VIP Bridge: Integrating Several Sensor Networks into One Virtual Sensor Network

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Abstract

Some applications need to collect information from several different sensor networks to provide comprehensive services. In order to simplify the complexity of dealing with heterogeneous sensor networks, a uniform interface should be provided for users. This paper describes a novel approach to integrate these different sensor networks into one virtual sensor network. Users can easily query data through this virtual sensor network. By having the comparison and prototyping work we claim that our new approach can cover most advantages of related researches.

1. Introduction

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. Furthermore, most of sensor networks are application-specific, which request different energy efficient routing protocols should be deployed for different corresponding application scenarios. In order to achieve the energy efficiency, routing protocols of different sensor networks should be chosen freely based on their application requirements.

However, sometimes several different sensor networks which are locating in different places should be integrated into one virtual sensor network over the IP based wire/wireless networks to provide comprehensive services for remote users. These sensor networks may use totally different routing protocols to reduce the energy consumption for their application scenarios. How to easily and efficiently connect sensor networks with IP based wire/wireless networks, and finally enable all these sensor networks to be integrated into one virtual sensor network comes to be the critical research issue.

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In this paper we propose a novel bridge based approach to integrate different sensor networks over IP based wire/wireless networks into one virtual sensor network. Through this virtual sensor network, user can easily query their interested information as well as directly query data from some special sensor nodes.

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*. In section 7, we describe the initial implementation of *VIP Bridge*. Finally, we conclude in section 8.

2. 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*.

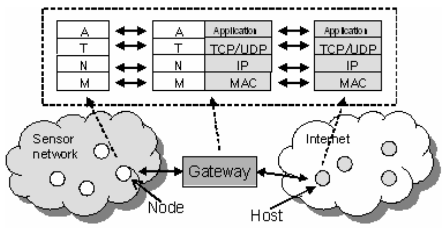

Fig. 1. Application-level Gateway

***Gateway-based approach*:** This is the common solution to integrate sensor networks with an external

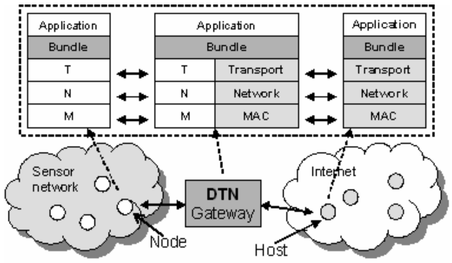

Fig. 2. Delay Tolerant Network

network by using *Application-level Gateways* [1] as the inter-face. 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* [2], also follows this *Gateway-based approach*. The key different point from [1] 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 [3] 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. The *sensor networks overlay TCP/IP* is proposed in [4]. 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 [4] 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

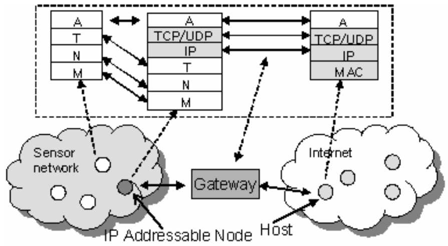

Fig. 3. TCP/IP overlay sensor networks

with current IP based working model, which makes it not suitable to meet requirements of Next Generation Network paradigm.

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.

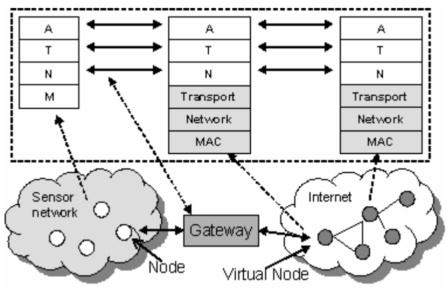

Fig. 4. Sensor networks overlay TCP/IP

3. Communication paradigms

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 [5]; 3) *Location-Centric*, using the location of sensor nodes as a primary means of address and routing packets, e.g. CODE [6]. ***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 [5] 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.

4. Major design principles

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.

5. VIP Bridge

5.1. 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 for connecting sensor networks with IP based wire/wireless networks. By using virtual IP addresses, different sensor networks can be integrated into one virtual sensor networks.***

5.2. 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 [7]. We consider that gateways and bridges are two different ways to provide connectivity. 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.

