An Inter-working Processing System for heterogeneous hierarchical wireless sensor networks

*　　**　　**　　***　　*

Sea-Young Ahn, Kang-Ho Woon, Seong-Dong Kim, We-Duke Cho and Sun-Shin An,

* Department of Electronics and Computer Engineering, Korea University, Korea,
asy1604@dsys.korea.ac.kr, sunshin@dsys.korea.ac.kr
** Ubiquitous Computing Research Center, Korea Electronics Technology Institute,
khwon@keti.re.kr, sdkim@keti.re.kr
*** Center of Excellence in Ubiquitous Computing & Network(CUCN),
chowd@ajou.ac.kr

ABSTRACT

Wireless sensor networks are networks composed of small, low-power sensor devices with abilities of environment sensing, data computing and wireless communication. Such sensor networks make many applications possible, for example, surveillance, smart home and offices, environment monitoring, and many others. In this paper, we introduce our heterogeneous hierarchical wireless sensor network architecture that is appropriate for the robust sensor management and the qualified user service providing in a home networking environment or inside a building. We also suggest IWF (Inter-working Function) that facilitates communication and management between heterogeneous entities that compose our architecture.

1. Introduction

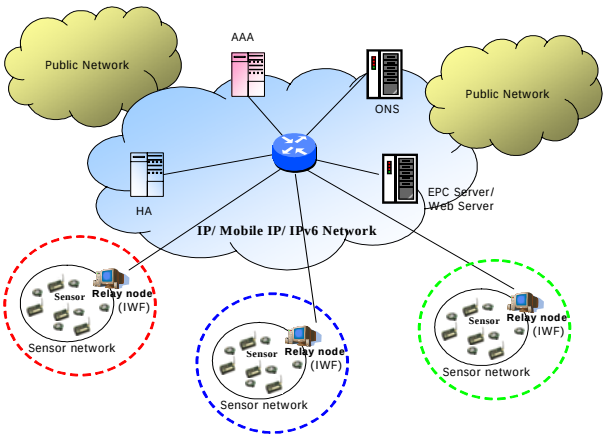

Figure 1 Architecture of reference sensor network

This work was partially supported by CUCN(National Center of Excellence in Ubiquitouse Computing and Networking).

The purpose of this paper is inter-working processing system protocol planning for interlocking IP network and heterogeneous sensor node. Let's define the node, which plays Gateway role between IP network and sensor network, as relay node, and inter-working processing system for interlocking two networks manages communication and Security. Also, relay node manages sensor nodes.

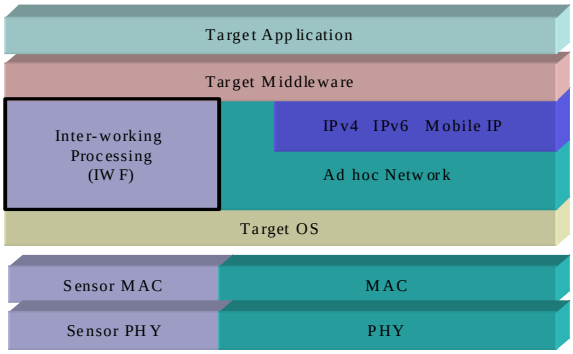

Figure 2 Relay node Protocol Stack

Figure 2 shows reference protocol stack of relay node. Inter-Working Processing, which is a part of Relay node, is located at the middle of target OS and target middleware. It also fills up the requirement about management of sensors from upper layer through communication with sensor, and transmits data communication and management signaling message efficiently from IP network (Ad hoc Network, etc Module). Let's call Inter-Working Processing System between relay node and sensor node as IWF (Inter-Working Function) module for the sake of convenience.

1.1 Assumption

There are few assumptions in this paper while we are planning Inter-Working Processing System between relay node and sensor node.

- Let's assume that MAC and PHY of Sensor noded is Zigbee/802.15.4 Compatible.

- Cluster-Tree Topology consists PAN that forms Sensor node, and Cluster Head consists relay node.
  Let's assume that Sensor node can interpret and process several massages that are showed up in the text.
- Symmetric key is assigned Sensor node when place arrange sensor node in the field.
- Sensor node uses 16 bits Logical ID, 16bits PAN ID or IEEE 64bits ID based on 802.15.4 Spec.

