Connecting Heterogeneous Sensor Networks with IP Based Wire/Wireless Networks

Shu Lei, Wu Xiaoling, Xu Hui, Yang Jie, Jinsung Cho, and Sungyoung Lee

Department of Computer Engineering
Kyung Hee University, Korea
{sl8132, xiaoling, xuhui, yangjie, sylee}@oslab.khu.ac.kr
chojs@khu.ac.kr

***Abstract*—Several heterogeneous sensor networks which are physically deployed in different places sometimes need to be integrated over IP based wire/wireless networks into one virtual sensor networks to provide meaningful services for users. However, how to connect sensor networks with IP based networks comes out to be an aforethought issue for this integration problem. In this paper, we analyze and compare all the existing solutions for connecting sensor networks with TCP/IP network, then based on the analysis result we present the basic design principle and key idea for connecting sensor networks with TCP/IP network. After comparing with related researches we claim that our solution can cover most of the benefits of related researches.[1]**

I. Introduction

Wireless sensor networks are based on collaborative efforts of many small wireless sensor nodes, which are collectively able to form networks through which sensor information can be gathered. Such networks usually cannot operate in complete isolation, but must be connected to an external network through which monitoring and controlling entities can reach the sensor networks. As TCP/IP, the Internet protocol suite has become the de facto standard for large scale network, it is quite reasonable to connect wireless sensor networks with TCP/IP network to provide meaningful services for large number of Internet users.

Furthermore, in the desired 4G paradigm [1], each mobile device will have global unique IPv6 address, all kinds of heterogeneous wireless networks and current existing IP based Internet should be integrated into one pervasive network to provide transparent pervasive accessibility and mobility for users. Internet users can seamlessly access and use the services provided by heterogeneous wireless networks without knowing which kind of wireless networks they are. Sensor networks as a family member of wireless networks should also be integrated.

In the new appeared pervasive computing paradigm [2], by using ubiquitous sensor networks as the underlying infrastructure, middleware which is considered as the key solution to realize the ubiquitous computing paradigm has been invested in many famous research projects, such as Gaia, Context Toolkit, Aura, TOTA, etc [3]. Ubiquitous sensor networks play an important role in our daily life to provide the seamless pervasive accessibility to users.

However, even though we know it is very important to connect sensor networks with TCP/IP network, the nature limitations of sensor networks, such as limited energy resource and low processing capability make it very difficult to deploy full IP protocol stack in sensor nodes. Therefore, in this paper we propose a novel bridge based approach to connect ubiquitous sensor networks with TCP/IP network.

In next section, we present a short survey on related researches. Section 3 discusses the suitable communication paradigms of sensor networks for connecting with TCP/IP network. In section 4, we present the major principle of designing new solution. Section 5 presents the key idea and detailed description of our *VIP Bridge*. In section 6, we present the comparison between related researches and our approach; in addition, we show that we can easily integrate several different sensor networks into one virtual sensor networks by using our *VIP Bridge*. Finally, we conclude this paper in section 7.

II. Related Work

Since the attention of present research community is mostly paid to other issues of sensor networks, such as energy efficiency and security, very limited numbers of related researches have been performed. Basically, related researches can be categorized into two different approaches: 1) *Gateway-based approach*; 2) *Overlay-based approach*.

***Gateway-based approach*:** This is the common solution to integrate sensor networks with an external network by using *Application-level Gateways* [4] as the inter-face.

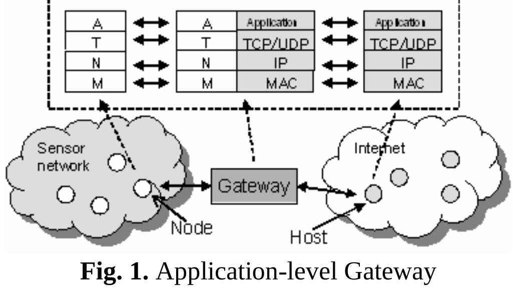

Fig. 1. Application-level Gateway

[1] Dr. Sungyoung Lee is the corresponding author.

