Ubiquitous Korea Project

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1 Introduction

This chapter consists of four sections. Each section introduces a major project related with ubiquitous computing technology which has been conducted by Korean government. In the second section, we introduce UCN (Ubiquitous Computing Network) project in which service convergence solutions have been developed to design and manage human-centered composite services. In the third section, we introduce a project on intelligent service robots in ubiquitous environment. The fourth describes several projects related with ubiquitous health. Finally, we introduce a project which focuses on the architecture of USN (Ubiquitous Sensor Network) technology for nation-wide monitoring.

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2 Ubiquitous Computing Network

2.1 Project Overview

UCN(Ubiquitous Computing & Network) is the long-term governmental R&D project supported by the Ministry of Knowledge Economy of Republic of Korea. It has begun in 2003 and continues for 10 years. For it Korean government invests $139.5 million. It envisions “realization of Ubiquitous Smart Space for life care” and aims at developing core fundamental technologies based on Community Computing and system solution in a well-being and safety domain.

2.2 Vision: Ubiquitous Smart Space(USS)

UCN has designed USS as a technological architecture of knowledge-based u-society. USS is the user-centered convergence space which fuses physical, virtual and logical space to provide goal-oriented services. It is characteristic of situation awareness, autonomic collaboration, and self-growing. In USS users can achieve own goal by autonomic collaboration among computing entities and services become optimized continuously by learning the change of situation and process.

2.3 Reference System Architecture and Deployment of USS

Fig. 1 and Fig. 2 depict reference system architecture and deployment of USS, respectively.

2.4 R&D Strategy

To achieve the above vision UCN has 4 strategic approaches.

- Multi-disciplinary research to analyze social and economic needs and develop u-Services in a coming society
- Concentration of core technologies: intelligent system components, smart objects, and service convergence platform
- Evolution of Intelligence level with a view of situation awareness, autonomic collaboration, and self-growing
- Enhancement of technology competence through collaborating with global network

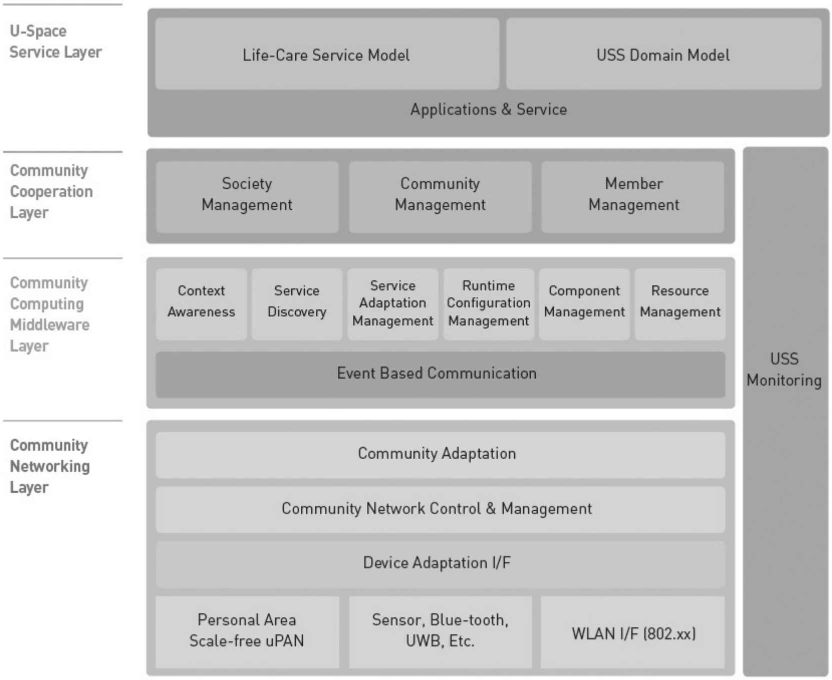

Fig. 1 Reference Architecture of USS

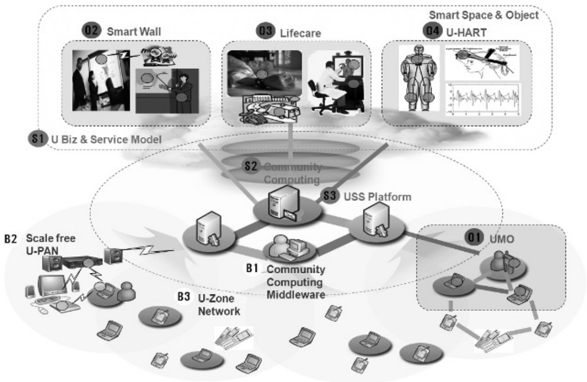

Fig. 2 Deployment of USS

2.5 Actual Results

UCN has attained strong actual results with a passionate effort and strategy since 2003. As of 2007 it delivered 489 papers, 235 patents(domestic and overseas), 7 technology transfers and 39 prototypes.

2.6 Sub-projects

UCN has four categories of project as follows.

Categories	Research theme
System Design & Integration	S1a: UCASE(Space Engineering) Technology which makes it possible that directs the space rapidly and corporately which can be handled by users through applying pre-provided space contents or following the pre-defined space composition. S1b: U-Commerce, U-Media, U-Finance Value Improved and Privacy Enhanced Economic Activities in Ubiquitous Environment by using seamless communication. S2: CDTK(Community Development Tool Kit) It can generate USS services based on communities consisting of computing elements. S3a: USPi(ubiquitous smart space Platform Initiative) The u-system platform which supports development of index-based, situation-aware and autonomous converged services for human life care. S3b: Well-being Life Care System It calculates unconstrainedly well-being index from activities of daily living(ADLs) and provides life care services to prevent Metabolic Syndrome. S3c: Intelligent System for Public Safety The public safety system which supports context-aware and secure management of various dangerous situations with public infrastructure such as CCTV.
Middleware	B1a: Intelligent middleware platform based on context-aware agent Intelligent middleware platform providing users with context-aware services using intelligent context-aware agent. B1b: Group-Aware Software Infrastructure for Heterogeneous Multiple Smart Spaces - High performance context management for user and user group - Dynamic service reconfiguration supporting user mobility and collaboration - Continuous service interaction for heterogeneity and self evolving - Scalable semantic service discovery considering group context.

