts can be seen in computer systems, such as service oriented architecture (SOA). SOA provides design principles for constructing large-scale information systems and has been adopted in various middleware stacks, especially in web service systems. In combination with the concepts of grid or cloud computing systems, many commercial services with high dependability are available today. However, these concepts are not sufficient for robotic systems.

The major difference between information systems and robotic systems is where the applications reside. Information system applications reside in cyberspace using information terminals such as personal computers or mobile phones. This is especially clear for web-based systems where applications run through web browsers. Based on the information shown on the screen, users perform actions such as business procedures, travel and cooking. Thus, the actual work in the physical world is left to the customers. This is where the robotic systems with sensor networks start. Robotic systems need to consider various factors in real-world environments, including physical abilities and limitations of both customers and devices. Moreover, as stated previously, a variety of different devices need to be integrated to realize continuous robotic support in our daily lives.

As such, one needs to focus on different kinds of "ubiquity", not just for location but also for various applications and ways of providing each service on the basis of customer attributes, as well as inter-application and inter-location continuity. As the complexity of robotic devices is much higher than that of traditional information systems, abstract, common access methods need to be provided for application programmers and service providers to make the development process easy and highly reusable. A new framework is now required that can bridge the gap between systems that realize the above ubiquity and those that improve and extend traditional robot systems which satisfy such demands. Based on such considerations, an extended infrastructure based on NRS is defined in this Recommendation, the ubiquitous network robot platform (UNR-PF) [b-Sato2011b] and [b-Kamei2012]. UNR-PF combines multiple robots in multiple areas for the support of NGN, USN and their middleware that provide access to sensor networks and portable devices. This concept offers the possibility of providing innovative services promptly and at low lost.

6.2 Relationships between USN and UNR-PF

UNR-PF utilizes USN and USN middleware in two ways: a) as an infrastructure with advanced functionalities such as intelligent routing of messages, and b) as a representative of various sensor networks/nodes. USN may provide connectivity not only to sensors, or unconscious-type robots, but also to robots of the visible and virtual types. UNR-PF can be seen as a middleware for USN applications that provides detailed information and control over USN, such as detailed device profiles, common representation of measurements and an abstract command interface. UNR-PF can also be considered as a higher layer router over USN. UNR-PF selects and allocates appropriate devices to applications. This allocation may change dynamically over time, while the applications do not care or notice the actual changes.

Figure 1 shows the relationship between the open USN service platform and UNR-PF defined in this Recommendation.

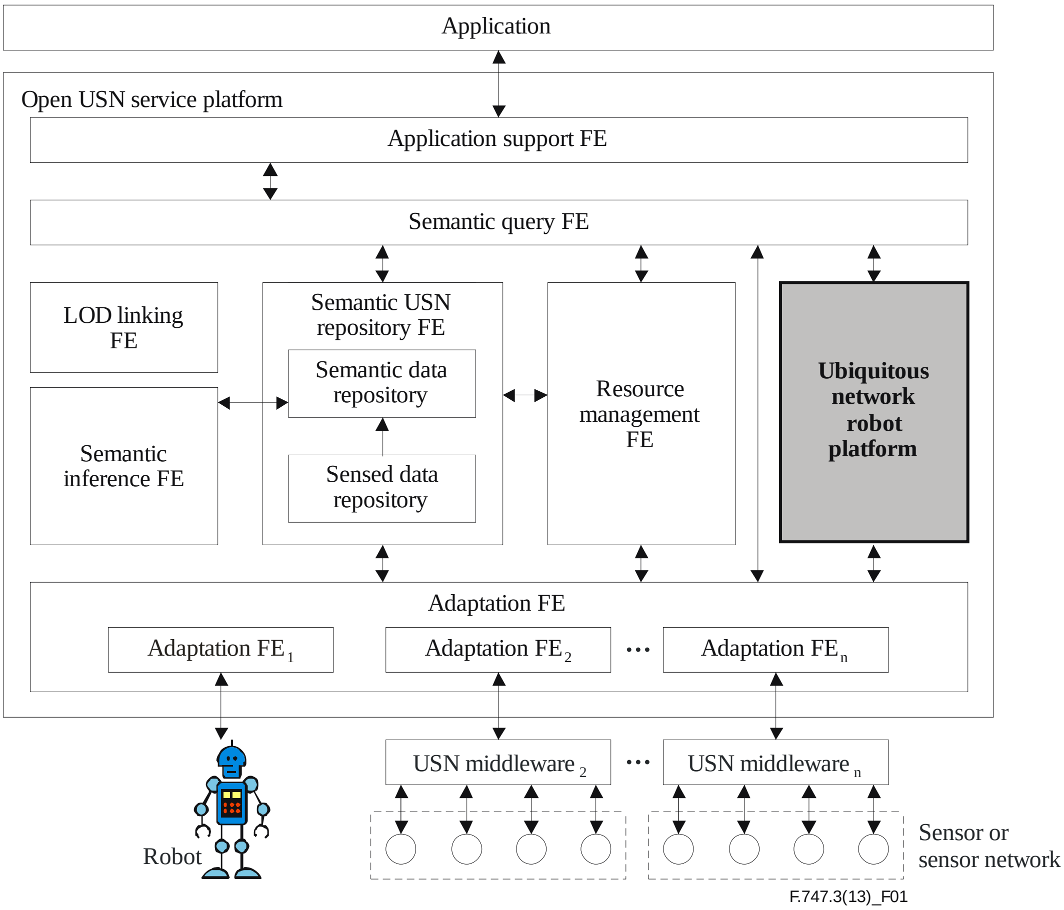


Figure 1 – Relation between open USN service platform and UNR-PF

7 Use cases of ubiquitous network robot platform

7.1 Health support service

A health support service using two different platforms is shown in Figure 2.