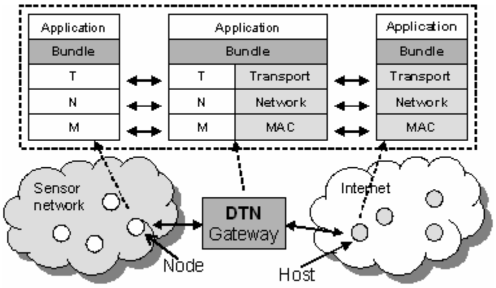

Fig. 2. Delay Tolerant Network

Different protocols in both networks are translated in the application layer as the figure 1 shows. The main role of this gateway is to relay packets to different networks. The advantage is: the communication protocol used in the sensor networks may be chosen freely. However, the drawback is: Internet users cannot directly access any special sensor node. Another research work, *Delay Tolerant Network* [5], also follows this *Gateway-based approach*. The key different point from [4] is that a *Bundle Layer* is deployed in both TCP/IP network and non-TCP/IP network protocol stacks to store and forward packets, as figure 2 shows. It is very easy to integrate with different heterogeneous wireless networks by deploying this *Bundler Layer* into their protocol stacks. But the drawback also comes from the deployment of *Bundle Layer* into existing protocols, which is a costly job.

***Overlay-based approach*:** There are two kinds of overlay-based approaches for connecting sensor networks with TCP/IP network: 1) *TCP/IP overlay sensor networks*; 2) *sensor networks overlay TCP/IP*. Research work in [6, 7] provides a solution to implement IP protocol stack on sensor nodes which is named as **u-IP**. The key advantage is: Internet host can directly send commands to some particular nodes in sensor networks via IP address. However, this **u-IP** can only be deployed on some sensor nodes which have enough processing capabilities. Another problem is that the communication inside sensor networks based on IP address will bring more protocol overhead, e.g. tunneling. We show **u-IP** approach in figure 3.

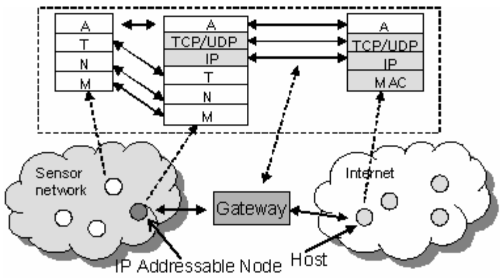

Fig. 3. TCP/IP overlay sensor networks

The *sensor networks overlay TCP/IP* is proposed in [8]. As figure 4 shows, sensor networks protocol stack is deployed over the TCP/IP and each Internet host is considered as a virtual sensor node. By doing so, the Internet host can directly communicate with sensor node and Internet host will process packets exactly as sensor nodes do. The problem of [8] is: it has to deploy an additional protocol stack into the Internet host, which brings more protocol header overhead to TCP/IP network. In addition, it loses the consistency with current IP based working model, which makes it not suitable to meet requirements of Next Generation Network paradigm.

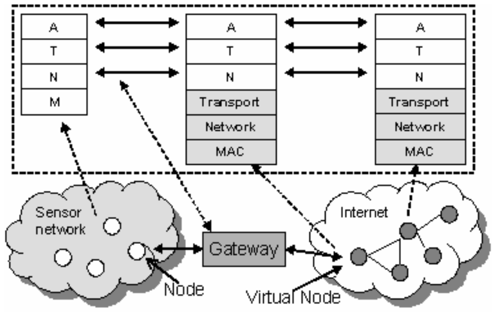

Fig. 4. Sensor networks overlay TCP/IP

By analyzing related researches, it is not difficult to figure out that ***we must propose a new approach which can cover all advantages of existing researches and still have consistency with IP based working model to realize the NGN paradigm***. So, what are the major principles of designing this new approach? Before presenting the major design principles let us have a look at the different communication paradigms of sensor networks for more detailed analysis.