2. Inter-working Processing System

2.1 Inter-Working Processing System Architecture

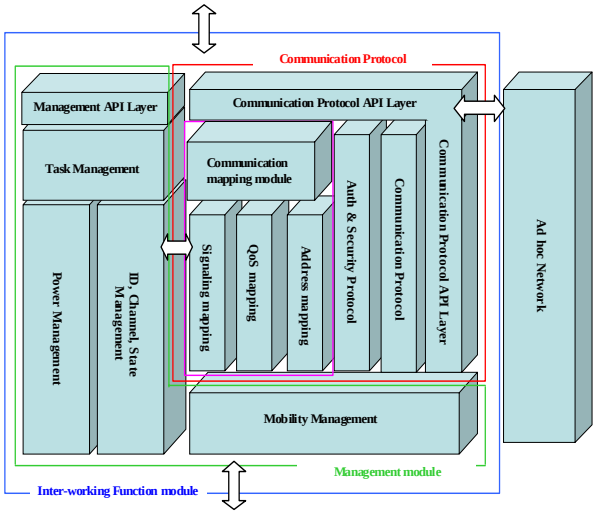

Figure 3 Inter-Working Module Software Architecture

Figure 3 shows block diagram of Inter-Working Function module[1][2]. IWF (Inter-Working Function) Module is composed of two big parts. First part is called as communication protocol module and it take charge of communication Protocol and Security Protocol, and second one is called as communication mapping module. Communication mapping module is divided to three modules which are address mapping module, signaling mapping module and QoS mapping module.

Another one is the management protocol module that provides task management, power management, mobility management and ID, Channel, State management functions in order to manage senor node from relay node. These modules provide API to Upper Layer and Ad hoc network module and control Lower Layer.

2.2 Communication Protocol

- Communication Protocol
  Communication protocol has abilities which communicate with communicate heterogeneous sensor nodes and relay nodes in other cluster through interface of Ad hoc network module.
- Security Protocol
  Security protocol can authentication about Sending message. Support framework for integrity checking and encryption.
- Communication mapping module
  Communication mapping module is divided to three modules which are address mapping module, signaling mapping module and QoS mapping module. Address mapping module means mapping between address system of IP network IPv6(or IPv4) and sensor node ID of sensor network. Signaling mapping module play signaling mapping role between IP network and sensor network.

2.3 Management Module

- Mobility Management
  Most of sensor node is fixed node but some sensor nodes are mobile sensor node in user requirements. Mobility management module support a efficiency management movement of mobile sensor node likely Figure 3.
  This function use tracking special movement of sensor and mobility management. General management is divided two types according to organization type, centralized and distributed type. This paper using distributed type based cluster[3].
- Power Management
  Power management supports facility adjusting power mode and beacon order of sensor node using power consumption of sensor and expected lifetime information[4][5].
- Task Management
  Task management supports efficient task assignment using task object concept and supports adaptive task management using data aggregation and filtering rule.
- ID, Channel, State Management
  ID management supports ID assignment for efficient communication and management inside cluster, channel management supports channel selection through the energy level measurement and State management supports management about sensor node and cluster state.

3. Inter-Working Module System Specification

3.1 Intra-Cluster Routing

Inter-cluster routing which is composed of relay node is achieved based on ID assignment to be stated at the paper.

Figure 4 represents the inter-cluster routing algorithms based on logical ID which gets from a relay node.

According to the logical ID structure, in case of different PID or different CID(Cluster ID), the message is transmitted to relay node which has ability of Cluster-Header and is transmitted to the outside through Ad hoc Network Module based on IP network. Otherwise, the

message is transmitted to the outside according to the formed Cluster-Tree and NID(Node ID) of Logical ID. Cluster-Tree supports to four hierarchies including the relay-node Relay node is level 0 ID node, sensor node attached to a relay-node is level 1 ID node and the node below level 1 node is level 2 ID node. In each level, we can use the ID value from 1 to 15. Zero value means that the node ID of level is not assigned.

