SARIF: A NOVEL FRAMEWORK FOR INTEGRATING WIRELESS SENSOR AND RFID NETWORKS

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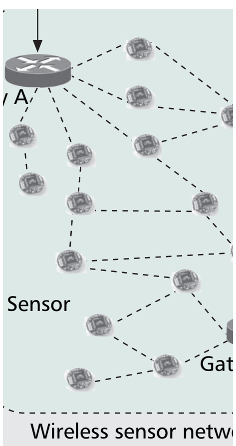

The authors identify key requirements for designing an efficient and flexible integration framework. Based on the requirements, we propose a sensor and an RFID integration framework (SARIF).

ABSTRACT

Radio frequency identification (RFID) is a promising technology for ubiquitous computing. When we embed RFID tags into environment-sensitive objects, RFID networks must be integrated with wireless sensor networks (WSNs). In this article, we first identify key requirements for designing an efficient and flexible integration framework. Based on the requirements, we propose a sensor and an RFID integration framework (SARIF). As middleware that operates on top of RFID networks and WSNs, SARIF enables the design of diverse applications flexibly and manages network resources efficiently. We also demonstrate the effectiveness of SARIF by implementing a prototype.

INTRODUCTION

As micro-electro mechanical systems and communication technologies evolve, devices are becoming smaller and more intelligent. This advance will proliferate ubiquitous computing in daily lives. One of the key technologies for ubiquitous computing is radio frequency identification (RFID), which enables an object (e.g., a product, animal, or person) to be identified at a short distance without manual intervention. Recently, various types of RFID tags and service platforms have become available in global commercial markets [1]. For example, Wal-Mart has published key requirements for its vendors to place RFID tags on their products [2], and the Canadian Cattle Identification Agency has started using RFID tags instead of barcodes [3].

The main purpose of RFID is to support object tracking and management, such as transport payment systems [4], baggage tracking systems at airports [5], and telemedicine [6]. These objects can be classified into two categories:
- Environment-sensitive objects (e.g., foods, flowers, and medicines) that are very sensitive to environmental conditions, such as temperature and humidity
- Environment-non-sensitive objects

In this work, we focus on environment-sensitive objects. As an illustrative example of environment-sensitive objects, we can consider an emergency situation, such as an earthquake that effects a large area. In this situation, we have a great need for the careful management of pharmaceutical products and blood pouches to enable timely and appropriate treatment to save lives. With a loss of facilities, medicines and blood pouches might be kept in temporary storage where they could deteriorate and become unusable. Hence, if the temperature (or any other physical condition) in the storage goes beyond a suitable range, the emergency control center must receive notification as soon as possible.

Although monitoring of the surrounding physical environment is indispensable in the management of environment-sensitive objects, existing RFID networks and services lack this capability. Let us take an example of an asset management system using RFID. By employing RFID alone, it is possible to keep track of the current location of a particular asset. However, the environmental information, such as temperature and humidity is not available. In such cases, the surrounding conditions can be learned through wireless sensor networks (WSNs), which are made up of many small-size computing and sensing devices with wireless communication facilities. WSNs can collect, aggregate, and analyze environmental information, and thus they can be employed in diverse applications such as fire detection, environment monitoring, and so on. Consequently, by integrating RFID systems with WSNs, we can build an object tracking and management system that can provide richer information about the environments of objects, as well as their locations of objects.

Recently, how to integrate RFID networks and WSNs has been investigated in a few works. Zhang and Wang [7] proposed system architectures, in which a gateway and a sensor in a wireless sensor network are integrated with an RFID reader and an RFID tag, respectively. Although the architectures can physically combine RFID

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and sensor networks, the study does not explore any design issues, for example, how to flexibly design an application that exploits the unique characteristics in both networks. Mason et al. [8] introduced a prototype system for asset tracking with RFID and sensor networks. The authors were concerned with how to interface between RFID readers and sensors by colocating an RFID reader and a sensor node. However, integrating RFID readers with sensors is not a cost-effective architecture when we consider the limited sensing range and the power consumption of sensors. Lopez et al. [9] have proposed a service framework that operates on top of a single network consisting of sensors and RFID tags. They considered mobility in the integrated network and defined three service types: home service, personal service, and object service. For these services, the authors presented how the network can be connected to the telecommunications infrastructure. However, they did not show how to process sensory data and tag identifiers in an integrated and systematic fashion.