Smart Objects	O1a: UMO(Ubiquitous Mobile Object) Framework It could provide the most suitable service to customer with sharing resource and context. Final goal is to develop S/W stack and H/W platform for UMO. O1b: CAMAR(Context-Aware Mobile Augmented Reality) Companion It augments personalized contents and enables users to share the contents with others through their mobile devices. It manages users' contextual information and visualizes personalized contents over mobile devices. Moreover, it enables users to attach their contents to physical objects and to share the contents with others in CAMAR communities. O2: SMeet(Smart Meeting Space) System It supports efficient and easy collaboration with large and heterogeneous network displays reflecting users' intention. O3: Personalized Well-being Life Care Service To promote well-being life it manages physical disease and mental stress levels by analyzing the user's biological information. O4a: A high-tech human activity recognition system based on integrated WSN It performs robustly and accurately human activity recognition and reasoning in wide complicated environment by integrating Visual Sensor Network(VSN) and Wearable Sensor Network(WSN). O4b: Smart Object interactive human activity sensing device It stores the activity data which uses the small-sized sensor with radio. This data will be able to analyze a momentum.
Networking	B2: Environment-adaptive Scale-free uPAN It varies the data rate(20Kbps - 400Mbps) and transmits parameters according to environment change. B3: Intelligent Equipment (u-Zone Master) and OS for u-Zone Community Network It is self-constructed satisfying requirement(self-configuration, optimization, quality) of community members without internet infrastructure.

2.7 Test Bed

UCN holds a test bed which is equipped with system integrated platform and smart objects. It shows a future life focused on intelligent well-being and safety services by life index and is located in Ajou University.

3 Intelligent Service Robots in Ubiquitous Environment

3.1 Introduction

Intelligent service robot project is one of the ten next generations driving forces in industry selected by Korean government in 2003. The project is being progressed through 3 stages over ten year period to 2013. By the year 2013, it aims to produce household service robots with which we can live together. For the past five years, the focus has been on securing core technology and building foundatation for the intelligent service robot. Development of intelligent service robots is characterized by the demand for integration of various technologies including artificial intelligence, intelligent human-robot interactions, and the ubiquitous network [23]. One of the key technologies we have developed for this grand project is an intelligence integration technology to ease the immense complexity of integrating numerous components and information as one consistent unit.

An intelligent service robot in ubiquitous computing environment interacts with human and environment to provide services for the user using its sensors and manipulators. As an intelligent system, the robot needs to adapt to changing environment and the quality of the services is to increase over time. Such a robot is a complex distributed system as it asynchronously interacts with various elements in the environment using its sensors and manipulators. Furthermore the robot itself consists of multiple components on distributed computers to provide enough computing power for real-time requirement. As well as the integrated control of distributed functional components, an effective integration of data or information in the robot is also crucial for consistent and synergetic interoperation of the components. Without proper organization of control and data for both internal and external components and orderly interactions with the environment, the overwhelming complexity of the intelligent system would deter effective integration into a unified system.

The complexity of the intelligent service robot can be managed by proper level of abstraction. Abstraction is the key to cope with the complexity and heterogeneity of intelligent service robots in ubiquitous environment. Although the complexity remains same, abstraction allows developers to focus on a few important concepts by factoring out details. Abstraction provides a perception of simplicity to the developers so that developers can conceptualize at a high level and design large complex systems like intelligent service robots.

Abstraction in general can be classified into *control abstraction* and *data abstraction*. Control abstraction is the abstraction of actions while data abstraction is that of information or knowledge. The result of control abstraction is often represented as a framework while data abstraction as an ontological data model.

In this article, we present an agent-based control framework based on the traditional three-layer robot architecture [10] to provide appropriate level of *control abstraction* enabling integration of knowledge and functionalities for intelligent service robots. The framework is designed borrowing the core concept of the service-oriented modeling [3] and model-driven architecture [14] to provide *data abstraction* in terms of ontological definition of shared knowledge. In the following sections, we first motivate our approach to control and data abstraction for an intelligent service robot and present the framework with design rationales with experimental results.

3.2 Task and Knowledge Management Framework

Comprehensive range of diverse functionalities and unavoidable complexity in developing intelligent service robots call for a unified but simple control of the functional components. The diverse functionalities include recognition, speech understanding, manipulation, expression, navigation, reasoning, decision making, planning, and so on.

The most important lesson learned from the past five years of development of intelligent service robots is the significance of the framework to handle the complexity of integration.

Our framework is designed based on the following observations about an intelligent service robots.

- Intelligent system: An intelligent service robot is by definition is an intelligent system. According to Erman [7], intelligent systems (1) pursue goals which vary over time, (2) incorporate, use, and maintain knowledge, (3) exploit diverse, ad hoc subsystems embodying a variety of selected methods, (4) interact intelligibly with users and other systems, and (5) need to be introspective and aware of their progress in applying their knowledge and subsystems in pursuit of their goals.
- Heterogeneous system: An intelligent service robot consists of multiple functional components that are heterogeneous in terms of implementation languages and platforms.
- Distributed system: The components and information to be integrated as an intelligent service robot may be distributed over multiple, typically single board computers, to satisfy the required processing power and timeliness and to properly handle parallel and layered activities.
- Evolving system: The performance goals for an intelligent robot system are continually increasing in complexity.

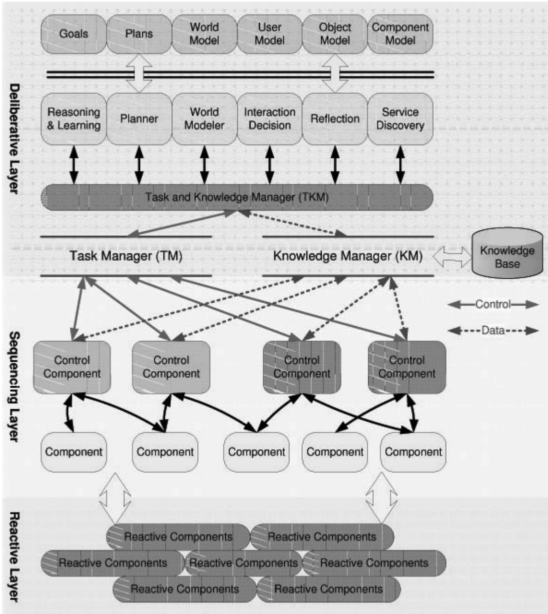

Fig. 3 Task and Knowledge Manager(TKM) in the deliberative layer of the underlying three-layer robot architecture consist of two parts: The Task Manager(TM) provides interface to the Control Components in the sequencing layer for a consistent and unified *control* view to the functional components. Knowledge Manager(KM), on the other hand, provides *data* interface as an information integration framework so that the distributed and heterogeneous components may share information and interact consistently.

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Our basic control abstraction is based on the three-layer architecture [10] which consists of three components: a reactive feedback control mechanism (reactive layer), a mechanism for performing time-consuming deliberative computations (deliberative layer), and a reactive plan execution mechanism (sequencing layer) that connected the first two layers (Fig. 3.2). These components run as separate computational processes as this is essential for three-layer architectures. In addition to the control abstraction provide by the three-layer architecture, we developed simplified abstract control interface reflecting the characteristics of intelligent service robots as identified as an intelligent, heterogeneous, distributed, and evolving system (see Section 3.5).

