Research and Development of Very Large-scale Information Sharing Network Technologies

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In this chapter, the research and development activities, which are related to the 'Very large-scale information sharing network' technologies, are roughly introduced. The activities are part of a project called New-Generation Network (NWGN) project that aims to provide a platform for advanced future ICT services for human's daily life utilizing network-connected 'things' such as sensors or devices.

1 Introduction

Development of wireless and wired network technologies and device technologies has enabled network access for small 'things' such as sensors, mobile-terminals and embedded devices for which it had been difficult in the past to give them such capabilities. In such environment, there are growing expectations for realizing Internet of Things (IoT) services, in which things distributed in the real world interact with online services, to provide advanced ICT services closely involved in people's daily lives.

There are active efforts to realize IoT services, such as R&D projects for platform technologies for IoT services, standardization activities from the aspect of machine to machine (M2M) communications, etc. In March 2012, an organization called oneM2M[1] was established, in which standardization groups of Japan, USA, Europe, China, Korea, etc., participate. The aim of oneM2M is to establish end-to-end communications specifications for M2M. At the ITU-T, in an organization called IoT-GSI[2], there are active discussions on standards needed for global IoT deployments. The U.S. NSF has been funding the R&D issues of achieving Cyber-Physical Systems (CPS), which are services and systems that link cyber space created via online services to information from sensor networks in the physical space. In the EU, many companies and research institutes are participating in an industry-driven program called FI-PPP[3] that aims to establish infrastructure construction technologies for smart services; they published the results of the program, such as FIWARE[4] which provides FI-PPP related functional elements called 'generic-enabler.' In Japan, there are research and development projects on ubiquitous networks which the Ministry of Internal Affairs and Communications had funded until 2010 as the u-Japan policy. The Information Explosion Project of the Ministry of Education, Culture, Sports, Science and Technology also treated similar issues.

However, there are various technical issues for practical implementation of IoT services. In the large-scale environments where a huge number of things connect to networks and huge amounts of data is generated, it is especially a big issue to achieve ICT services that search for and connect to communication targets, process data obtained, and notify user terminals within a realistic period of time and processing load. Analysts forecast that 50 billion terminals and trillions of sensors must be accommodated in the networks[5][6] in the near future. We must consider how to treat vast numbers of things on ICT services.

Aiming to solve such issues, the authors have been involved in an R&D project called "very large-scale information sharing network" that handles a huge number of diverse nodes on distributed networks and establishes base technology for future IoT services as a part of the "New-Generation Network Project[7]" that aims to improve the Internet in a clean slate approach.

This chapter describes the very large-scale information sharing network technology project.

2 Function elements of very large-scale information sharing network platform

The Internet basically assumes that services and users are connected end-to-end on the network, which is a so-called client-server, centralized architecture. However, to achieve a network of things that could handle a huge number of accommodated objects, distributed architecture is necessary to achieve a scalable and efficient network, in which various devices and terminals operate autonomously and process data on shared processors with optimal data transfers. Figure 1 shows the structure and functional elements of a very large-scale information sharing network. Each functional element is described below.

2.1 Provision of virtualized IoT services

To achieve efficient IoT services, the service providers must flexibly allocate functional elements of various IoT services, to devices and terminals distributed on the network.

Since the small things have restricted computing resources and data storage volume, utilization of abundant computer resources and various kinds of data in the cloud is necessary to execute complex data processing for applications such as precise optimization and forecasts, in addition to the data exchanges and processing on things. In the cloud architecture, the locations of computing resources could be far from the physical places where applications services are provided. Therefore, there could be a problem of large communications delays. In the existing cloud systems, the locations of computing resources that are assigned for a service are basically fixed. Hence, it is difficult to achieve applications which must perform actuations that require very small response time or appropriate timing control to display information or send control commands to the terminals or things in the real world. Moreover, if observation data sent from sensors is processed on the cloud, then when a large number of sensors are utilized by an application service, huge traffic could be concentrated on the cloud server or on the route to reach the cloud server. However, only a small part of the traffic is actually meaningful for data utilization in actuation services; the great majority of the traffic is useless.

To solve this issue, there has been a proposal for "hierarchical cloud architecture" that sets up computing resources which are located physically close to the terminals or users on the network to execute part of the process (a hierarchical cloud). By a hierarchical cloud, if the storage and computing resources are located close to the terminals or users, we can expect reduction of communications delays and response time. Also, by executing an information filtering process on the computing resources located near terminals or users, we can limit the uselessly generated traffic on the route to the cloud.

On the other hand, in IoT services, there are great needs for securing confidentiality in each service. To avoid concerns of attacks such as traffic interception, it must be possible to set up policies not to share a network with other services. Also, even without malice, we must consider failures and misconfigurations, which generate unplanned data traffic and network malfunctions.

Considering these issues, networks of IoT services need to be highly customizable to flexibly allocate functional elements and need to have independent data traffic separated in each IoT service.