To the best of our knowledge, so far the relation between an object (identified by its RFID tag) and its environmental parameters has not been taken into account explicitly in designing an integration architecture. In this article, we propose a novel framework, called SARIF (sensor and RFID integration framework), that enables an application to be designed flexibly while hiding the details of the RFID networks and WSNs. This means that a user must specify only the requirements of the objects in the corresponding application, and then SARIF will manage the environment-sensitive objects transparently. The remainder of this article is organized as follows. We first identify the key requirements for designing an integration framework. Then, we describe functional entities in SARIF and present an implementation. Finally, we summarize our work and discuss future directions.

Requirements for Integrating RFID Networks and WSNs

Unlike client-server networks, in which a large data stream is transferred from servers to clients, the main data flow in RFID networks and WSNs is from many devices (or clients) to a few servers. The sensors must be able to detect events, and the RFID readers must be able to recognize tags, and this information is then forwarded to one or more servers. When the information is obtained, a server then must combine the information from the RFID networks and WSNs within a time-frame that is short enough to allow appropriate action to be taken. The following requirements should be satisfied in the integration framework:

Energy Efficiency: RFID active tags and sensors have constraints, such as small size, low bandwidth, and a limited energy budget. Usually, in WSNs, it is not economical to replace the batteries of the sensors in the field, and therefore minimizing the energy consumption of the sensors is a critical problem. In addition, it is important to prolong the overall lifetime of a WSN by balancing the energy consumption among sensors. Typically, sensors located around the gateways must relay sensory data more frequently than those located far away. Therefore, the sensors in proximity to the gateway tend to deplete their energy more quickly. If all the sensors around a particular gateway die, the gateway becomes isolated, and then the life of the network (or system availability) ends. Consequently, energy efficiency in terms of minimizing energy consumption and balanced load distribution among sensors are required for the integration framework.

Timeliness and Reliability: Timely and reliable data delivery is indispensable for an integration system, that is, all data generated from RFID networks or WSNs should be delivered to the applications (or users) within tolerable end-to-end latency. Then, decisions based on the received tag identifiers and sensory data will be made at the application, which may immediately take appropriate action. Also, reliability requirements should be taken into account. The degree of reliability is dependent on the task. In a critical task, a high degree of reliability is required in delivering events. But if partial reliability (e.g., 70 percent of sensory data must be delivered) is permitted, it is possible to trade energy consumption against reliability by adjusting retransmission parameters.

Correctness: All the tasks should be correctly assigned to the relevant sensors and RFID readers. Because the wireless channel condition is often poor in WSNs, it is important to confirm whether the desired task is transferred and the designated sensors received the task.

Network Maintenance: Since many devices may be installed in a WSN, manual configuration may not be feasible. Hence, when a sensor fails due to lack of energy or a malfunction, the network must be able to isolate the failed sensor and report it to the application.

The Sensor and RFID Integration Framework

SARIF can play a vital role in the provision of context-aware ubiquitous services by integrating WSNs and RFID networks. As shown in Fig. 1, the whole integrated system comprises an integration server, RFID networks, and WSNs. The integration server is a key element that embodies SARIF and manages all tasks in RFID networks and WSNs. RFID networks include an EPC (electronic product code) information server, RFID readers and RFID tags, whereas WSNs consist of gateway nodes and sensor nodes.

In an RFID network, an RFID reader scans a tag (or multiple tags concurrently) and transmits the tag identifier to the EPC information server. The EPC information server maintains attributes for each tag identifier and transmits the attributes to the integration server. Depending on the information received from the RFID network, the integration server initiates a particular task in the WSN. To perform that task, the integration server first retrieves the relevant attributes and constructs a message, which in turn is distributed to the WSN through one or

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The RFID task manager is required to interwork with the RFID network. This component receives the EPC information from the RFID network and stores it to the event data DB. If necessary, the RFID task manager can be assigned a task by the information processing manager.