Our architecture is basically a knowledge-based architecture for integration of both control and information as shown in Figure 3.2. The agent-based *Task Manager* (TM) works as an integration middleware and provides a consistent and unified control view for the functional components which may be distributed over a network. *Knowledge Manager* (KM) provides an abstract interface, called Knowledge Source, to a common data repository for the distributed components so that they can share information or knowledge. The common data repository is designed based on the blackboard architecture model [2, 7, 4].

3.3 Task Manager

As shown in left-hand side of Figure 3.2, *Task Manager* resides in the deliberative layer of the underlying three-layer robot architecture and provides abstract control interface to the *Control Components* in the sequencing layer.

Control Components are components which are designed to interact with the Task Manager. Robot software components implement the functionalities required for the intelligent robot to perceive, reason, and acts. These components may be assembled as needed to build a Control Components which has an interface to interact with the Task Manager. Several Control Components can run at the same time. Task Manager may `start`, `stop`, `supend`, and `resume` the exeuction of Control Components as shown in Fig. 4. Control Components, on the other hand, can send information on local events anytime asynchronously to the Task Manager using the `notify` interface and query Task Manager to get information from the Task Manager.

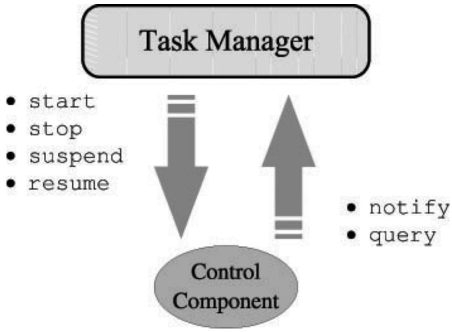

Fig. 4 On the other hand, CC can `notify` the TM to send events asynchronously to TM. CC can also `query` TM to get information from the TM.

3.4 Knowledge Manager

As mentioned in the previous section, Task Manager(TM) provides a consistent and unified *control* abstraction for the functional components. Knowledge Manager(KM), on the other hand, provides a consistent and unified *data* abstraction for components of the system. Knowledge Manager works as a framework for integration of information to be shared among the distributed and heterogeneous components of an intelligent service robot. Our Knowledge Manager is designed based on the blackboard architecture model [2, 7, 4]. In this model, a group of specialists, called Knowledge Sources(KSs), interact using blackboard as the workspace, or a global database containing all information to be shared among Knowledge Sources. The data on the blackboard thus need to be formalized for Knowledge Sources to understand and to be simple enough for efficient accessing and matching operations among the Knowledge Sources. To meet these requirements, we use the generalized-list expression (GL-Expression). A GL-expression is a predicate consisting of a predicate name and the associated parameters in the form of `(predicate-name p1 p2 ...)`, where the parameters `p1 p2 ...` can be a value, a variable, or another GL-expression.

For the purpose of establishing a framework for data abstraction, we also created our own interface for KSs and interaction protocols upon the basic blackboard model as illustrated in Fig. 5.

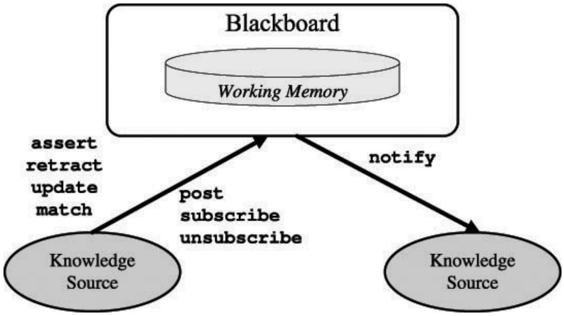

Fig. 5 Knowledge Source interface includes abstract data operations such as `assert`, `retract`, `update`, and `match`, and event operations such as `post`, `subscribe`, and `unsubscribe`. Blackboard can `notify` the occurrence of the subscribed event to the Knowledge Source.

A Knowledge Source interacts with other Knowledge Sources only through the blackboard. The blackboard in our Knowledge Management Framework provides the following abstract data interfaces for Knowledge Sources to access the blackboard.

- `assert` asserts a fact in the form of the generalized list.
- `retract` retracts a fact that matches the generalized list.
- `update` replaces the matched fact with a new fact.
- `match` find a fact on the blackboard that matches the given generalized list to get bindings for the variables in the generalized list.

In addition to the data operations, Knowledge Source also can interact with other Knowledge Source using *event operations* through the blackboard.

- `post` operation raises an event to the blackboard. The posted event is then delivered directly to the Knowledge Source that have subscribed on that event.
- `subscribe` operation is used for Knowledge Source to subscribe on an event. When the subscribed event occurs, the blackboard *asynchronously* notify the associated Knowledge Sources to release Knowledge Source from the burden and overhead of polling the blackboard to find out the occurrences of particular events.

3.5 Service Agent

Control abstraction and data abstraction can be further generalized to higher-level interface, that is, agent-level interface. Most agent interactions employ message-based protocol such as KQML [8]. The protocol ensures coherence of interaction by imposing constraints to the communicated messages. In order to provide an agent-level abstraction, we developed the notion of service agent that has message-based agent interaction and ontological domain model to provide the intended services as shown in Fig. 6.

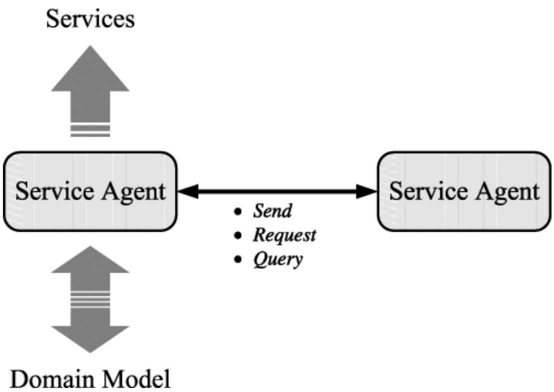

Fig. 6 Service Agent (SA) provides data abstraction by the explicit domain model and control abstraction by agent-level interaction using an agent communication language. The type of agent communication includes `send` to send any information to other SA, `query` to query information from other SA, and `request` to ask other SA to complete the goal.

The notion of service agent enables us to build an open intelligent system in that each service agent has explicit model and specification of functions and information. The explicit model defines schema, instances, and services ontologically. Explicitness of the model allows us to incorporate new services into the system dynamically and to ease the complexity of integration for intelligent service robots. Abstraction at the agent-level provides data abstraction by explicit domain model and control abstraction by agent communication language.

The overall relationship between Control Component, Knowledge Source, and Service Agent are depicted in Fig. 7. The basic unit to implement the functionalities of an intelligent service robot is Control Component. Control Component uses KS interface to access the shared knowledge in the blackboard, and SA interface to become a Service Agent interacting with other Service Agents.