In the figure, '1' is an electronic tag attestation platform. A user is registered in an entrance area as the first step. At the same time, disclosure level of user information is set here. The attestation platform discloses customer information to the user according to the user's demand. Next, the user sets up the alarm clock of get-up time in an alarm clock support area. The user can then exercise in the physical exercise area where the user's health condition is checked. A teacher robot gives instructions for the exercise and the assistance robot instructs the user according to the actions performed. The user's health condition is checked by the action recognition unit embedded in the robots. Finally, the user gets the health condition results in the health check area.

This example shows an implementation of two or more cooperative services and one independent service (alarm clock support area) on the network robot platform.

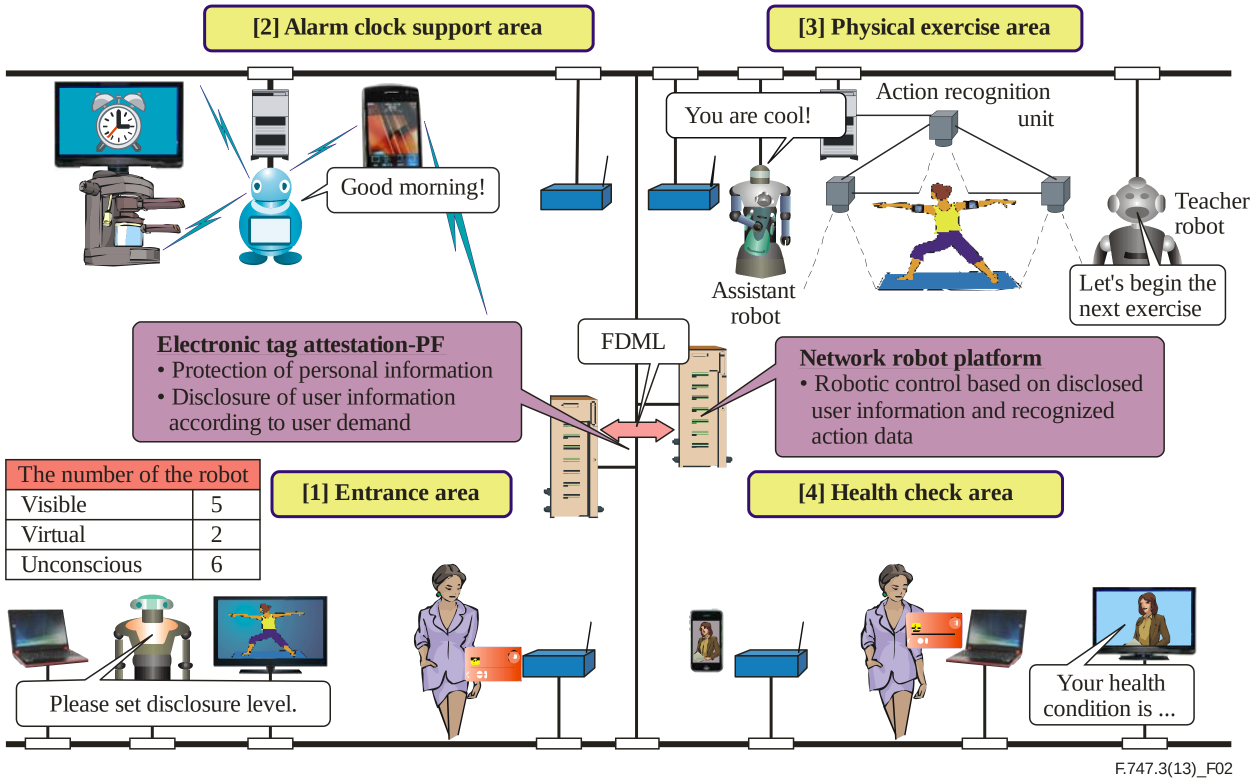


Figure 2 – Health support service

7.2 Shopping support service

The second use case of UNR-PF is shopping support ([b-Nishio2010], [b-OMG2012] and [b-Kamei2012]). Figure 3 shows the overview of the scenario. A typical service scenario is performed across three areas: customer's home (Area 1 in Figure 3), shopping mall (Area 2) and support centre (Area 3).

When a customer feels like going for shopping, he/she first makes reservation of the service using a smartphone. Here, with help from a remote operator, the customer makes a rough plan on what to buy. The operator or the smartphone application may provide the customer with recommendations on things to buy ("fish on sale today") or on where to go shopping ("many customers gave store X a high ranking"). After arriving at the mall, the customer finds that a robot is already waiting for him/her at the entrance. In this example, as the customer has a walking disability, a wheelchair robot is prepared. The customer sits on the wheelchair robot and is guided in the mall so that he/she can purchase the planned items.