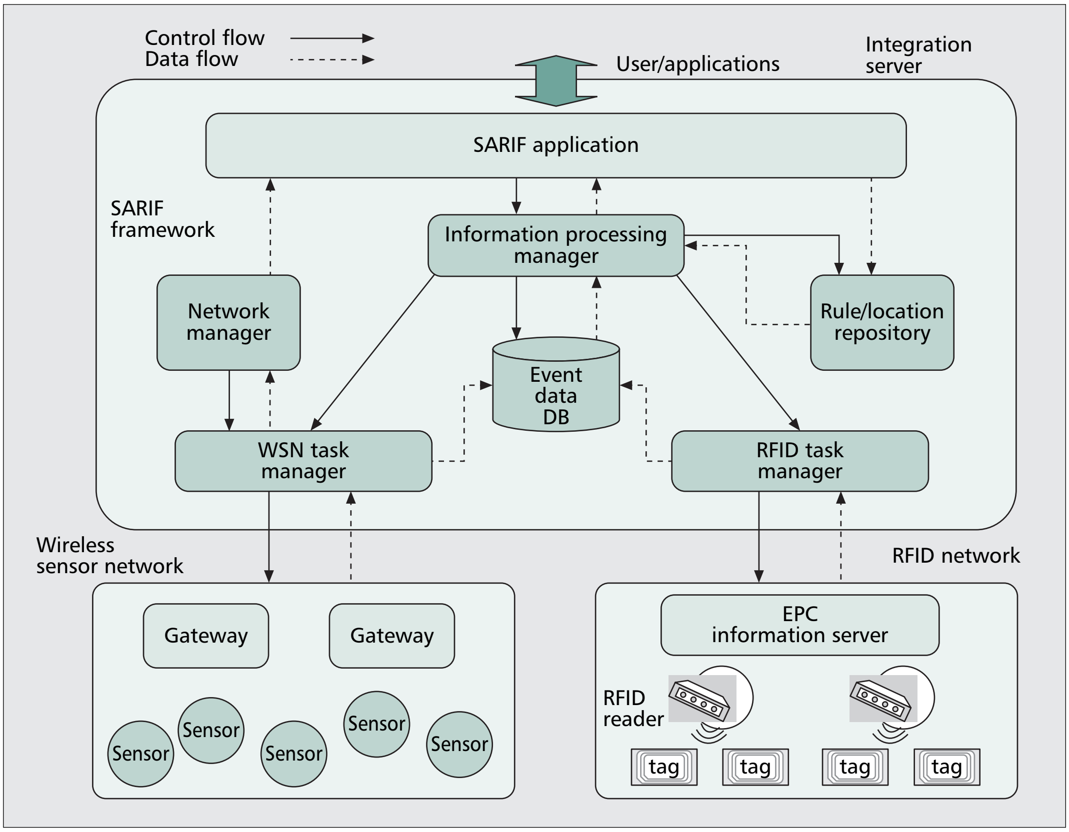

Figure 1. *Functional components of SARIF.*

more gateways. Next, every sensor to which the task is assigned starts sensing the environmental conditions and processes them by using event processing techniques. Depending on the operation defined by the task, the sensors report raw sensory data to the gateway(s). At intermediate sensors along the routing path between the gateway(s) and the sensors, in-network processing mechanisms, such as data aggregation or filtering can be performed while satisfying the given delay and reliability requirements.

In some cases, the integration server must access the RFID network to assign RFID tasks. For instance, if an emergency event occurs someplace, how many instances of a particular object that is stocked in the place should be collected? After receiving their RFID tasks, the relevant RFID readers scan RFID tags within their ranges and transmit the scanned identifiers to the integration server through the EPC information server.

In the following sections, we detail the following functional components in SARIF: *WSN task manager, RFID task manager, network manager, information processing manager, rule/location repository, event data DB*, and *SARIF application*.

WSN Task Manager

The WSN task manager takes charge of task (re)assignment to manage the operations of the sensors. When a task is issued by the information processing manager or the network manager, the WSN task manager processes the task and adapts it to the WSN environments, considering sensor types and locations. That is, the WSN task manager, if necessary, should divide the task into one or more subtasks that can be assigned to a specific sensor(s) or sensor group(s). The subtasks are transferred to the WSN through multiple gateways that relay (or broadcast) each subtask to specific sensors (or sensor groups), using a task assignment protocol. When sensory data are reported by sensors, the WSN task manager stores them in the event data database (DB) to enable other components to access them. If the energy level of the network is reported, it is transferred to the network manager for network load balance or maintenance.

RFID Task Manager

The RFID task manager is required to interwork with the RFID network. This component receives the EPC information from the RFID network and stores it to the event data DB. If necessary, the RFID task manager can be assigned a task by the information processing manager. Like the WSN task manager, the RFID task manager can transform a task into one or more RFID subtasks, each of which is transferred to an RFID reader (or a group of readers) to locate objects specified by the EPC information server.