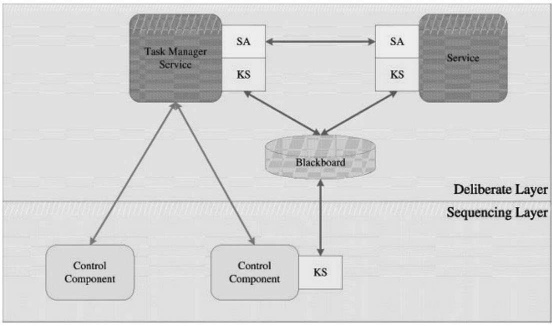

Fig. 7 Control Component in sequencing layer is the component that has the control interface with Task Manager. Knowledge Source has an data interface (KS) to the blackboard, a shared place for information. Service Agent has an agent interface (SA) to interact with other Service Agents.

3.6 Results and Conclusion

As an integration framework, Task Manager has been deployed to the developers in the Intelligent Robotics Development Program, one of the 21St Century Frontier R&D Programs funded by the Ministry of Commerce, Industry and Energy of Republic of Korea. As an framework for control abstraction, the effectiveness of Task Manager has been experimentally proven. *T-Rot*, a bartender robot, at the IT exhibition at the 2005 Asia-Pacific Economic Corporation (APEC) summit is an example.

In order to efficiently experiment with Knowledge Manager and Service Agent along with the Task Manager, we also developed a simulator Fig. 8 and conducted experiments for various errand tasks that are appropriate for the intelligent service robots.

The experiment results are satisfactory in that the abstractions provided by Task Manager, Knowledge Manager, and Service Agent together resulted in effective design and implementation of intelligent service robots as an open, evolving, distributed, intelligent system in ubiquitous environment. In summary, our framework for intelligent service robots provides following features.

- Control and data abstraction over three-layer robot architecture using the blackboard-based asynchronous interaction model.
- Simple high-level abstract interactions using the request- and query-protocol in the Service Agent.
- Flexible ontological message-based interface for both control and data abstraction

In this paper, we introduced an integration framework to support both control and data abstraction through the agent-based Task Manager/ (TM) and blackboard-based Knowledge Manager/ (KM). While the Task Manager works as a middleware to provide a consistent and unified *control* abstraction for the functional components, our Knowledge Manager provides a consistent and unified *data* abstraction through a common data repository for the distributed components in a robot. Service Agent utilizing the control and data abstraction accomplishes agent-level abstraction. We

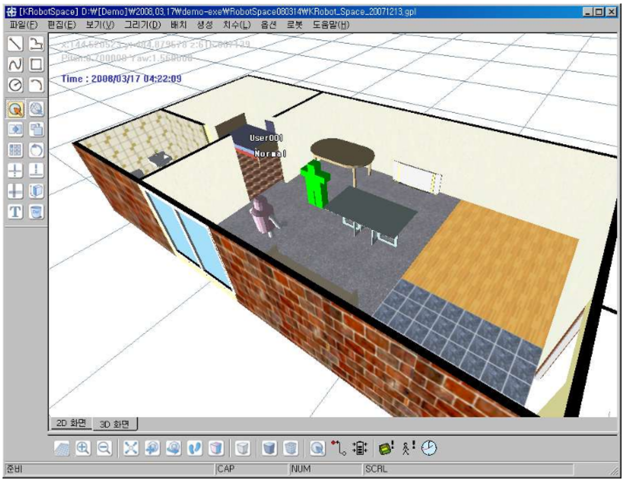

Fig. 8 A user and an intelligent service robot interact in the simulated ubiquitous environment. In real applications, the simulated environment may reflect the real world and could be used as an interaction media where the user can designate the object to fetch and lay out steps to follow to complete the task.

believe that our abstraction framework will effectively serve the purpose of coping with complexity of intelligent service robots.

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4 U-Health Projects in Korea

4.1 Concepts of u-Health

A consensus on the definition of ubiquitous healthcare (u-health)is not yet available. The distinctions from similar terms such as telemedicine, telehealth, e-health, tele-monitoring, and mobile health are somewhat unclear. U-health can be roughly defined as "an intelligent system that enables health and medical services to be provided to consumers anytime and anywhere by making use of sensing, information, and communication technology." The extensions of time, space, providers, consumers, and services are key characteristics of u-health (Fig. 9).

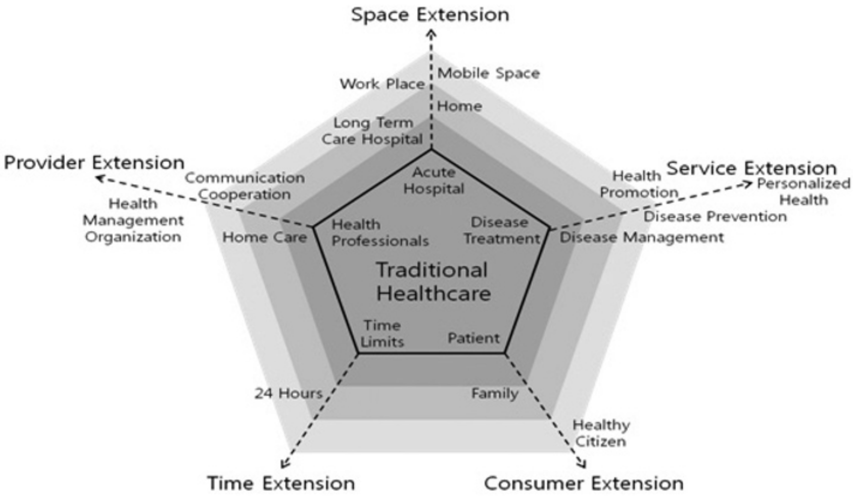

Fig. 9 Scope of u-health. Source: Modified from SW Kang, Samsung Economic Research Institute. CEO information 602, 2007.

4.2 Why u-Health?

The acute rise in national medical expenditures is accelerating, especially due to factors such as aging and chronic diseases. Building a cost-effective medical system is in international interests. National health insurance reimbursements for the elderly have been increasing abruptly, from 18.0% at 2000 to 26.8% at 2006 (National Health Insurance, 2006, 2007). National health insurance reimbursement for diabetes was 168 million USD at 2000, however, 280 million USD at 2005.

There have been changes in medical demands due to increasing incomes and the resulting increase of interest in health. Proactive health consumers, rather than passive patients, are increasing the demand for various health services. The Korean annual per capita medical expenditure of 303 USD in 1997 increased to 830 USD in 2004 (2006, OECD). In 2000, the annual outpatient visits per person was 10.8 days at 2000; however, that has increased to 14.7 days per year. In addition, the annual days of hospitalization per person increased to 1.33 days in 2006 from 0.88 days in 2000 (National Health Insurance, 2007).

Nevertheless, people living on islands or in remote places have difficulty obtaining medical service. The quality of medical service for them is still low. Therefore, there is a strong need for the government to restrain rising national medical expenditure and increase the cost-effectiveness of medical and health services throughout the nation.