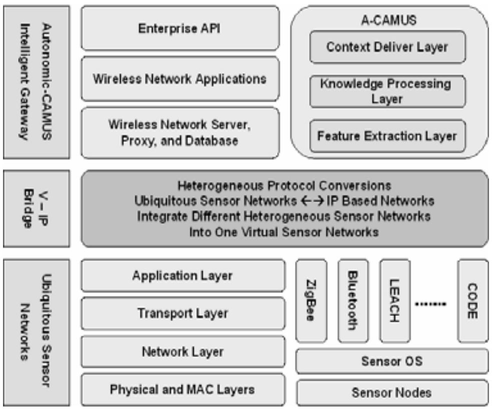

Fig. 5. Where should *VIP Bridge* be?

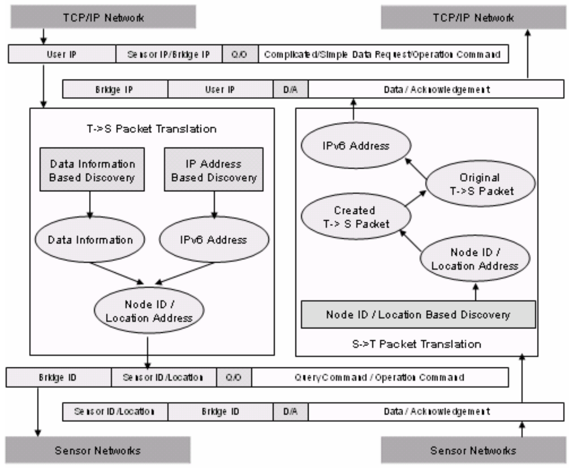

Fig. 6. The conceptual overview of *VIP Bridge*

5.3. Conceptual overview 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. 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

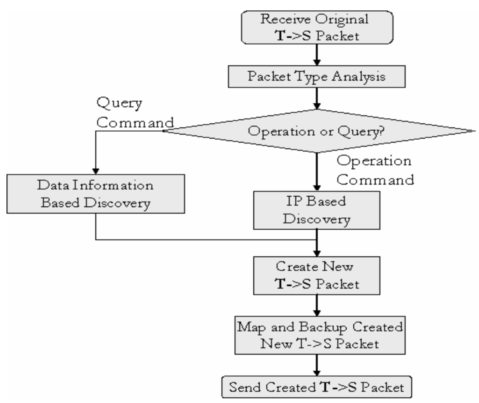

Fig. 7. Translation workflow of T->S

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.

5.4. Workflow of both transaction 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.

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

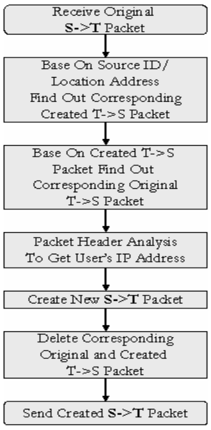

Fig. 8. Translation workflow of S->T

corresponding original and created *T->S Packets* to save the storage space of the database.

5.5. Component based overview of VIP Bridge

The component based overview of *VIP Bridge* is showed as Figure 9. Two Packet Analyzers analyze packets from both application layer and sensor network layer respectively. The registered *Data Information*, *Node ID/Location Address*, assigned *IPv6 Address*, and backup *Created New T->S Packet* are stored in Repository. After packet analysis, query packets are sent to Query Engine to extract the necessary information from Repository to compose the new packet format. The Mapping Table Exchanger exchanges mapping tables between different *VIP Bridges*, in order to integrate all mapping tables into one.

5.6. High Level Operation of VIP Bridge

The high level overview of *VIP Bridge* operation is show in Figure 10. After node discovering, sensor