Network Manager

The primary responsibility of the network manager is to provide the means for organizing the WSN and to keep track of the states of the sensors.[1] To facilitate this functionality, control

[1] *As RFID networks are not prone to failure, we believe RFID network maintenance is not strictly required.*

Object_name	Suitable_condition	Warning_condition	…
Apple	temp: 4~5°C humid: 30~50% …	temp <-1°C or temp > 10°C humid < 25% or humid > 55% …	…
Blood pouch	temp: -10~-5°C humid: 10~15% …	temp <-15°C or temp > 0°C humid < 5% or humid > 20% …	…
⋮			

(a)

Sensor_ID	Location_ID
Sen_1	Warehouse A
Sen_2	Warehouse A
Sen_3	Warehouse B
Sen_4	Warehouse B
⋮	

Location_ID	Object_name
Warehouse A	Apple
Warehouse B	Blood pouch
⋮	

Reader_ID	Warehouse A
Rd_1	Warehouse A
Rd_2	Warehouse B
⋮	

(b)

Figure 2. *a) Rule table; b) location tables.*

messages are propagated to the WSN, in part or in whole. In other words, each gateway may periodically flood an advertisement message network-wide. For residual energy monitoring and failure detection, the residual energy level of each sensor is periodically reported to the network manager through the WSN task manager. Also, the network manager, depending on the energy level of the sensors, requests the WSN task manager to adjust the sensors operations (e.g., the frequency of reporting and the wake-up/sleep scheduling). Moreover, this component should give notification to users when any region cannot be sensed due to sensor energy depletion or node malfunction.

Rule/Location Repository

The rule/location repository maintains a list of available rules and location mapping tables for sensors and readers. The information processing manager accesses the rule/location repository to retrieve the information required to construct a task for sensor and RFID networks or to return the answers to queries from applications or users. Two rules are illustrated in Fig. 2a, where an object requires environmental conditions for temperature and humidity. Figure 2b shows three location tables by which the information processing manager can map the positions of the sensors to those of the readers and vice versa for location tracking. For instance, when a new object enters the RFID network and its information is delivered to the integration server, the information processing manager triggers a new task for sensors according to the rule/location repository.

Information Processing Manager

The information processing manager handles incoming sensory and RFID data by accessing the event data DB. For each query request from users, the information processing manager provides advanced processing techniques such as data aggregation, filtering, and mapping. When it receives a query about historic data from a SARIF application, the information processing manager accesses the event data DB and the rule/location repository and processes the relevant data to return results. When the query requires the present or future data, it look ups the rule/location repository and dispatch tasks to the WSN and/or the RFID network. As requested by the tasks, the WSN and/or the RFID network reports the requested data to the event data DB.

Other Components

The event data DB stores raw data collected from the sensor network and the RFID network. The raw data are transformed into the high-level information for the user by the information processing manager. A SARIF application can provide entry points for external applications (or users) in various ways, for example, hypertext transfer protocol (HTTP) and short message service (SMS).

SARIF Prototype Implementation

To validate SARIF, we implement a SARIF prototype and perform measurement studies.

Platform Configuration

For measurement studies, we built a SARIF prototype testbed where there are 16 MICA2 motes [10] and two gateways as illustrated in Fig. 3. A MICA2 mote has a 38.4 kbps radio transceiver on a 900-MHz channel. A MTS 300 [10], combined with a MICA2 mote, is a sensor board with a variety of sensing modalities, such as light, temperature, and sound. The sensor node runs on top of TinyOS [11], which is modified for the sensor network operations in SARIF. DRIVE [12] is used to emulate the RFID network. DRIVE is an integrated development environment from IBM that simplifies the development of RFID applications by enabling the composition of model-based components. We omit the details of DRIVE due to the limitation of space. Instead, we elaborate on the WSN and the integration server.