Korea's telecommunication infrastructure is known to be well-established. The broadband penetration rate and mobile communication infrastructure of Korea rank among the top in the world (Fig.11). The hospital information system penetration rate is also high (Fig.12).

From the health industry's point of view, the purpose of the various u-health projects in Korea is to study and develop u-health service models integrating various technologies [WLAN, WiBro, HSDPA(high-speed data packet access)]; set up commercialization plans for u-Health service models by testing their technological and business feasibility; pursue the development of relevant industries and balanced

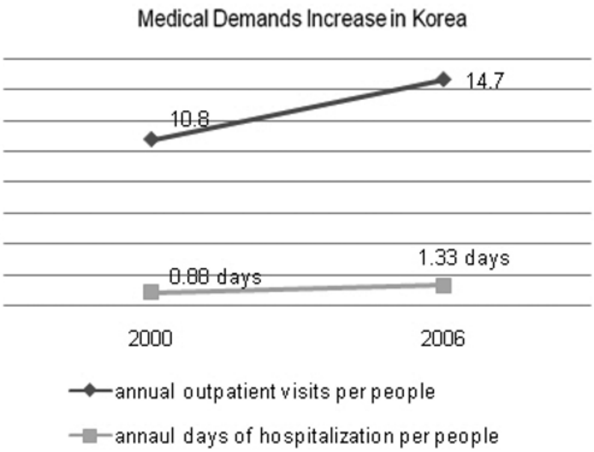

Fig. 10 Change on health service usage in Korea 2000-2006. Source: National Health Insurance Corporation, Republic of Korea, 2007.

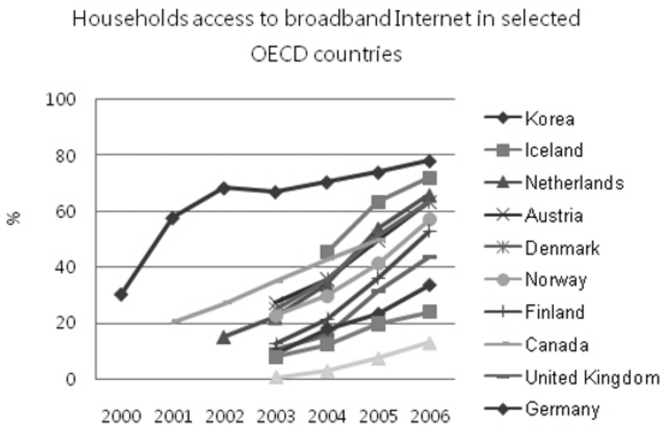

Fig. 11 Households access to broadband Internet in selected OECD countries. Source: Modified from OECD, DSTI/ICCP/IE(2007)4/FINAL

regional development by attracting the participation of medical centers, medical companies, communication service providers, and local governing bodies; create a new IT market; and facilitate technology development.

4.3 U-Health Projects in Korea

There were 54 projects related to u-health in Korea between 1998 and 2007. Thirty were still ongoing until 2007. (Ministry for Health, Welfare and Family Affairs, 2007). Medical practice through telemedicine is rare in Korea, as medical law allows telemedicine to only be practiced between doctors. Therefore, most of the past pilot projects mainly focused upon health counseling or consultations between doctors for second opinions (Fig.13).

Some selected subjects of the u-health pilot projects in Korea include tele-PACS, telemedicine, emergency care services, ADHD (attention deficit hyperactivity disorder) screening services using Actiwatch, factory environment and workers' health status monitoring services, remote health monitoring services for the elderly living alone through infrared sensor and power consumption monitoring, mobile health monitoring through wearable shirts, diabetes monitoring services using mobile phones, RFID-based drug management systems, and visiting nurse systems. Some of them will be briefly described

- Wearable computer-based health monitoring service, 2006, Daegu City: A mobile vital sign monitoring service using wearable shirts. The heart rate, respira-

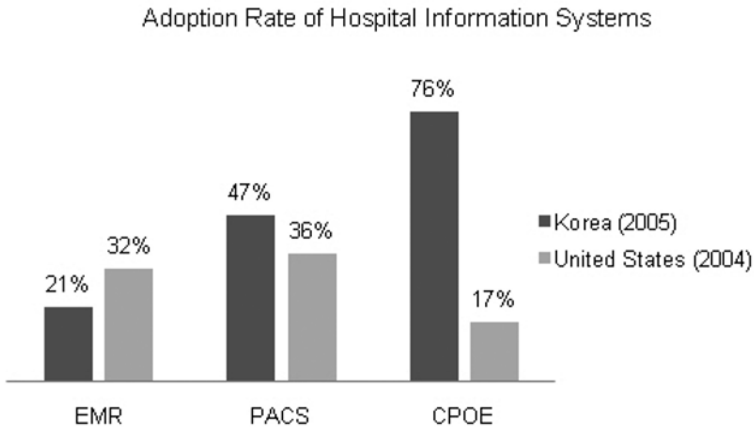

Fig. 12 Adoption ratio of hospital information systems. Source: Health Insurance Review and Assessment Service (HIRA), 2005; RAND, 2005

tion rate and actinography of the subjects in motion were remotely monitored in real-time.

- Mobile diabetes monitoring service: A diabetes management service. A patient can measure his or her blood glucose level continuously by using a glucometer-equipped mobile phone (diabetes phone). The results are transmitted to a central server though CDMA communication. His or her physician evaluates the change in patients' glucose level. The results of evaluation are fed back to the patient. Significant improvements were observed in the HbA1c of the subjects.
- RFID-based u-drug information sharing system pilot project, 2006: A 6-month pilot project funded by the Ministry of Information and Communication to facilitate transparent and efficient drug logistics, manage medicine history, guarantee genuine products, and prevent adverse drug events. The total budget was about 0.7 million USD. The project was continued up to the "u-Drug total management system construction project" in 2007. Through this project, the Ministry tried to audit the entire drug process ranging from manufacture and logistics to consumption in hospitals through RFID technology. An RFID-tag auto-labeling system was introduced to pharmacy factories.
- Busan City u-healthcare project for public emergency and home healthcare service (2006-2007): This project was funded by Busan City and the Ministry of Information and Communication. The total budget was 2.5 million USD. The project consisted of visiting nurse and emergency services.
  - The targets for the service were 105 disabled elderly and handicapped people. One emergency center, 4 health centers, and 36 visiting nurses participated in the project. Visiting nurses visited their disabled, elderly, or handicapped patients with a mobile tele-monitoring device and a UMPC (ultramobile PC). The visiting nurse assessed and measured the patient's vi-