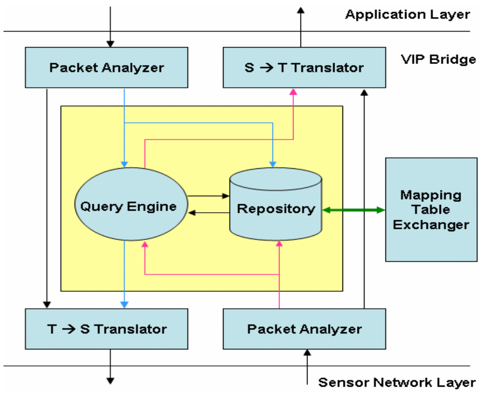

Fig. 9. Component based overview of *VIP Bridge*

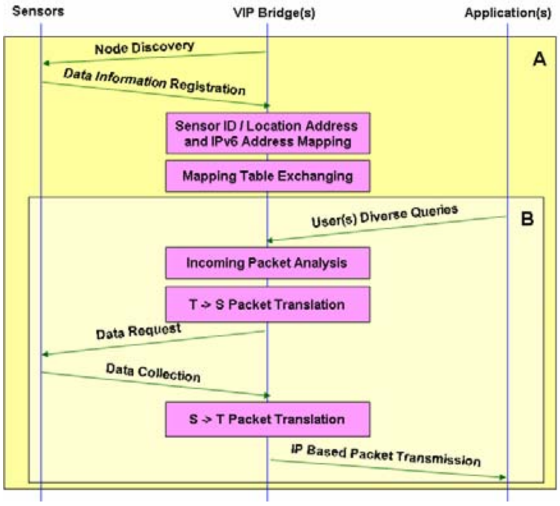

Fig. 10. High Level Overview of *VIP Bridge* Operation

nodes register their *Node ID/Location Address* and *Data Information* into *VIP Bridge*. *VIP Bridge* should create the mapping table and assign the *IPv6 Address*. Before receiving queries from users, *VIP Bridges* should exchange mapping tables to create the view of virtual sensor networks. After all these preparation in part A, the real query process can start as in part B.

5.7. Mapping Table Exchanging in VIP Bridge

A message format is a standard form of message that has elements. These elements consist of message type, destination identification, source identification, the sequence number of message, and contents. A message style is a way which information is given, we use a XML document. It allows users to create their transmission, validation, and interpretation of data between applications. Many documents and data have been expressed by XML because they easily and dynamically converted to another type documents. Therefore, XML is very suitable to express information in the network environment participated in various nodes. In our approach, we use XML to express our *Mapping Tables*. SOAP (**S**imple **O**bject **A**ccess **P**rotocol) is a lightweight XML-based messaging protocol used to encode the information in Web Service request and response messages before sending them over a network. SOAP messages are independent of any operating or protocol. The SOAP protocol extends XML so that computer programs can easily pass parameters to server applications and then receive and understand the returned semi-structured XML data document. In our approach, all the communication between different VIP Bridges is

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

accomplished by SOAP.

6. Discussion

6.1. 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.

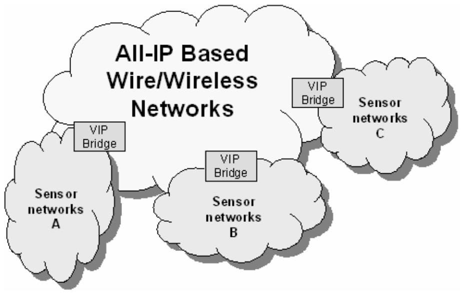

Fig. 11. Integration of Different sensor networks

6.2. 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 11 shows. Sometimes these sensor networks should be integrated into one virtual sensor networks over wired/wireless networks to provide comprehensive services for users. 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*. 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.

7. Initial implementation

In order to prove that our *VIP Bridge* can successfully support the integration function, we build up our test bed to integrate three different ZigBee based sensor networks over IP based TCP/IP network into one virtual sensor network. We employ the Nano-24 sensor board [8], developed by the Korean

CPU		Atmega128L
Internal Memory	SDRAM	4KByte
	FLASH	128KByte
RF		2.4GHz, ZigBee
Security		DSSS Supported
Low Power		AA Type Battery
Transmission Speed		250Kbps
Sensor Board		Included

Fig. 12. Nano – 24 From Octacomm

Octacomm company as our hardware platform. The hardware configuration is show as Figure 12. A collection of sensors are integrated on-board: 1) A light sensor for the detection of visible light; 2) A temperature sensor; 3) A humidity sensor.There is a separated ZigBee based communication board, which is designed for low-power applications. In our implementation, we apply Qplus [9] as operating system. Qplus is an embedded Linux operating system developed by ETRI. Qplus consists of a reconfigurable embedded Linux kernel, system libraries, a graphic window system, and a target builder. ETRI and Red Hat cooperatively developed Qplus based on Red Hat's embedded software solutions and standards.