III. Communication Paradigms of Sensor Networks

Typically, there are three kinds of communication paradigms in sensor networks: 1) *Node-Centric*, sensor nodes are labeled with some IDs and routing is performed based on these IDs, e.g. some table-driven-routing protocols; 2) *Data-Centric*, trying to make sensor networks answer "Give me the data that satisfies a certain condition", e.g. Directed-Diffusion [9]; 3) *Location-Centric*, using the location of sensor nodes as a primary means of address and routing packets, e.g. CODE [10].

Then, which communication paradigm is suitable for connecting sensor networks with TCP/IP network? In nowadays Internet, every network entity such as personal computer, router, or printer has its own IP address for identifying itself from others. Commercial databases used to provide diverse services for Internet users are stored in different computers. Internet users can access these services by using the IP addresses of those computers. However, the difficulty of remembering IP address for service motivates the using of Domain Name, which probably uses the name of this service. Internet users can easily use the Domain Name to access the corresponding service, with the assumption that this service's domain name or IP address can be known by users in advance. The routing in Internet is also IP address based. ***This kind of working model is similar with those of Node-Centric and Location-Centric.***

Data-Centric approach presented in paper Directed Diffusion [9] has its foremost different assumption from the IP based Internet working model: ***users don't know the exact locations of their interested sensors or data in advance***. In order to find the needed data, users request the gateway to broadcast the *Interest packet* to all the sensor nodes of sensor networks and look for the data source. On the other side, the sensor nodes which have the needed data also broadcast the *advertisement packet* to tell other nodes that they have this kind of data. Once the *Interest packet* and *advertisement packet* meet each other in certain sensor node, the transmission path from data source to gateway will be set up. If we consider the data provided by these sensor nodes as the services, we realize that the working approach of *Data-Centric* is more like a Service (Data) Discovery approach.

Now we can easily answer that "***In order to provide the consistency between the working models of sensor networks and TCP/IP network, the Node-Centric and Location-Centric communication paradigms are more suitable for connecting sensor networks with TCP/IP network.***"

After having these aforementioned analyses, we can present our major design principles in the following section now.

IV. MAJOR DESIGN PRINCIPLE

These following principles of designing our new approach must be clearly figured out, so that we can successfully deploy a comprehensive approach to connect sensor networks with TCP/IP network.

– **Consistency:** The new approach should be IPv6 based, because it should have the consistency with the working paradigm of Next Generation Network.

– **Transparency:** By using IP based approach, non-system-designer users should be able to use services provided by sensor networks without knowing that "these services are provided by certain sensor networks."

– **Energy efficiency:** Sensor networks should be able to freely choose routing protocol to optimize energy efficiency and performance.

– **Direct accessibility:** Some sensor nodes should be able to be accessed and operated by Internet users directly by using IP address to identify them from others.

– **No overlay approach:** Because both of *TCP/IP overlay sensor networks* and or *sensor networks overlay TCP/IP* require modification on protocol stacks.

– **Easy integration between different sensor networks:** Several locating in different place's sensor networks should be easily integrated into one virtual sensor networks based on IP addresses.

– **Taking the advantage of knowing sensor node's label (ID) or location address:** Because both sensor nodes' label (ID) and location addresses are unique information inside sensor networks, it can be used to identify different sensor nodes.

V. VIP BRIDGE

A. Key Idea

Taking all of these foregoing principles into consideration, we create our key idea ***VIP Bridge: Basing on Node-Centric or Location-Centric communication paradigm, mapping the node label (ID) or location address with IP address in bridge. The IP address will not be physically deployed on sensor node, but just store in bridge as a virtual IP address for Internet users. Packets that come from one side will be translated into corresponding packet formats and sent to another side by this VIP Bridge.***

B. Where should VIP Bridge be?

Figure 5 shows the logical location of our *VIP Bridge*. The A-CAMUS in the upper layer is another research project in our laboratory. Readers can know more information about this project from [11]. We consider that gateways and bridges are two different ways to provide connectivity.