Software Development

The programs for sensors are written in NesC [13], and their structure is illustrated in Fig. 4, where the components in boxes are built-in functions in TinyOS, and the components in ovals are developed for this study. The *SinkM* compo-

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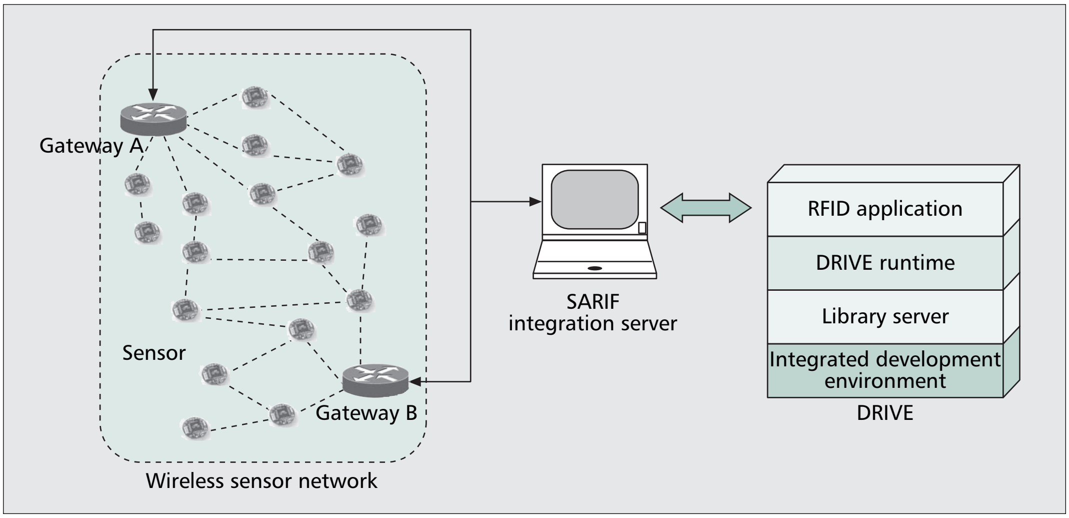
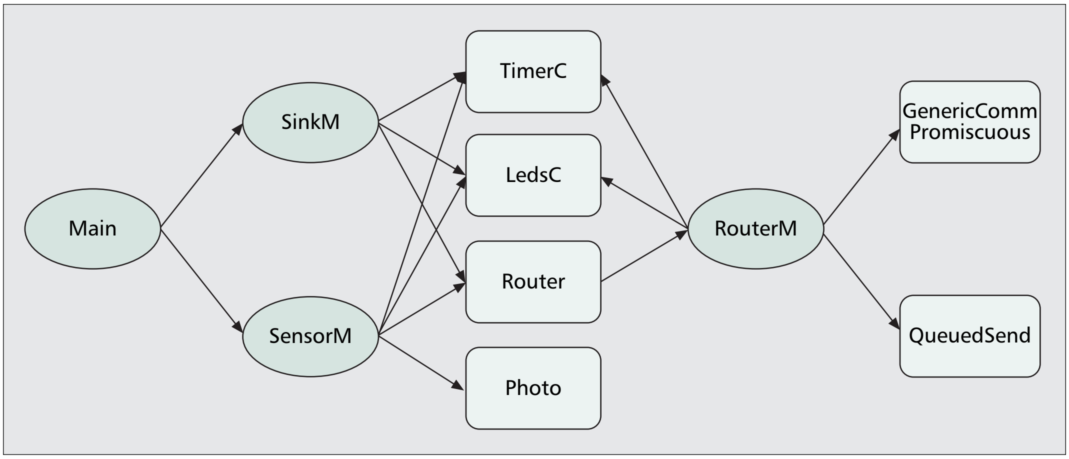


■ **Figure 3.** *SARIF prototype architecture.*



■ **Figure 4.** *Sensor node structure.*

nent contains the program code for gateway functions, and it calls built-in, low-level functions. In addition, SinkM distributes subtasks to the sensors and receives sensory raw data and residual energy reports from the sensors. On the other hand, the component *SensorM* implements the sensor node operations and calls *TimerC*, *LedsC*, *photo*, and *Router* functions for event sensing and data reporting. TimerC checks the time of incoming/outgoing events and LedsC manages the LEDs on the MICA board to display events of sending or receiving data. Photo obtains the sensory data from the sensing board, whereas the router sends/receives data by a WSN routing protocol and sends control messages to the RouterM component. The RouterM component implements a simple proactive routing protocol and also calls TimerC, LedsC, *GenericCommPromiscuous*, and *QueuedSend* functions. GenericCommPromiscuous implements B-MAC [14] as a medium access control (MAC) protocol in the WSN, and QueuedSend provides the data queue from which data are transmitted to other nodes.