The authors have developed JOSE (the Japan-wide Orchestrated Smart/Sensor Environment), as a platform that provides functional elements as a service

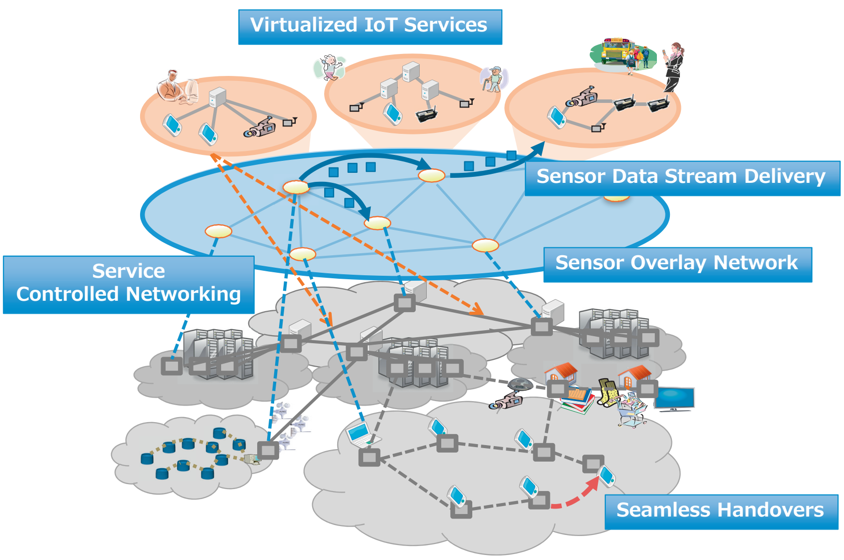

Fig. 1 Functional elements of very large-scale information sharing network platform

on virtualized networks for IoT services (IoT services platform). JOSE is a sort of Infrastructure as a Service (IaaS) specialized for IoT services. By using JOSE, IoT service providers can configure IoT services by reducing the investment costs for physical computers and network facilities, and can provide customizable and independent services. For details on JOSE, see **7-2**.

2.2 Sensor overlay network

One of the promising network technologies that can handle huge numbers of nodes (devices and terminals on the network) with great scalability is *structured overlay network* technology. Many structured overlay network protocols have been studied. Well-known protocols include Chord[8], used in Distributed Hash Tables (DHT) and Skip Graph[9]. These protocols enable nodes to search or disseminate data on nodes with a small number of hops, such as O(logN) hops (or less) for N nodes. Many of such protocols assume P2P networks in which user terminals participate in the network as nodes. Therefore, they have mechanisms that can maintain the structure even if nodes frequently join and leave the network.

To achieve a platform of large scale information sharing networks that handle huge numbers of devices, the authors propose PIAX[10][11] and its implementing technologies as a platform of "sensor overlay networks" based on self-organizing range search P2P technology.

As an example of a sensor overlay network by PIAX, a sensor information sharing platform called JSF (JOSE Sensing Foundation) is implemented on JOSE. The details of JSF are described in **7-2**. As a basic technology of sensor overlay networks, we are studying a method to construct a structured overlay network that considers the distances between physical networks. The details of this method are described in **7-3**.

2.3 Sensor data stream delivery

In the advanced IoT services, we must assume that a sensor can be used for multiple purposes, not only one purpose. For example, video data taken by a camera near a river can be sensor data, but in addition, by analysis processing, it could be used by multiple applications: to investigate water levels, investigate weather, investigate bridge traffic volume, etc. Sensor data is basically generated periodically, and some applications need to obtain the data as a stream, that is, each time data is generated, the application processes the data. At that time, depending on the application, the cycles of required sensor data could differ, and applications need to treat multiple different cycles of streaming data using the smallest possible resources.

For multiple IoT services to share one sensor, the authors have been involved in R&D on P2P type sensor data stream delivery systems that treat different cycles of sensor data into multiple data streams and deliver sensor data to multiple terminals with different applications. Those results are described in **7-4**.

2.4 Dynamic control of networks by services

In IoT services, we also need to assume that the amount of computing resources assigned to the applications changes according to events occurring in the real world. For example, in a weather forecast application that executes simulation when there is rainfall and does not do any processing when there is no rainfall, the amount of computing resources changes according to the rainfall status phenomena. Along with the changes in the amount of computation resources, the amount of data transferred on the network also changes. Changes in the amount of data can cause network congestion especially when there is a bottleneck link in the network. In that case, to maintain the data transfer performance, appropriate network route changes are needed. In the New-Generation Network Project, there is an R&D project for a mechanism to control networks in IoT services dynamically according to the changes in requirements occurring due to events in the real world, called Service Controlled Networking (SCN) project. The details of SCN are described in **7-5**.

2.5 Seamless handover

On the Internet, to specify the communication target node, IP addresses are used. The IP address specifies the location on the network for communications. In IoT services, a problem occurs when actuations are needed for mobile nodes or devices that move and change location and IP address. Even changes in the communication media for wireless access network can occur, depending on the node. For example, the communications media can change from Wi-Fi to short distance wireless. However, upper layer applications do not want to worry about the changes in IP addresses and communication media to actuate mobile nodes. To satisfy such requirements, a unified seamless interface is desirable to be provided on the network.

Thus, in the New-Generation Network Project, for applications to seamlessly handle mobile nodes such as mobile sensors and actuators, we have been involved in R&D on a new network function which uses the mobile node's identifier, instead of specifying the IP address of a mobile node, for specifying communication targets, which we call HIMALIS. HIMALIS enables continued communication with actuators regardless of the terminal's location through seamless handover. The details of HIMALIS are described in **7-6**.

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