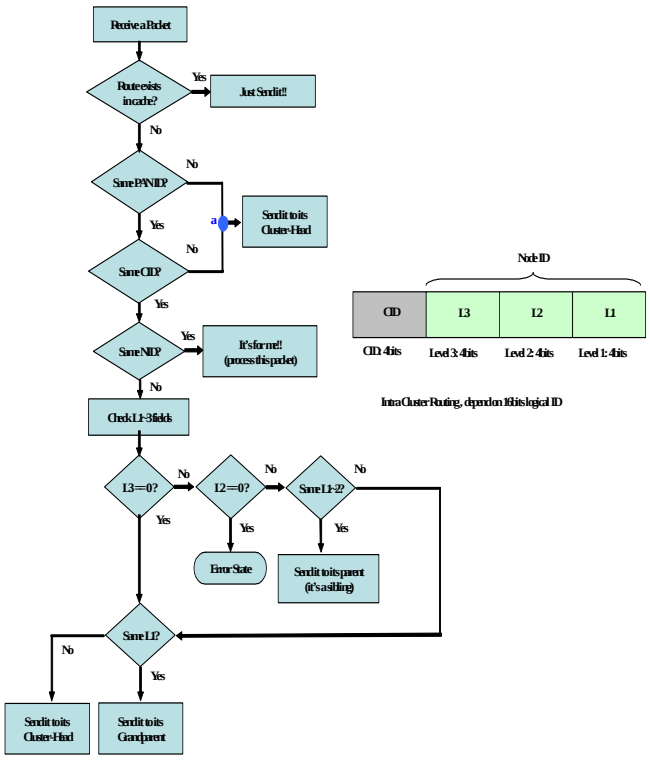

Figure 4 Intra-Cluster Routing Algorithm

If the value of the level 3 is 0, sensor node can be identified as a node which is existed in level 2 or 1. After the checking up whether the destination node is own sibling or not. If it isn't own sibling, then transmit parent node. This simple algorithm enables to the Inter-Cluster Routing. The algorithm can implemented with allocating efficiently the Logical ID of the IEEE 802.15.4. We can refer the ID Management part to set up ID of each node.

The point 'a' which is above Figure act as border of the Inter-Cluster Routing Part, Which is related to Ad hoc Network Module of the Figure 1 and not the scope of the Inter-working Processing. So it will not mentioned in this Thesis In Figure 4 the sample of the Intra-Cluster Routing is well presented. It is presented in the order which is the structure of CID:Level1:Level2:Level3 for convenience sake, but we note that the structure of the logical ID is actually presented in the order of CID:Level3:Level2:Level1. In practice to develope Intra-Cluster Routing easily, we reverse the order of the Logical ID.

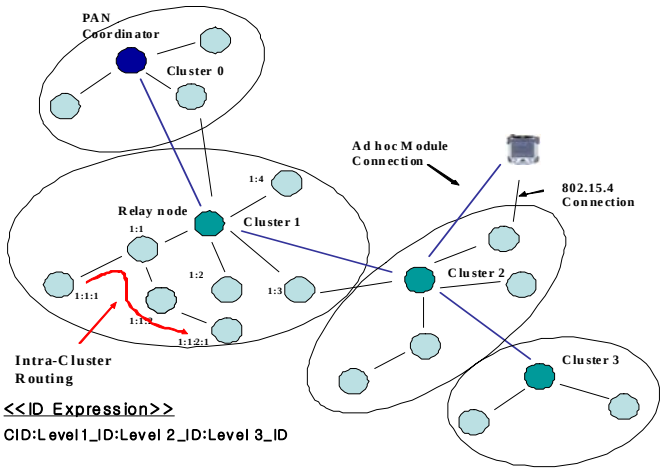

Figure 5 Intra-Cluster Routing Based on Assigned ID

3.2 Message Format

message format should include each field as below

Control Field The field is various transmission options.; Message Transfer Mode, Message Type, In-network Processing Control, Source Address Type, Destination Address Type, Message Priority, SecurityA, SecurityE, SecurityI

Hop Limit Hop Limit is range of transmission. So discount 1 when through a node. If Hop Limit is 0, The sensor node is not forwarding.

Seq Num It is Sequence Number, count 1 when new message transmission.

Dest. ID Destination Node ID.

Src. ID Source Node ID.

Payload enter a data and a control data for management in the field

Security MAC It is optional field about message authentication code.

3.3 Signaling Message Format

Signaling Message is divided into two part. Frist is Signaling Control Field about signaling message option or type. The other is signaling object about data or control data for management.

3.4 Task Message Format

Task Message is divided into message payload field and option field.