For integrating the WSN and the RFID network, an integration server implemented by JAVA is located between the two networks. The integration server implements all the functional components of SARIF (as shown in Fig. 1) and provides a user interface, for example, beep sounds and query inputs.

Wireless Sensor Network Protocols

For efficient integration, we devise a task assignment scheme and a dynamic load balancing scheme, which can extend the battery life of the sensors and ensure that tasks are dispatched correctly.

The task assignment scheme has three phases: task (re)assignment, (re)assignment validation, and termination. In the first phase, the integration server parses an instruction from the RFID network or a query from users and generates a sensor task. Then the *WSN task manager* sends a sensor subtask to the gateways, which transform the subtask to an appropriate message for dissemination to the relevant sensor nodes. In the second phase, on receipt of the task, the sensor should check whether the task pertains to the sensor. If it has received a valid task, the sensor replies with an acknowledgement message to the gateway, which in turn is delivered to the WSN task manager. If a duplicate task arrives, it should be dropped. If the integration server does not receive an acknowledgement message from some of the sensors, it may retransmit the task to these sensors, depending on the application requirements. In the last phase, the task process is terminated with the expiration of the task duration.

For the balanced energy consumption network-wide [15], the integration server calculates weights for each gateway and disseminates these values to the sensors. Actually, the gateways themselves are mains-powered, and the weight allocated to a gateway is a measure of the average remaining energy level at the one-hop neighbors of the gateway. To keep the weights up-to-date, the one-hop neighbors of a gateway periodically feedback their remaining energies to the integration server through the gateway. The weights are periodically updated and disseminated network-wide.

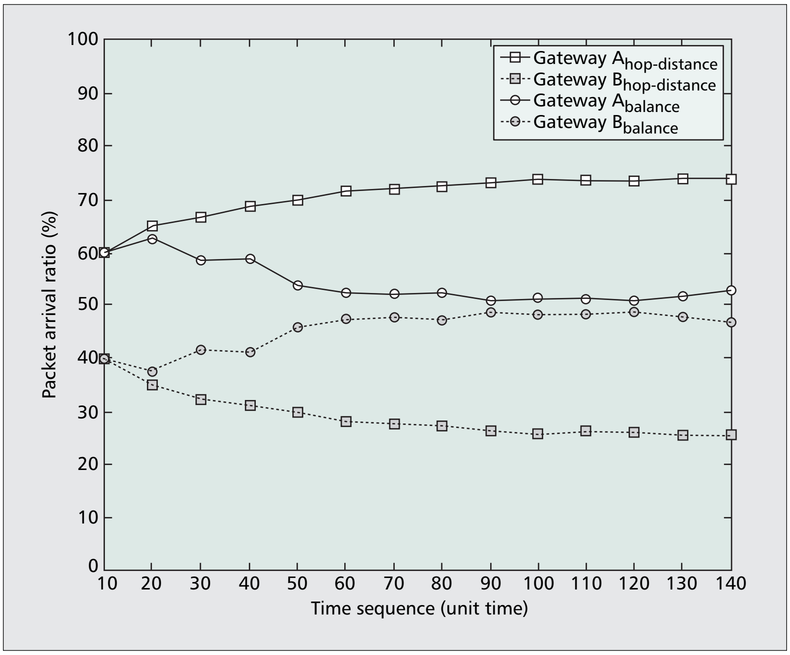
Whenever a task is (re)assigned or the weights are advertised on the network, each sensor node calculates the forwarding probability for each gateway. Both weights and the hop counts are considered for calculating the forwarding probabilities for each gateway. For each sensory data report, sensor nodes select one of the gateways as the destination depending on the forwarding probabilities. Thus, the proposed task-assignment scheme enables load balancing among the gateways and increases the network lifetime.