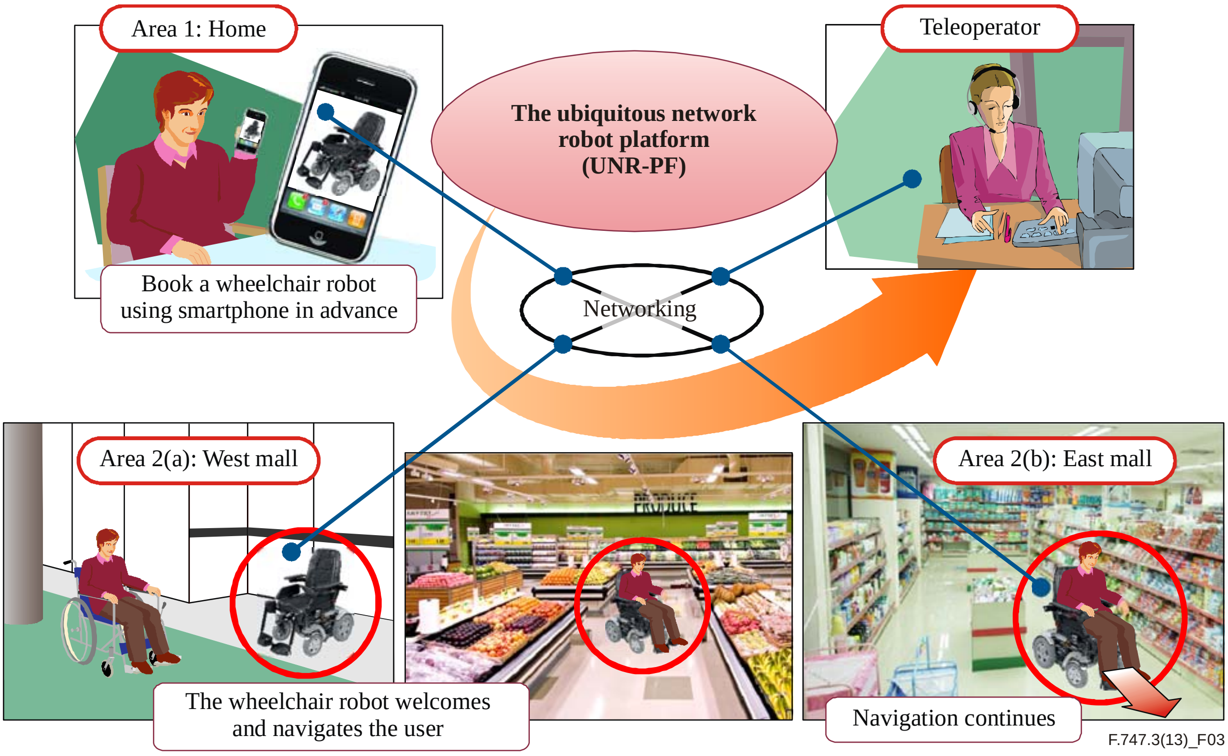


Figure 3 – Overview of the shopping support service

Figure 4 shows the structure and interaction sequence of the service. The customer first makes a reservation via the virtual-type robot on the mobile device at home. The virtual-type robot is connected to the local platform (LPF) installed in the user's home. LPF notifies the global platform (GPF) of the reservation information. The shopping support service application is connected to the GPF and receives the reservation request. After receiving the reservation request, the service application registers its service ID and a trigger condition (the user's arrival at the shopping mall, in the example) to the service queue on the GPF. The GPF refers to its map registry to confirm the LPF of the shopping mall and then registers the service and its starting condition to the LPF's service queue. When the user approaches the shopping mall, the virtual-type robot on the user's mobile device connects to the LPF of the shopping mall and notifies it of the user arrival. Then, the LPF of the shopping mall determines that the state meets the starting condition for the service and notifies the service application of the start via the GPF. Next, the service application requests the resource manager to reserve the robot in the shopping mall and the operator in the support centre via the GPF. To reserve the robot, the resource manager refers to the user registry and selects a suitable robot for the user. In the shopping support service, the resource manager selects a wheelchair robot if the user has difficulty in walking. Otherwise, it selects another type of mobile robot. After the allocation of the resources, the service is executed in accordance with the service flow defined in the service application. The service application refers to the map registry in the LPF and instructs the robot to navigate around the shopping mall.

In the case of a large shopping mall, the shopping support service is provided across several areas managed by different LPFs. When the robot comes close to the boundary between the two areas, the robot notifies GPF's state manager via the state manager of the LPF of the current area. Then, GPF's state manager refers to its map registry to find the LPF of the next area and then registers the service and its trigger condition, i.e., the customer's arrival at the next area or the service queue of the LPF. When the user arrives at the next area, the robot disconnects from the LPF of the first area and connects to the next LPF, if the robot is able to continue working in the next area. Otherwise, another robot in the next area comes to pick up the customer. Thus, the service is executed continuously. In this way, the customer can receive the service seamlessly in a wide area regardless of the area segmentation for the robotic system. When an operator is required, the service application requests the assignment of an operator to the LPF through GPF. The assigned operator will assist the user by remotely taking the user's detailed request and adapting it for the platform.