3.5 Data Message Format

The format describe a characteristic of data, consist of

data object and optional field.

3.6 Mobility Control

Mobility control always updates movement of Mobile sensor node in sensor network and sensor nodes in and out of clusters. Because relay node maintains Logical Channel and send Connect Request Message to Mobility Control. Figure 6 shows that if node D moves as Node S communicate with Node D , Node I as middle node in routing send Route Error Message to nodes. When Node S also send it back to Cluster Head as relay Node, IEEE 64bits Address of Destination Node is required.

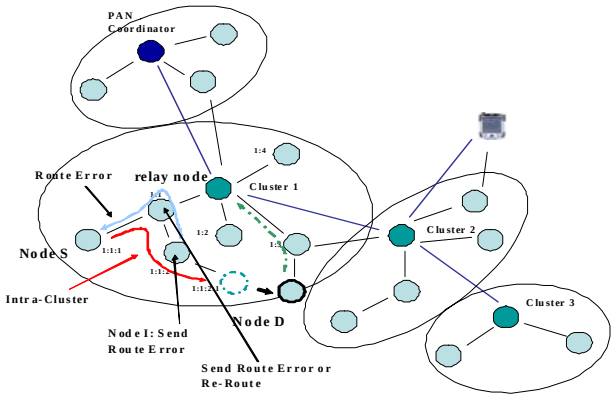

Figure 5 Mobility Control (Intra-Cluster)

Both Initial Info. Message and State Info. Update Message are happening when sensor nodes in cluster only directly sent to relay node as cluster head. So Initial Info. Message and State Info. Update Message can not made when sensor node moves into other clusters . (Figure 7)

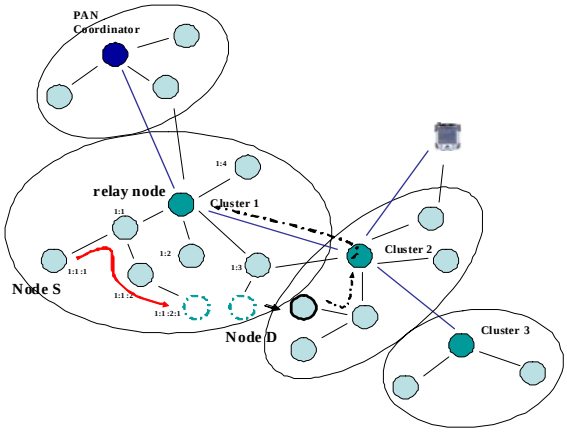

Figure 6 Mobility Control (Inter-Cluster)

Relay node can Connect Request Message to Mobile sensor node to track the location of Mobile sensor node. After getting Connect Request Message, sensor node sends the data being location of Mobile sensor node(Logical ID) and updates it in a periodic time.

To update location, Bind update Message should be sent into relay node before receiving Disconnect Request Message or connect request during the time indicated by Connect Request Message.

3.7 Task Management Module

3.7.1 Task Object

From Relay node to sensor network Task Assignment is executed when Task Object is sent by payload of message. Task has four types of classifications.

- ***Periodic***
  It is the Task Type which requires to sending Periodic Sensing Data collecting temperature, humidity and pressures in a period.
- ***Event Detected***
  It is the Task Type of Task Assignment which reports that some events that could be invasion, motion and etc happened, not to send Sensing data periodly.
- ***Query Response***
  It is the Task Type which requires response when being queried data.
- ***Hybrid***
  It is the Task Type which mixes two Task Types of Periodic, Event Detected, Query Response at the same time. Task Type is the field that expresses the string of task classifications. Its data include Periodic, Event Detected, Query Response and Hybrid.
  Also Time Info is a field including time date of task.

Time Info is a subAttribute which has initTime (first time allotted task), Period (time period requiring data report), TimeLimit (The value is limited reply time), ExpiredTime (available time of task).

Option Flags indicate Target Node, Aggregation Rule Set, Attachment and etc. Target Node is option which is able to have Attribute based Naming and it does not allow task message to special location. TargetID has Unicast/Broadcast address of Target S-Engine, Groupcast address in sensor network. Target Location is an option that executes some tasks of tracking in axis in sensor network. It is called Geocast..