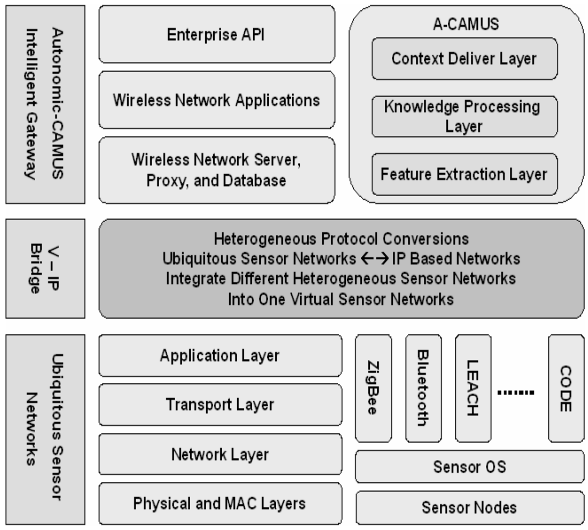

Fig. 5. Where VIP Bridge should be?

Gateways provide a more full featured connectivity and allow a greater diversity of devices and applications to connect the ubiquitous sensor networks. However, bridges are much simpler than gateways and hence would be a lower cost to the user but serve a smaller application space. Here, our *VIP Bridge* has only one simple major function that is to connect heterogeneous sensor networks with IP based wire/wireless networks, and integrate these sensor networks into one virtual sensor networks.

C. System Model of VIP Bridge

In this *VIP Bridge*, there are two major components to translate packets for both sides, as figure 6 shows: *1) TCP/IP Network -> Sensor Networks (T->S) Packet Translation*, translating packets from TCP/IP network into the packet format of sensor networks; *2) Sensor Networks -> TCP/IP Network (S->T) Packet Translation*, translating packets from sensor networks into the packet format of TCP/IP network. We use *T->S Packet* to represent the packet that comes from TCP/IP network, and *S->T Packet* to represent the packet that comes from sensor networks.

The packet format of original *T->S Packet* has four major fields:

1) *User IP*, used to represent the IP address of user's who sends this packet;

2) *Sensor IP/Bridge IP*, used to represent the destination of this packet, which can be the bridge IP address or some special sensor node's IP address;

3) *Q/O*, used to represent packet type: *Query Command* or *Operation Command*;

4) *Complicated/Simple Data Request / Operation Command*, used to represent the real content that is carried by this packet.

The packet format of created *T->S Packet* has the following four major fields:

1) *Bridge ID/Location*, used to represent the ID or location address of Bridge, which sends the packet to sensor networks;

2) *Sensor ID/Location*, used to represent the ID or location of data source;

3) *Q/O*, used to represent packet type: *Query Command* or *Operation Command*;

4) *Complicated/Simple Data Request / Operation Command*, used to represent the real content that is carried by this packet.

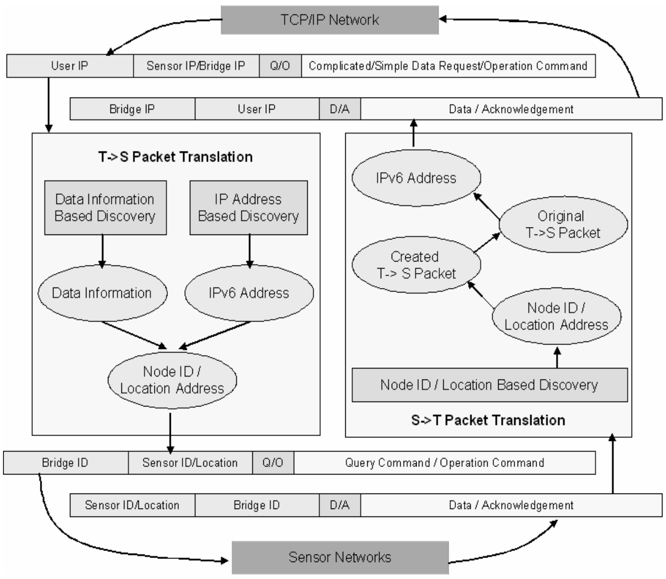

Fig. 6. Architecture of VIP Bridge

The *Query Command* is used to request data from sensor networks, it can be as simple as query data just from one special sensor node, or it can be as complicated as query data from many sensor nodes at the same time. *Operation Command* is used to remote control one special sensor node's working status.