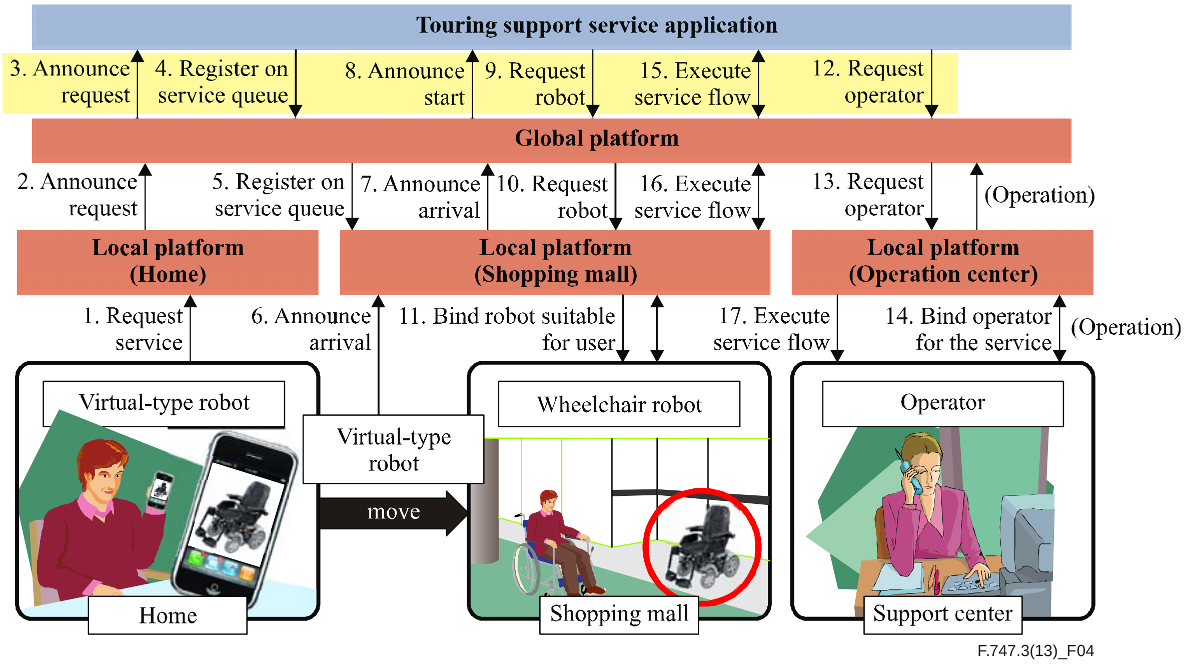


Figure 4 – Overview of the shopping support service sequence

8 Requirements for UNR-PF

8.1 Abstraction of functionality

It is required that UNR-PF provides a standardized and abstracted interface for controlling as well as receiving results from USN nodes. That is, from application point of view, UNR-PF provides access to a set of abstracted functionalities instead of raw USN nodes.

One of the most simple use cases of UNR-PF is collaboration among sensor networks and robots. A sensor network measures phenomena in the real world, notifies them to one or more applications, and then the application commands actuator devices, such as robots and smartphones, to interact with people. Such collaboration may be performed by USN, without UNR-PF, when treating robots as one of the "sensor nodes" with actuator facility. However, by the abstraction of functionality provided by UNR-PF, this can be realized in a much simpler way.

Consider the example shown in Figure 5. Here, based on the sensing result, a person is approaching a dangerous construction area, a robot warns the person. In order to warn the person, a) a mobile robot can approach the person and give a warning, or b) a nearby loudspeaker can warn the person. From the viewpoint of the effect, i.e., to let the person know that he/she is approaching a dangerous area, these two devices perform equivalent services. Dangerous spots change every day. If the application is coded to use a navigation robot and if there are no robots available nearby, the customer would not receive a warning. However, if the application is programmed to utilize the "alert" functionality, then the system would search for a device that can provide such functionality and choose it based on resource availability. This is also useful from the point that applications are not bound to a certain device at the time when it was coded. The application can then continue to provide service without change even though the devices have changed, if they provide the same kind of functionality.

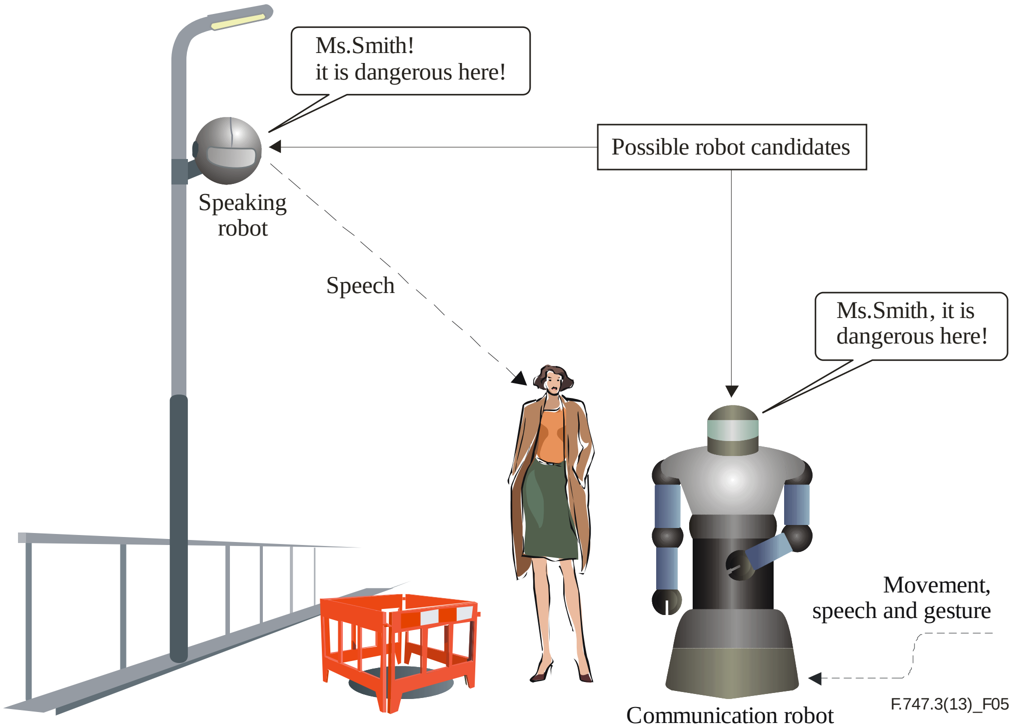


Figure 5 – Service execution by abstracted functionalities

Although the above case focuses on the actuation part, the same concept can be applied for the sensing part. When the sensing functionality is also abstracted, applications can request abstracted sensing functionalities, such as detection of dangerous areas, to the infrastructure, while the actual sensing equipment or sensor network in use may change.

8.2 Inter-service collaboration

It is required that UNR-PF provides functionalities to allow collaboration between different USN applications for realizing compositional applications.

Consider the photo printing service shown in Figure 6(a). This service has two tasks: taking a picture and then printing it out. This represents a simple functional dependency. Robot A possesses the photo taking function while Robot B possesses the photo printing function; they are spatially separated, but linked via a network. To realize this service, the photo printing task can be performed only after the photo taking task. Therefore, the robots need to interact with the customer based on the customer's history.