3.7.2 Data Aggregation and Filtering

name	rule indicator	description
Equal	IS	Equal
Greater than	GRE	Greater than
Less than	LES	Less than
Similar Value	AsSimilarAs#	in the range of #(num)%
Logical Not	NOT	logical NOT
Logical AND	AND	logical AND
Logical OR	OR	logical OR

Table 1 Data Aggregation and Filtering Rule

The chart as below shows the Data Aggregation and Filtering policies. Table 1 shows features Rule Set.

Figure 8 shows the scenario that uses Data Aggregation and Filtering Rule.

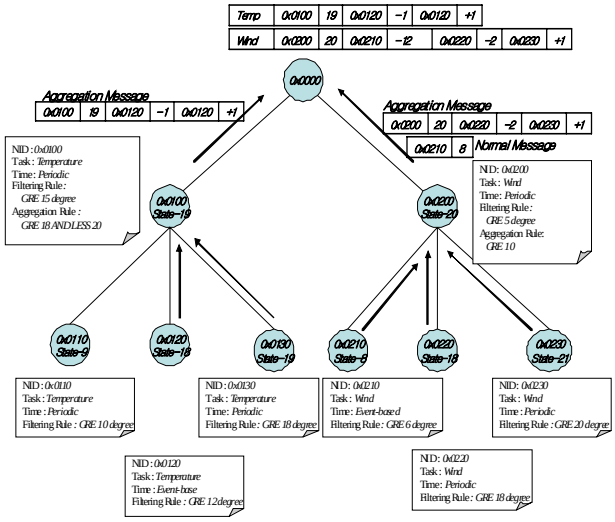

Figure 8 Scenario of Data Aggregation & Filtering

3.8 Power Management Module

Relay node manages power of sensor in sensor network.. it reports the servers managing all power ,balancing power mode of sensor node, expecting power level left in sensor node by using power state information that has Initial Info. Message including initial power information and period of sensor node.

3.8.1 Power Object

Power Object is included in Signaling Message to change Power Mode. It should include each field as below

PowerMode sensor node getting Power Mode

Timestamp Sending time of Power Object

ExpiredTime expired date of Power Object

Period time period when requiring wakeup

Priority Message Priority, Power Object can be ignored. When sensor node is doing some tasks depended on priority

Power mode has

Normal To execute some tasks

Sleep Mode To stop all task during the time set

Transmit Off To ban from transmit Message transmit

Receive Off To ban from Message Receive Message. In the case it is necessary to have periodic wakeup estimation

3.9 ID Channel State Information Management Module

ID, Channel and State Information Management Module collects and manages varieties of sensor nodes.

ID Management is easy to assign Logical ID of based 802.15.4 for Intra-Cluster Routing.

Channel Management function is to estimate Channel Energy Level and reassign Channel State Information Management function is to collect and manage varieties of sensor node.

3.9.1 Varieties of ID

There are three ID in a sensor node.

- **IEEE 64 bits Address**
  It is an Hardware address in MAC of IEEE 802.15.4. It is also an ID to grantee Identity of node and is assigned sensor node when being manufactured.
- **PAN ID**
  It is the16bits address to distinguish pan from pan. Coordinator Node gives PAN ID made in IEEE 802.15.4 when Coordinator Node and PAN ID are associated.
- **Logical ID**
  It is the16bits address to grantee Identity among S-Engine in same pan and cancel the defects that has overload to control long IEEE 64bits Address.
- **SNID** (sensor ID)
  It is necessary to distinguish pan from pan. And PAN ID and Logical ID.

3.9.2 Logical ID Assignment

It is assumed that MAC and PHY are applicable devices of IEEE 802.15.4. Both MAC and PHY give Logical ID to each sensor to efficiently route and manage.

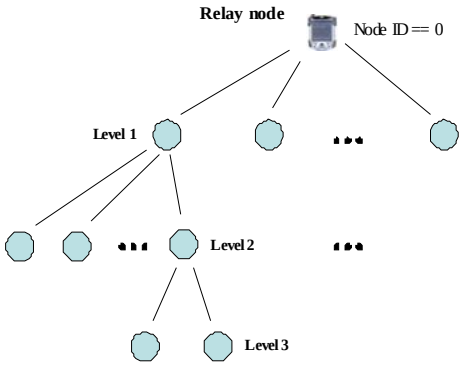

Figure 9 Cluster Hierarchy

Cluster is consisted of relay node in Hierarchy. Figure 9 shows that Logical ID structure which divides CID (Cluster ID) and NID (Node ID) Part

- **CID** (Cluster ID)

It represents characteristic ID that 4 MSB (Most Significant Bit) of Logical ID to distinguish cluster in PAN.