The intended network scenario is a simple office monitoring. Sensor nodes are deployed in three separate rooms: Professor’s Office (Room 313), Korean Students Research Lab (Room 351), Foreign Students Research Lab (Room B08). A lab administrator can use a website based interface to query the office environment status and decide whether to remotely turn on or turn off air-conditions for saving energy as Figure 13. In order to create the view of virtual sensor networks, each *VIP Bridge* sends request to other *VIP Bridge*s to ask for their mapping tables and finally every *VIP Bridge* will have all the mapping tables about other sensor networks as Figure 14. These mapping tables will be integrated into one, so that in users’ side, through any *VIP Bridge* users are able to query sensor information over this whole virtual sensor networks by virtual IP addresses. By using our *VIP Bridge*, two different types of query can be achieved on virtual sensor networks: 1) users know target sensor nodes’ virtual IP addresses; 2) users don’t know target sensor nodes’ virtual IP addresses, but have their *Interest*. In order to make the client side be lightweight, we use web as the platform for sending the XML based query to *VIP Bridge*. As Figure 15 shows, the incoming queries will be analyzed to classify them into two types of queries: 1) IP address based query, which allow users to directly access some special sensor nodes; 2) User’s *Interest* based query, which is used to support the standard query of sensor networks, such as Direct Diffusion [5].

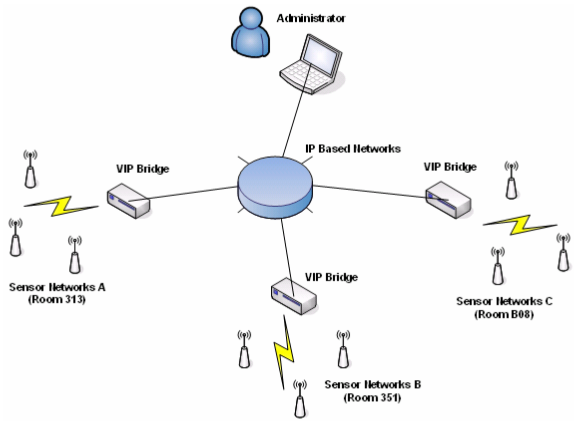

Fig. 13. Scenario: Office Monitoring

Because sensor nodes have already register their *Data Information* in *VIP Bridge* in advance, and there are mapping tables between *Data Information* and *IP Address* in *VIP Bridge*, it is very easy to search the corresponding IP addresses based on user *Interest*. Even though we claim that our *VIP Bridge* can cover most of the benefits of related researches, through the prototyping work we realize that our approach also has several drawbacks: **Single point of failure:** Once a *VIP Bridge* is doesn't work correctly, sensor networks that connected to this bridge will not be able to be used any more. **Bottleneck problem:** Because these packets need to be translated into different packet formats by *VIP Bridge* 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.

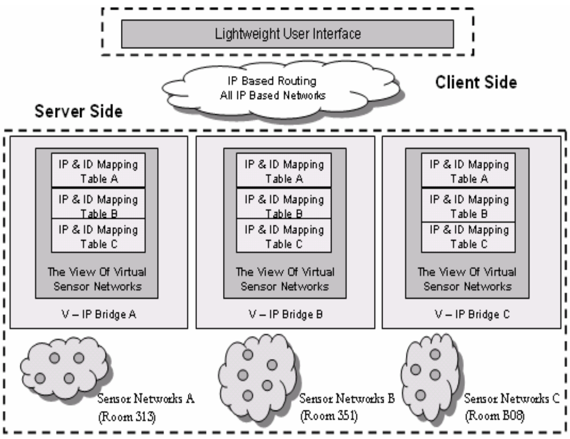

Fig. 14. The View of Virtual Sensor Networks

8. 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 the design and implementation work by using our *VIP Bridge* to integrate different sensor networks into one virtual sensor network. Through our prototyping work, we find out that our *VIP Bridge* still has some limitations and drawbacks, which we are going to solve in future.

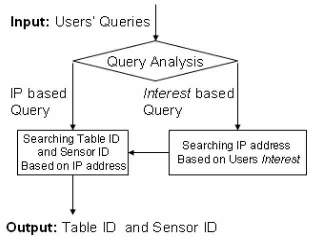

Fig. 15. Query Process

9. Acknowledgement

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