Another example is a service that guides exhibits in a museum, exhibition hall, etc., as shown in Figure 6(b). The tasks are to explain the exhibit and to guide the visitor to the next exhibit. Given that the visitor is free to visit the exhibits in any order, each robot needs to modify its responses according to the visitor's service history.

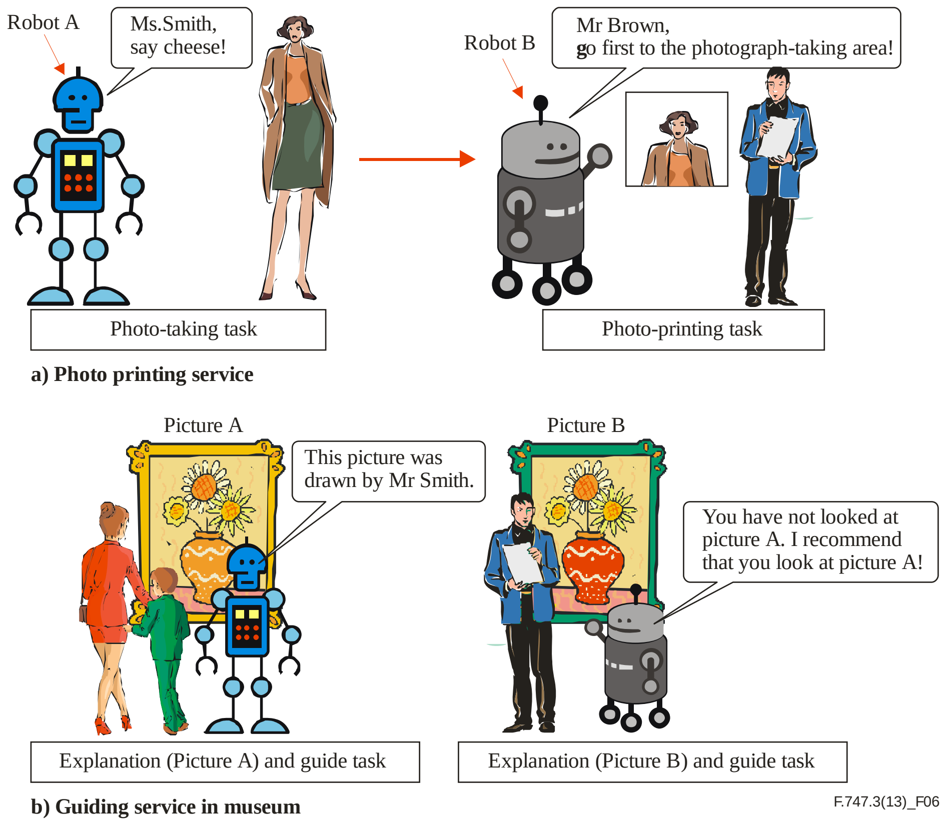


Figure 6 – Inter-service collaboration

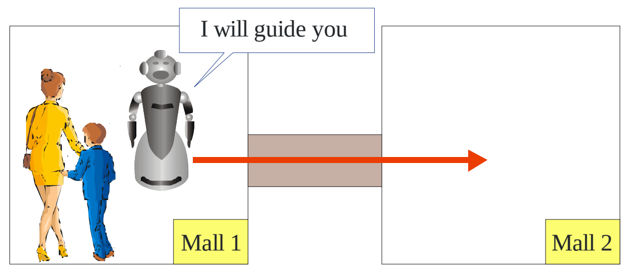
As can be seen from these examples, there are many cases where multiple tasks or applications need to collaborate with each other to provide a consistent service to customers. In some cases, applications from different service providers need to collaborate. In the photo printing service example, photo taking and printing may be performed by different companies. In both situations of Figure 6, the important thing is that the applications share certain aspects of customer history. In the photo printing service case, only photograph data may be exchanged. However, in the museum guidance service, robots may share more detailed information, such as in which point the customer was interested, what kind of questions did the customer ask, or how long the customer spent in front of a Van Gogh painting. In some cases, such information sharing can be performed within frameworks of traditional information system. However, a common infrastructure is needed for sharing information required for affecting human-robot interaction and reflecting it on the behaviour of the robot.

8.3 Service among multiple areas

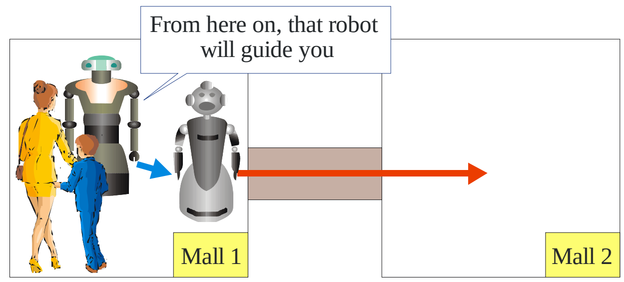
It is required that UNR-PF provides functionalities to allow applications to seamlessly utilize USN nodes in multiple areas.

One of the key aspects in multiple-device collaboration is resource allocation in the spatiotemporal domain. Robots, as well as sensor networks, can only be effective in limited areas due to their physical nature. Sensors can only sense phenomena happening in a limited area, and robots can only serve within a certain area. For example, robots nowadays have a limited navigation capability and suffer interference from obstacles, floor materials and bumps. Battery life is another concern; after a while, robots need to be recharged. Due to these limits, in order to serve people that have much wider area of activity, multiple robots and sensor networks need to collaborate with each other while applications run continuously. For example, consider a navigation service where a robot guides a customer around a shopping mall. Depending on its ability, the robot may not be able to navigate in certain areas such as outdoor corridor between different mall buildings. In such cases, however, the service must continue. Therefore, UNR-PF will perform handover of the navigation act that is necessary for the guidance service (Figure 7). Such handover may occur in different patterns based on the ability of the robot and the resource availability. A similar situation is likely to happen for sensing equipment, such as for localizing or identifying people throughout the mall. When a customer reaches the end of sensing area of one device, UNR-PF searches for other devices that can continue to sense the customer so that the application can continue to receive and utilize sensing results.