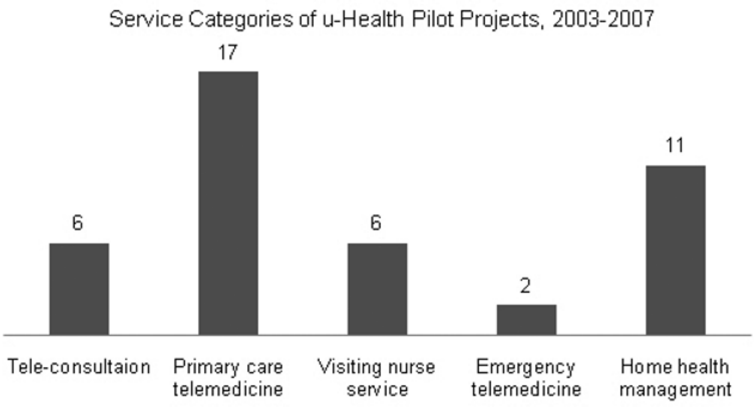

Fig. 13 Service categories of u-health pilot projects during 2003-2007. Source: U-healthcare National Survey, Ministry for Health, Welfare and Family Affairs, Republic of Korea. 2007

tal signs, peripheral blood glucose, and health status. The recorded data on the UMPC were transmitted to the central management server. The CDSS (clinical decision support system) in the UMPC supported the visiting nurse for proper patient management. Doctors in the center could evaluate the patients' health status in real-time and health management plans could be adjusted to the measured health data. The service reduced administrative work and assisted visiting nurses in the systematic health management of their patients.

– u-Emergency service: For this project, 2 emergency centers, 10 ambulances, 6 medical centers, 30 medical workers, and 14 paramedics were involved. Portable telemedicine and tele-monitoring devices were equipped in 10 ambulance cars. Paramedics could identify patients with RFID cards and measure their vital signs. They could discuss a patient's health status with the doctors in an emergency center via videoconferencing while in transit through the HSDPA mobile communication network. Portable monitoring devices could measure the blood pressure, heart rate, respiration rate, and ECG. A total of 742 patients participated in the project. However, the heavy weight and inaccuracy of the tele-monitoring devices and constraints due to medical law limited the spread of the service.

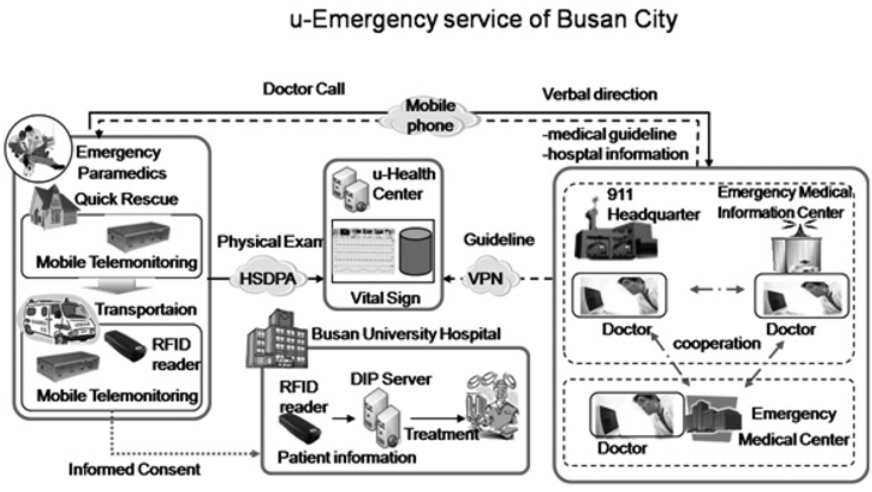

Fig. 14 Busan City u-healthcare project service diagram.

4.4 Today's Reality to Overcome

There are numerous challenges for u-health to confront: legal restrictions, technical immaturity, system and service management difficulties, no insurance reimbursement by national medical insurance, experience limited to pilot projects, etc. Korean medical law permits telemedicine to only be performed between doctors. There is no use of telemedicine between nations. This is due to fears of adverse events caused by telemedicine devices or communication troubles. The cost-effectiveness of u-health is under a cloud. Both insurance reimbursement and government incentives are essential for the spread of u-health, but they are not in place. Most pilot projects focus on chronic diseases, especially diabetes and hypertension. Trials for other diseases are very rare.

In spite of the many aforementioned challenges, industries and the government are cooperating together to promote u-health. A master plan for u-Healthcare R&D was issued in June 2008 by the Ministry for Health, Welfare and Family Affairs. In addition, the ąőSpecial Act on U-health Promotion' is in the planning stages.

5 USN Technology for Nation-wide Monitoring

Wireless Sensor Networks (WSNs) consist of large number of small, low power, and intelligent sensors, and are envisioned to change the way in which data has been collected from environment; giving a new paradigm to monitor and control the ambient environments. Major applications of WSN are in the areas of environmental monitoring and control, medical, military and smart spaces.

Network management refers to the process of managing, monitoring, and controlling the behavior of a network. A network management system generally provides a set of management functions that integrate configuration, operation, administration, security, and maintenance of all elements and services of a network. A large number of management solutions exist for traditional networks but these solutions are not directly applicable to WSNs because of the unique operational and functional attributes of WSNs. The uniqueness of the purported challenges in these networks makes management techniques of traditional networks readily impractical. For example, first the occurrence of a fault is a problem in networks but a ąőfeature' of WSNs. In case of large scale WSNs, i.e., of size more than hundreds of thousands nodes with severe resource constraints, faults occur frequently and components maintenance or energy recharge is not an option. The sensor nodes are often considered disposable and may be used only for once. In a few cases as reported in [13], configuration errors and even the environment interference can cause the loss of an entire WSN even before it starts to operate.

Second, unlike for traditional networks, wherein the primary goals are to minimize response time and provide detailed management information, sensor networks are designed with the primary goal of minimizing the energy usage [22]. Optimizing the operational and functional properties of WSNs may require a unique solution for each application problem [11]. A workable method to achieve this goal may be to carry out the management activity through minimum communication between the network elements for monitoring purposes. The main task of WSN monitoring is to gather data about various network- and node-state attributes like battery level, transceiver power consumption, network topology, wireless bandwidth, link state, and the coverage and exposure bounds of WSNs. A sensor network management system should be able to perform a variety of management operations on the network elements based on the monitored data, e.g., controlling sampling frequency, switching node on/off (power management), controlling wireless bandwidth usage (traffic management), and performing network reconfiguration in order to recover from node and communication faults (fault management).

Third, sensor nodes are typically deployed in remote or harsh conditions and the configuration of nodes in WSNs changes dynamically. Thus, a sensor network management system should allow the network to self-form, self-organize, and ideally to self-configure in the event of failures without prior knowledge of the network topology. In self-managed WSNs, after the nodes are deployed, say in an ad hoc manner, they wake up, perform a self-test, find out their localization [21] and monitor their energy levels (operational state), usage state, and administrative state. These activities are performed by management functions at network element level. Once the nodes find out their location, they can organize themselves in groups. Despite the importance of sensor network management, there is no existing generalized solution for WSN management [20].