Similarly, the packet format of *S->T Packet* also has four major fields:

1) *Sensor ID/Location*, used to represent the ID or location of data source;

2) *Bridge ID/Location*, used to represent the ID or location address of Bridge, which is the destination of this packet;

3) *D/A*, used to represent packet type: *Data Packet* or *Acknowledgement Packet*;

4) *Data/Acknowledgement*, used to represent real content carried by this packet.

The packet format of created *S->T Packet* has the following four major fields:

1) *Bridge IP*, used to represent the IP address of Bridge, which sends the packet to TCP/IP network;

2) *User IP*, used to represent the IP address of receiver's;

3) *D/A*, used to represent packet type: *Data Packet* or *Acknowledgement Packet*;

4) *Data/Acknowledgement*, used to represent real content carried by this packet.

The *Data Packet* corresponds to the *Query Command*, and the *Acknowledgement Packet* corresponds to the *Operation Command*.

A *Node ID/Location Address* is the node ID or location address of a sensor node. A *Data Information* is a description about what kind of data can be provide by this sensor node. An *IPv6 Address* is the assigned IP address for this special sensor node. *VIP Bridge* will actively collect *Node ID/Location Address*, *Data Information* for all sensor nodes, and also actively assign *IPv6 Address* for these sensor nodes. All these information are stored in a database which physically locating in the *VIP Bridge*. Furthermore, ***bridge will map these three different kinds of information with each other.***

In next subsection, we will present the detailed workflow of two translation components to explain how we translate different packets for both sides.

D. Workflow of Both Translation Components

TCP/IP Network -> Sensor Networks Packet Translation: After receiving packets from TCP/IP network, there are two ways to translate them into the packet format that used by sensor networks: 1) *Data Information Based Discovery*; 2) *IPv6 Address Based Discovery*. The translation workflow is showed in figure 7.

Bridge will analyze these received packets based on the field "*Q/O*" to categorize them into *Query Command* and *Operation Command*. If a packet is an *Operation Command*, then bridge can base on the *Sensor IP* to search the database to find out the corresponding *Node ID/Location Address* of this sensor node through the mapping between *IPv6 Address* and *Node ID/Location Address*. If a packet is a *Query Command*, then bridge can base on *Complicated/Simple Data Request* to search the database to find out the corresponding *Node ID/Location Address* of this sensor node through the mapping between *Data Information* and *Node ID/Location Address*.

After knowing *Node ID/Location Address* of this sensor node, we can easily create the new packet for sensor networks. Before sending new created packet to sensor networks, we backup this new *T->S packet*, and map it with the original *T->S packet* in bridge. These saved packets will be used when we translate packets that come from sensor networks into the packet format of TCP/IP network.

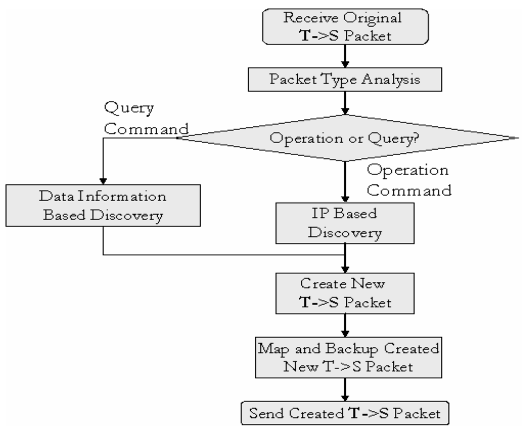

Fig. 7. Translation workflow of T->S

Sensor Networks -> TCP/IP Network Packet Translation: The workflow of *S->T translation* is showed in figure 8.

After receiving the *S->T Packet* from sensor networks, bridge first bases on packet's *Sensor ID/Location* to find out the created *T->S Packet*, then through the mapping between the created *T->S Packet* and the original *T->S Packet*, bridge can easily find out the original *T->S Packet*.

By analyzing the original *T->S Packet*, bridge can get the *User IP*, and then create the new *S->T Packet*. Before sending this new *S->T Packet*, bridge will delete the corresponding original and created *T->S Packets* to save the storage space of the database.