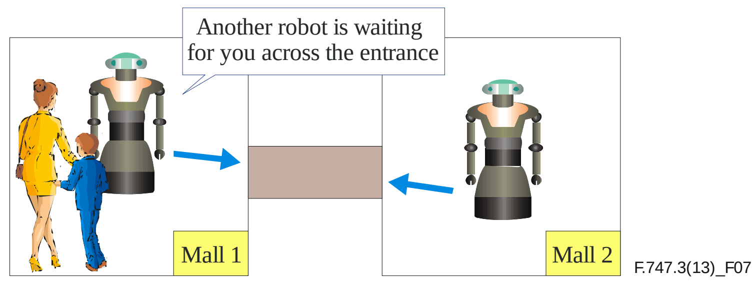
In order to realize a smooth handover between various devices, UNR-PF shall provide rich support so that applications do not need to be concerned about the actual resource availability or the device ability. UNR-PF shall manage various devices not only spatially but also in temporal space in order to effectively allocate them according to application requirements. At the same time, in order to perform effective handovers among devices of various natures and in varieties of areas, UNR-PF needs to manage spatial information as well as specifications of devices. As shown in Figure 8 ([b-Kolbe2011] and [b-OGC2011]), the navigation service is one typical example that clearly shows necessity for such information. In many indoor and outdoor areas, there are places not suitable for robots to move around. This limitation depends on the specifications of robots and of the kind of service the robot needs to perform. Moreover, the spatial nature may change with time. For example, think of a case where a robot guides the user around a station. In mornings and evenings of weekdays there are huge numbers of people passing through during the rush-hour, and thus the corridors become not suitable for robots to move around. But at other hours, the station is less crowded and the robot can easily perform its service. As there are many cases where such dynamic changes occur, the spatiotemporal nature of areas shall be managed and considered by UNR-PF.



a) If the robot is able to navigate all the way, the same robot continues the service



b) If the first robot cannot navigate all the way but there is another robot that can, the service is handled by the other robot



c) If there are no robots that can navigate through the corridor, the service is passed over to another robot at a distant location

Figure 7 – Example of service handover between robots

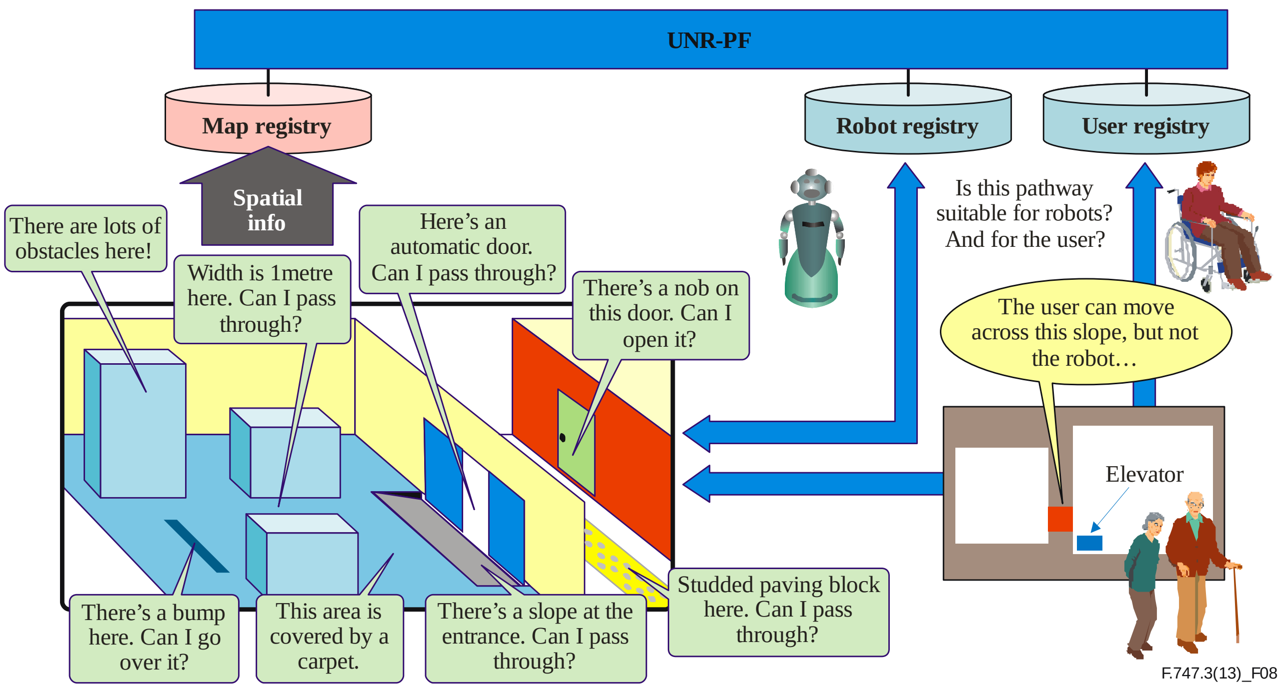


Figure 8 – Spatial information for robot and customer activities

8.4 Service execution based on customer attributes

It is required that UNR-PF provides functionalities for selecting appropriate USN nodes based on customer attributes.