Fourth, the ad-hoc and traditional networks are designed to run a large number of user applications. Therefore, the network components are installed, and configured with an objective to support a large number of different kinds of services. The WSNs are generally application-oriented. The wireless sensor nodes generally run a common application in a cooperative fashion, a behavior that is in contrast with the traditional and ad-hoc networks.

A network management system designed for WSNs should provide a set of management functions that addresses such unprecedented network and behavioral features of WSNs. In this chapter we focus on the provision of a management framework for monitoring and controlling WSNs.

5.1 IP-USN as an Integrating Technology

IP based Ubiquitous Sensor Networks (IP-USNs) are formed as a dovetail of WSNs and Internet Protocol (IP) network. These networks are unique and challenging at the same time, in the sense that these networks have acquired a niche, that is very diverse as compared to the peer wireless technologies (Fig.15).

The management considerations for these networks greatly depend upon their distinct characteristics that arise from their unique design. A management architecture for USN must reflect the interpretation of the differences, that USNs have from WSNs and Mobile Ad hoc Networks (MANETs). (Fig.16) illustrates the architectural, operational and functional differences between WSNs, MANETs and USNs. Architecturally, USN varies from these networks mainly in the network elements and the communication paradigm (shown through correspondence in the inset). The operational differences lie within the device roles of USN, especially due to the user and application heterogeneity. The functional differences arise from their application-specific form factors and code footprints.

These distinctive characteristics of IP-USN form considerations for its management system, which pose specific requirements (Figure 15).

Each of these requirements has a direct impact on the management system design as shown in (Fig.16). For instance R.1 purports the support for newer query types and formats, query generation and processing support at devices in the Internet domain, at the intermediate gateway and at the wireless devices in the WSN domain. R.2 mandates that the query transmissions and response transmissions between end points must be handled through intelligent means under the constraints that channel behavior varies under wireless-cum-wired multi-hop paths, and that the intermediate devices may altogether fail to deliver such transmissions due to a malfunction. The importance to optimally map the management roles, viz, manager and managed agents across the available devices in USN is signified in R.3. The differing form factors of devices in the Internet, the gateway and the sensor nodes requires (R.4)

	IP-based	Proprietary
Technology	IP-USN	MANET, WSN
Connectivity Scope	Access, Edge, Core, Internet	Access

Fig. 15 IP-USNs encompass all the scopes of connectivity

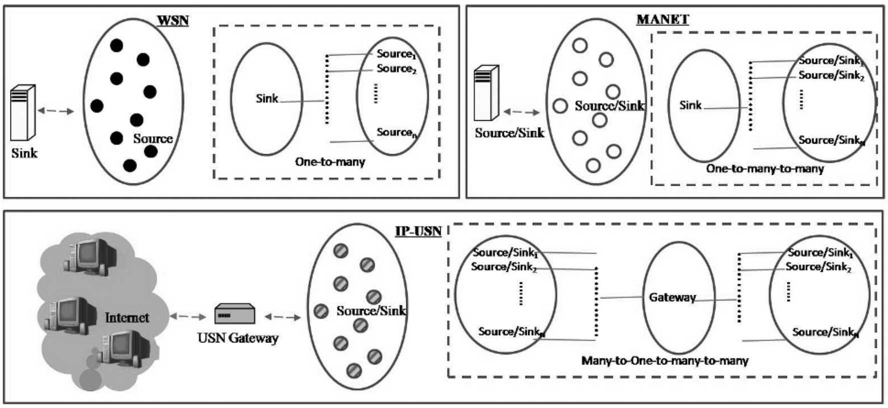

Fig. 16 Architectural presentations of WSNs, MANETs and IP-USNs (Inset: Communication paradigm)

Considerations for IP-USN	Requirements for IP-USN management system (IP-USN NMS)
C.1 IP-USNs exhibit user heterogeneity	**R.1** Queries should be supported across user domains
C.2 Communication is across networks	**R.2** Network management framework must cognize and act to network and channel behaviours.
C.3 Network elements are many and heterogeneous	**R.3** Elements of IP-USN NMS must be distributed across networks, optimally
C.4 Syntax and semantics vary across networks	**R.4** Translators and proxies should be embedded in IP-USN NMS, wherever necessary
C.5 Querying types and scopes vary across networks	**R.5** Consistent query types and specific Management Information Base (MIB) must be defined

Fig. 17 Considerations and requirements for IP-USN management system

the inclusion of proxies to translate complex syntax and bulky queries into lighter and manageable queries, while keeping the semantics same. Lastly, R.5 underpins the need to define newer MIBs for low to medium to high end devices, such as PAN Information Base (PIB) for sensor nodes, and the MIB definition for the adaptation layer at the gateway [15].

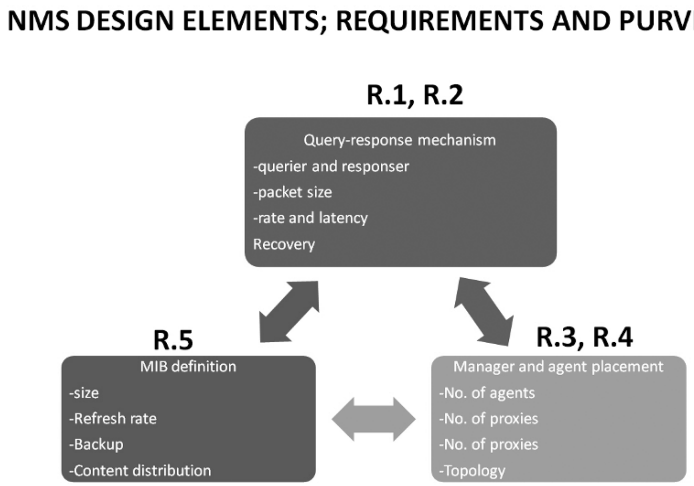

Fig. 18 Relationship between the IP-USN management requirements (overlay) and design elements (inlay)

The management purview turns out to be a good starting point to state goals for NMS including the protocol design. In the next sub-section, we present such goals that form basis for the proposal of USN NMS.