■ **NID** (Node ID)
Node ID classifies each node in cluster. It depends on level Where sensor node is assigned of logical ID.

3.9.3 Channel Management

First, Channel Management makes Cluster channel through ED Channel Scan of 802.15.4 in Relay node. Second it reassigns Channel of cluster. Third, it manages threshold estimations by Channel Management Policy provided by Upper Layer.

3.9.4 State Management

State of Sensor node represents State Object. Relay node can manage sensor node in cluster through State Object. The state of each Node is maintained and controlled by periodic State Update Message. State Object divides into eight classifications according to State object's condition.

State Object is consisted of those being as follows.

■ **ChannelState**
currentChannel It changes channel number to bit flag of integer.
transmitPower Transmit power level
energyLevel Checking Energy Level of Channel
channelsSupported It changes Available Channel Number into bit flag of integer as variable
channelScanInterval required period to scan channel(ED Scan)

■ **PowerState**
currentMode Present Power Mode
ExpectedMaxLifetime MAX Lifetime
RemainedLifetime It is expectation that Lifetime left

■ **SecurityState**
currentSecurityMode Present Security Mode

■ **TaskState**
numOfTask numbers of Task
taskList Checking Task Object doing

■ **MobilityState**
isBupdateRequired period of updating Bind ,namely, Whether it has Connect Request Message or not.
bindingUpdateInterval period of updating Bind

■ **IDState**
idType ID Type (Logical, PAN ID, SNID, IEEE 64bits address) of id field
id appropriate ID

■ **FullState**
There is consisted of ChannelState, PowerState, SecurityState, TaskState, MobilityState, IDState and StateUpdatePolicy

■ **StateUpdatePolicy**
isStateUpdateRequired Whether it updates or not
stateUpdatePeriod The period of State Info. Update Message sending to relay node both State Info. Update Message and State Object Descriptor field (estimation that which state object is embed) in Signaling message are sent. FullState that summarizes all state object is send when all required state.

4. Conclusion

Inter-Working Processing System has two modules that one is Communication Protocol and the other is Management Module.

Communication Protocol includes Communication Protocol, Security Protocol and Communication mapping module. Communication Protocol describes message Format and basic routing mechanism to communicate the relay node as gateway and sensor node. Security Protocol describes applicable frameworks to use Security Algorithm to Authentication, Integrity Checking and sensor node. Communication mapping module is divided to three modules which are address mapping module, signaling mapping module and QoS mapping module.

Management Module is consisted of Mobility Management, Task Management, and Power Management, ID_Channel_State Information Management sub-Modules. First, Management Module can manage the sensor node that is from the relay node linking IP network. Second, Mobility Management tracks location the sensor node in the relay node. Third, Task Management functions efficient Task Assignment and Data Aggregation. Fourth, Power Management checks consumption of power of the sensor node and changes power mode. Fifth, State Management function is to balance Intra-Cluster Routing in cluster. This paper represents an applicable system between IP network in All IP Network and sensor network.

REFERENCES

[1] L.B. Ruiz, J.M.S. Nogueira, and A.A.F. Loureiro. "MANNA: a management architecture for wireless sensor networks. IEEE Commun.Mag," 41(2),116-125, Feb.2003

[2] C. Srisathapornphat, C. Jaikaeo, C. Shen, Sensor information networking architecture, International Workshop Conference IEEE-EMBS, Hong Kong, 1998, pp. 1170 - 1173.

[3] A.P. Chandrakasan et al., "Design Considerations for Distributed Microsensor Systems," Proc. Custom Integrated Circuits Conf., IEEE, Piscataway,NJ, 1999, pp. 279-286.

[4] A. Sinha, A. Wang, and A.P. Chandrakasan,"Algorithmic Transforms for Efficient Energy Scalable Computation," Proc. Int'l Symp. on Low Power Electronics and Design, 2000, pp. 31-36.

[5] A. Sinha, A. Chandrakasan, Dynamic power management in wireless sensor networks, IEEE Design and Test of Computers, March/April 2001.