An important requirement for UNR-PF is the selection of devices based on customer attributes. Similar to selecting combination of robots based on spatiotemporal availability and robot ability, UNR-PF also needs to consider customer attributes for its robot allocation planning. As for utilizing general customer tendencies, many data mining algorithms and applications have been built and are now actively in use, such as online stores. In such sites, the application servers "remember" what a certain customer chose in the past and would recommend products that are likely to suit the customers. However, for real-world applications using robots, this is a more serious issue. One case that the UNR-PF handles relates to physical disabilities as shown in Figure 8. If a customer can only walk slowly, the robots also need to slow down. If a customer is troubled by steep inclines, the chosen route should consist of flat paths. When a customer requires a wheelchair to move around, a wheelchair robot or a robot that can push wheelchairs shall be used for application execution. As such, walking ability is one clear example to show why customer attributes are important in planning device allocation for service execution. There are, however, a number of such factors, including visual disabilities or impairment in audition. Based on descriptions for each customer, UNR-PF needs to carefully select appropriate devices to make the customer experience as good as possible.

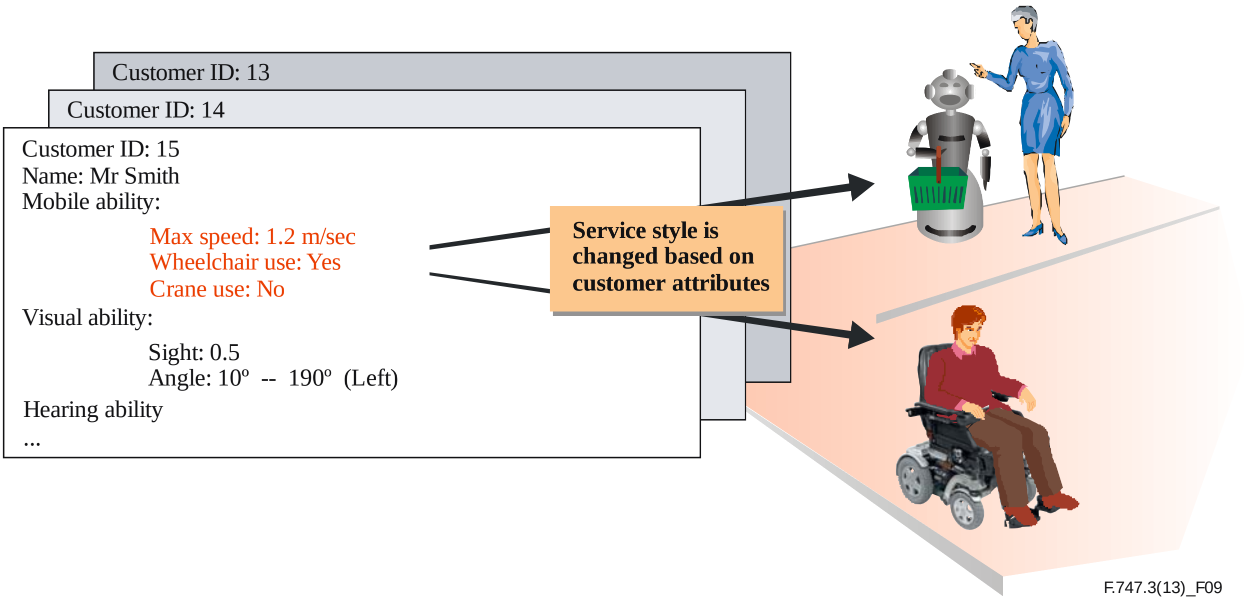


Figure 9 – Service execution based on customer ability

9 Functional model for UNR-PF

A general network robot system consists of three parts as shown in Figure 10:

1) Robot service applications
2) UNR-PF
3) Robotic functions

The first robotic function consists of robot service applications that define flow of the service contents, and are typically held and maintained by service providers, using the common interface that UNR-PF provides. The third robotic function consists of various robots that are dedicated to specific capabilities and registered to UNR-PF through the common interface.

The second robotic function is UNR-PF, which is the subject of this Recommendation, which establishes the interaction between the service applications and the robots. The functional model of UNR-PF is shown in the dotted part of Figure 10. This UNR-PF has two layers: the lower layer consists of reusable functional modules that belong to individual robots, and the higher layer manages logic for service contents.

The UNR-PF should be independent of and serve common functions to the other two parts. Once such a common platform is developed and is stable, it will separate robotic functions and services so that the whole robotic system can be developed at lower cost and become more dependable in terms of reusability, scalability and availability.