5.2 Design Goals of WSN Management

Management applications, when designed for traditional networks may have restrictions in terms of performance and response time as compared to the hardware limitations, when designed for sensor networks. The goals of network management for sensor networks need to establish a clear and direct relationship with the mission-oriented design of sensor networks. The goals are defined as follows,

1. Scalability: Sensor nodes are assumed to be deployed in large numbers. The management system should be able to handle a large quantity as well as high density of nodes.
2. Limited Power consumption: Sensor devices are mostly battery-operated; therefore, the management applications should be able to run on the sensor nodes without consuming too much energy. The management operations should be lightweight on node-local resources in order to prolong its lifetime, thereby, contributing to the network lifetime as a whole.
3. Memory and Processing Limitations: The sensor nodes are supposed to have limited memory and processing power. The management applications need to be aware of such constraints and may only impose minimal overhead on the low-powered nodes for the storage of management information and processing.
4. Limited Bandwidth consumption: The energy cost associated with communication is usually more than that of sensing and processing. Therefore the management applications should be designed with this consideration in mind. Moreover, some sensor technologies may also have bandwidth limitations in the presence of high channel impairments.
5. Adaptability: The management system should be able to adjust to network dynamics and rapid changes in the network topology. The system should be able to gather the reported state of the network and the topology changes. It should also be able to handle node mobility, the addition of new nodes, and the failure of existing nodes.
6. Fault tolerance: WSNs are different from traditional networks. Sensor nodes may run out of energy causing a fault in the network. Moreover the node may go to sleep mode to conserve energy or may be disconnected from the sink node because of network partitioning. The management system should be aware of such dynamics and it should adjust accordingly.
7. Responsiveness: Network dynamics, such as movement of nodes, must be quickly reported to the management system. The manager should be able to get the current state and the changes in the topology of the network.
8. Cost: The cost of each sensor node has to be kept low at least by allocating minimal resources to the management system.

5.3 LNMP Architecture

LNMP Architecture [12] was proposed to provide a management solution for 6LoWPANs (IPv6 over low power personal area networks) [15] which is a realization of the IP-USN concept. The system is composed of an operational and informational architecture for such networks. The management operations are carried out by the entities within the 6LoWPAN, in two successive steps. First, network discovery is performed before carrying out any management tasks to take a network-wide snapshot of resources, in that device state monitoring must be catered for, in the architecture, for example the devices could be energy-starved, sleeping, alive but not available etc. After the devices are discovered, the second step is the actual management of the available devices. In the network discovery, all the 6LoWPAN coordinators report the status of all the subordinates to gateway up through their ancestor coordinators in the hierarchy, the network initialization phase. After the network initialization, only the eventual updates regarding the changes in the subordinate states are reported to the gateway. The updates may be followed by an acknowledgement in order to enhance the accuracy of device discovery. Besides the network discovery part, the operational architecture provides support for the implementation of the Simple Network Management Protocol (SNMP). On the severely limited bandwidth of 6LoWPANs, only thirty-three bytes of data can be sent in worst case over User Datagram Protocol (UDP).

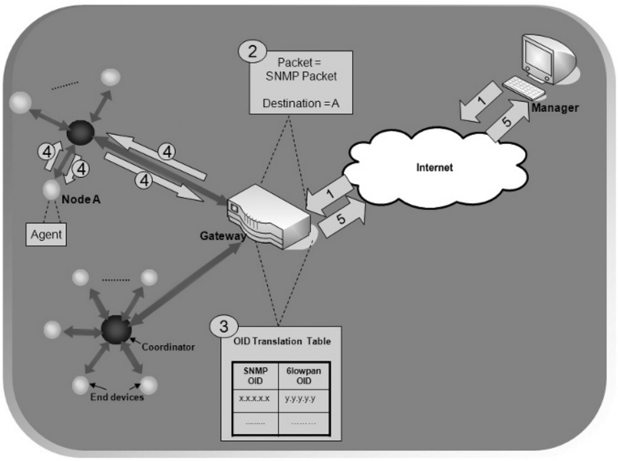

Fig. 19 LMNP Device Monitoring procedure

Therefore the architecture uses a proxy on the USN gateway in order to reduce the amount of fragmentation for sending the management packets and to reduce the traffic within the USN network by replying back the constant data from the gateway's Object identifier (OID) translation table. Local lightweight management messages are sent to the devices for variable data by parsing the incoming SNMP packets and the replies are translated back to SNMP when they leave the 6LoW-PAN. In (Fig.19), the steps 1 and 5 are SNMP requests and response respectively and step 4 shows the local lightweight management messages. In the informational architecture, Management Information Bases (MIBs) are defined by considering the special characteristics of these networks. The architecture focuses on approaches for the reuse of existing standard MIBs and defines an information base for special characteristics of this type of USNs.

5.4 Nationwide Deployment in Korea

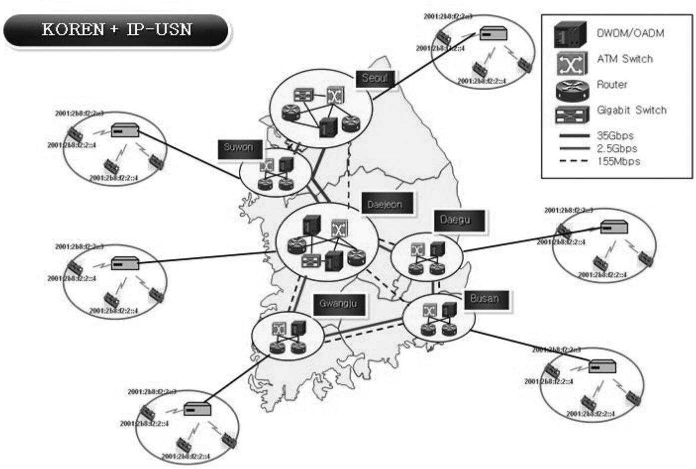

Fig. 20 Deployment of IP-USN with KOREN Project

IP-USNs are deployed throughout Korea under the KOREN project [16]. Fig.20 shows the deployment sites for the project within Korea and Fig.21 shows the data collection mechanism from the IP-USN networks. The data from these networks is currently being collected in a centralized server.

The IP-USN technology has been deployed throughout the nation. The deployed testbed consists of IP-USN networks from two different vendors and the interoperability between both the vendor specific networks has been tested. However, standardization of this technology is currently in progress and more standardization has to be done to make different vendor specific networks interoperable with each other.

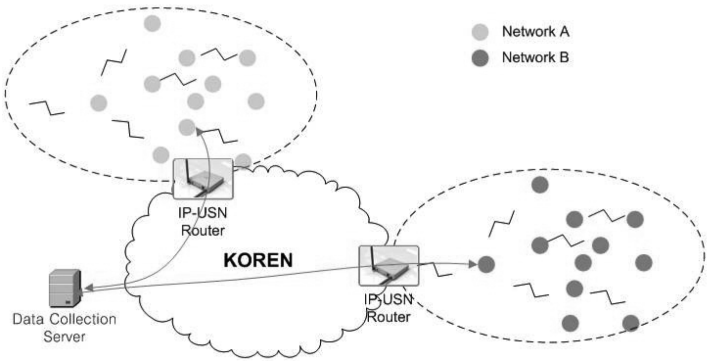

Fig. 21 Data Collection of the Sensor Data

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