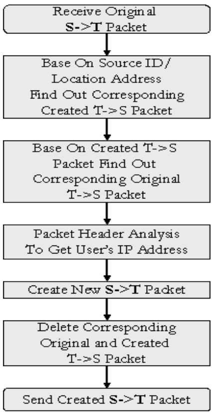

Fig. 8. Translation workflow of S->T

VI. Discussion

A. Comparison with Related Researches

We think that a table based comparison with related researches is essentially necessary to prove that our solution can cover most of the benefit of related researches, as table 1 shows.

After the integration of sensor networks and TCP/IP network, we can still keep the consistency with the IP based working model by hiding the sensor ID. Because in the view of Internet users, the sensor networks is IP based, they don't need to know which kind of routing protocol is used in sensor networks. In other words, sensor networks are transparent to Internet Users. However, for *sensor networks overlay TCP/IP*, users always have to deploy corresponding sensor networks routing protocol on Internet hosts, which means that users must know what kind of sensor networks they are.

Since we only deploy virtual IP addresses in bridge, rather than bring any modification to sensor networks protocols, sensor networks can still freely choose the optimized routing protocol which is *Node-Centric* or *Location-Centric* based. But the *TCP/IP overlay sensor networks* must modify the protocol stack of sensor networks.

Furthermore, Internet users can easily and directly access some special sensor nodes via *virtual IP addresses*. Since sensor networks can be *virtual-IP based*, it is very easy to integrate several locating in different place's sensor networks into one *virtual sensor networks*. Because we consider the integration of different sensor networks as a new research issue in the field of ubiquitous sensor networks, we are going to have more discussion about it in the following subsection.

B. Integration of Different Sensor Networks

Sensor networks which are physically located in different locations may use totally different routing protocols for their specific applications, as figure 9 shows. Sometimes these sensor networks should be integrated into one virtual sensor networks over wired/wireless networks to provide comprehensive services for users.

Table 1. Comparison with related researches

	Application level gateways	Delay Tolerant Network	TCP/IP overlay sensor networks	Sensor networks overlay TCP/IP	Virtual IP
Consistent with Internet working model	No	No	Yes	No	Yes
Transparent for Internet users	Yes	Yes	Yes	No	Yes
Freely choose routing protocol in sensor networks	Yes	Yes	No	Yes	Yes
Directly accessibility some special sensor node	No	No	Yes	Yes	Yes
Easy to integrate different sensor networks	No	Yes	No	Yes	Yes

In *Delay Tolerant Network*, because they deployed an additional *Bundle Layer* in both TCP/IP network and non-TCP/IP network protocol stacks, it is very easy to integrate different networks into one virtual network. However, it requests a lot of effort to modify existing routing protocols to deploy this new *Bundle Layer*.

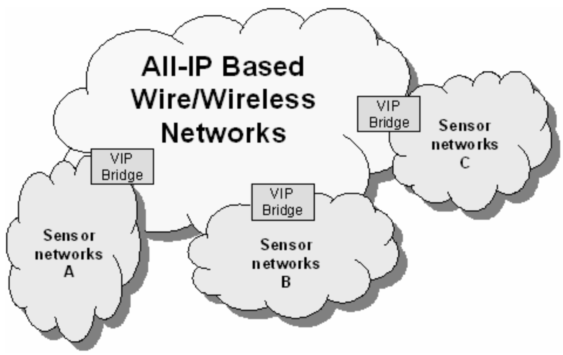

Fig. 9. Several sensor networks deployed in different locations

In *sensor networks overlay TCP/IP*, if several sensor networks are only physically located in different locations but still use the same routing protocol, users can deploy this routing protocol to overlay TCP/IP networks, so that these sensor networks can be integrated into one virtual sensor networks. If these sensor networks are using different routing protocols, then this *sensor networks overlay TCP/IP* is not suitable to integrate them into one virtual sensor networks.