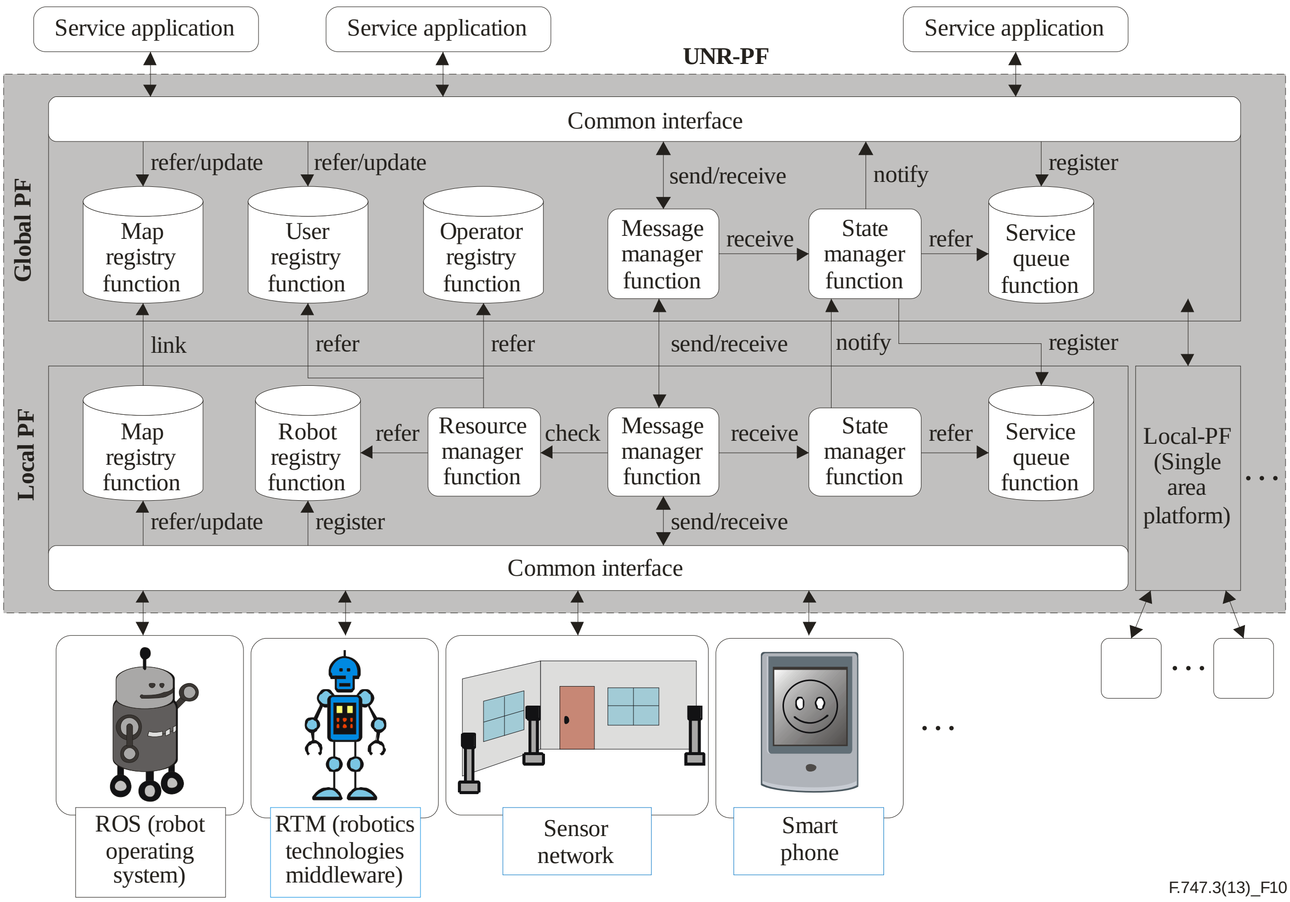


Figure 10 – Functional model of UNR-PF

As such, UNR-PF serves as middleware between services and robotic devices and is composed of two layers of network robot platforms: a local platform (LPF) and a global platform (GPF). LPF is a platform for configuring the robotic system in a single area. GPF is a platform for configuring the robotic system in a wider range of areas that includes a number of LPFs. These platforms serve as a middle-layer between robot service applications and robotic functions. The platform has five database functions and three management functions. The database functions consist of robot registry, operator registry, user registry, map registry and service queue. The management functions consist of a state manager, resource manager and message manager. Each function is detailed below. Refer to Figure 4 in clause 7.2 about concrete message flows among three parts.

UNR-PF contains several registries (database) for managing attributes for robots, operators and robotic service users. These are used for selecting appropriate robots and/or operators on the basis of each user's demands.

9.1 Robot registry function

The robot registry contains information about the robots available in each area, such as their shapes and capabilities as well as their statuses. In addition, functionalities that each robot provides, such as navigation, people detection or face recognition, are stored in the registry as functional profiles. These pieces of information show what kind of service a certain robot can perform, what kind of route the robot can navigate, and whether the robot is available now or in the near future. From this information, UNR-PF can decide what device to allocate for a certain application.

9.2 Operator registry function

Operators for tele-operation of robots are managed in the operator registry. Such operators are often necessary to compensate for the artificial intelligence limitations in the robot. In UNR-PF, operators are treated as one kind of robot. The same selection mechanism works for the operators on respective service application demands based on the information stored in the operator registry.

9.3 User registry function

The user registry holds attributes on each customer who wishes to receive robotic support, as well as a history of services that the customer has used. From these pieces of information, UNR-PF can allocate the robots and operators necessary to provide certain services.

9.4 Map registry function

The map registries in both LPF and GPF are used to improve the linkage between different areas. The map registry of the LPF contains spatial information of the service execution environment, such as the properties of the floor and information about movable zones and keep-out zones. The map registry of the GPF contains the positional relationship among single areas.

9.5 Service queue function

The service queue is a function implemented in both LPF and GPF. This function is used to manage the start of the service. This database contains IDs of the services and their initiation conditions. At first, the service application registers its ID and initiation condition to the service queue in the GPF and the state manager in the GPF registers the ID and condition to the service queue in the appropriate LPF in accordance with the state notification from the LPFs.

9.6 State manager function

The state manager is implemented in both LPF and GPF. This function subscribes to the message manager for the state notifications that are registered in the service queue. When receiving the state notification, the manager determines if the state complies with the start conditions in the service queue. If the state complies with the start condition, the manager sends a message to the service application to start the service.

9.7 Resource manager function

The resource manager is implemented in LPF. When receiving the command message for executing a service application, the resource manager refers to the robot registry, the user registry and the operator registry and reserves the robot suitable for the customer and the operator who can operate the service depending on the situation.

9.8 Message manager function

The message manager is implemented in both LPF and GPF. This function manages the messages exchanged between the service applications and the robotic functions through the common interface. The robotic functions provide the profile of available messages to the message manager.

When receiving the message from the service applications, the message manager refers to the profiles and selects the robotic functions that fit the service application requirements. In LPF, the message manager requires the resource manager to reserve the necessary resources. When receiving the message, i.e., the state notification from the robotic function, the message manager checks the delivery addresses, which are given at the time of the state notification subscription, and forwards the message to the appropriate state manager and/or the service applications.

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