Compared with our *VIP Bridge* approach, either *Delay*

Tolerant Network or *sensor networks overlay TCP/IP* needs to deploy or modify current existing protocol stacks. If these sensor networks have bridges which have *virtual IP address*es, then it is very easy to integrate them into one virtual sensor networks without any modification on existing protocols, because *virtual IP address* can hide all the heterogeneities of different sensor networks for upper layers.

C. Drawbacks of VIP Bridge

Even though we claim that our *VIP Gateway* can cover most of the benefits of related researches, through the prototyping work we realize that our approach also has several drawbacks:

1) ***Single point of failure*:** once this *VIP Bridge* is failure, sensor networks that connected to this bridge will not be able to be used any more.

2) ***Bottleneck problem*:** because of these packets need to be translated into different packet formats when they are sent to different sides, if the processing capability of this *VIP Bridge* is not powerful, it's easy to occur the bottleneck problem, which slows down the performance of whole system.

3) ***Major limitation*:** the routing protocols in sensor networks must be *Node-Centric* or *Location-Centric* based, which means many *Data-Centric* based routing protocols will not be supported.

VII. Conclusion and Future Work

Pervasive network which is considered as the next generation of current networks requests us to integrate all kind of heterogeneous networks into one global network. Sensor networks as a family member of wireless networks should be integrated with TCP/IP network to provide meaningful services. In this paper we present a new solution to connecting ubiquitous sensor networks with TCP/IP network. By comparison with related researches we claim that our new solution can cover most of the benefits of related researches. Here, we want to clearly point out that how to analyze one *Complicated Data Request* and create several *sub-Simple Data Requests* is another research issue, which is currently under investigation of another team in our group. The major contribution of this paper is that we present a comprehensive new solution to connect ubiquitous sensor networks with TCP/IP network.

Acknowledgment

This work was supported by grant No. R01-2005-000-10267-0 from Korea Science and Engineering Foundation in Ministry of Science and Technology.

References

[1]. Gary Legg, "Beyond 3G: The Changing Face of Cellular", http://www.techonline.com-/community/home/37977

[2]. Saha, D., Mukherjee, A. "Pervasive Computing: A Paradigm for the 21st Century", IEEE Computer, Volume: 36 Issue: 3, March 2003 Page(s): 25 – 31

[3]. N.Q. Hung, N.C. Ngoc, L.X. Hung, Shu Lei, and Sungyoung Lee, "A Survey on Middleware for Context-Awareness in Ubiquitous Computing Environments", Korean Information Processing Society Review ISSN 1226-9182 July 2003.

[4]. Z. Z. Marco, K. Bhaskar, "Integrating Future Large-scale Wireless Sensor Networks with the Internet", *USC Computer Science Technical Report CS 03-792*, 2003.

[5]. K. Fall, "A Delay-Tolerant Network Architecture for Challenged Internets". *In Proceedings of the SIGCOMM 2003 Conference*, 2003

[6]. A. Dunkels, J. Alonso, T. Voigt, "Making TCP/IP Viable for Wireless Sensor Networks", In *Proceedings of the First European Workshop on Wireless Sensor Networks (EWSN'04), work-in-progress session*, Berlin, Germany, January 2004.

[7]. A. Dunkels, J. Alonso, T. Voigt, H. Ritter, J. Schiller, "Connecting Wireless Sensornets with TCP/IP Networks", In *Proceedings of the Second International Conference on Wired/Wireless Internet Communications (WWIC2004)*, Frankfurt (Oder), Germany, February 2004.

[8]. H. Dai, R. Han, "Unifying Micro Sensor Networks with the Internet via Overlay Networking", in *Proc. IEEE Emnets-I*, Nov. 2004.

[9]. C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks", Proc. ACM MobiCom'00, Boston, MA, 2000, pp. 56-67

[10]. L.X. Hung, and S.Y. Lee, "A Coordination-based Data Dissemination for Wireless Sensor Networks", Proceeding of International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP 05) Melbourne, Australia December, 14-17, 2004.

[11]. L. K. Saad, R. Maria, SungYoung Lee, YK Lee, "A Distributed Middleware Solution for Context Awareness in Ubiquitous Systems," RTCSA 2005, 17-19 August 05, HongKong