Measurement Results

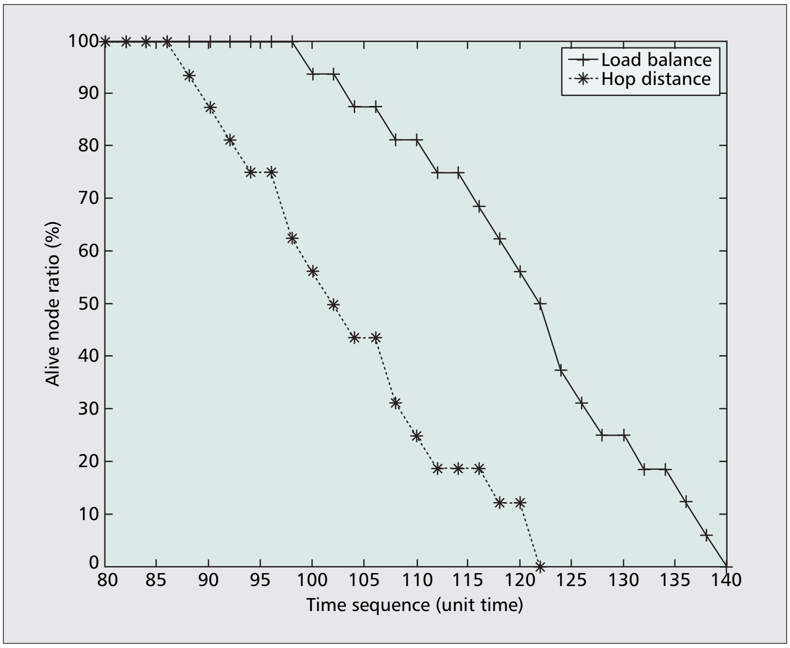
Using the SARIF prototype, we evaluate the effectiveness of load balancing in SARIF. In the network model, gateways A and B have five and three one-hop neighbors, respectively. The two gateways are located at the upper-left and lower-right corners of the test area. The 16 sensor nodes report data (e.g., sensory data and remaining energy levels) to a gateway every unit time.

We measure the ratio between the numbers of packets arriving at each gateway and the proportion of the nodes staying alive over time. We compare the load balancing scheme used in SARIF with the hop distance-based scheme, in which packets are simply routed to the closest gateway, and there is no load balancing.

Figure 5 and Fig. 6 show the packet arrival ratio for each gateway and the proportion of live nodes for each scheme. As shown in Fig. 5, the packet arrival ratio is distributed almost evenly between the two gateways in the load balancing scheme, whereas the packet arrival ratio at gateway A is much higher than the one at gateway B in the hop distance-based scheme. This is because, in the load-balancing scheme, all sensors select one of the gateways by the forwarding probability that favors a gateway whose one-hop neighbors' remaining energy levels are higher. On the other hand, in the hop distance-based scheme, sensors always choose a gateway that is closer. Figure 6 shows that the load-balancing scheme achieves the better energy efficiency by distributing the traffic load almost evenly between the gateways. In the hop distance-based scheme, it can be seen that the sensors around gateway B die more rapidly that those near gateway A, because there are fewer sensors around gateway B, and they are overloaded with traffic.



■ **Figure 5.** *Proportion of packets arriving at each gateway.*



■ **Figure 6.** *Proportion of sensors remaining alive over time.*

In the load balancing scheme, the traffic load is not biased to a specific gateway since sensors choose a gateway by considering the one-hop neighbors' energy levels of each gateway.

Conclusion

In this article, we proposed a novel framework, SARIF, that integrates RFID networks and WSNs for environment-sensitive object tracking and management. We first identified key requirements to integrate both technologies and described the functional components in SARIF. By implementing a prototype, we demonstrated that SARIF can achieve energy efficiency by

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ACKNOWLEDGMENT

This work is supported by the IT R&D program of MIC/IITA [2005-S601-02, Core Infrastructure Technology Development for RFID Adoption] and the Ubiquitous Computing and Network (UCN) Project, the Ministry of Information and Communication (MIC) 21st-Century Frontier R&D Program in Korea.

REFERENCES

[1] R. Want, "Enabling Ubiquitous Sensing with RFID," *IEEE Comp.*, vol. 37, no. 4, Apr. 2004, pp. 84–86.
[2] D. H. Williams, "The Strategic Implications of Wal-Mart's RFID Mandate," *Directions*, July. 2004.
[3] "Canadian Government Commits to RFID Cattle Tracking," available at http://www.rfidgazette.org/2005/06/index.html
[4] Smart Card Alliance, http://www.smartcardalliance.org
[5] B. Brewin, "Delta Has Success in RFID Baggage Tag Test," *Computerworld*, Dec. 2003.
[6] Y. Xiao *et al.*, "Security and Privacy in RFID and Applications in Telemedicine," *IEEE Commun. Mag.*, vol. 44, no. 4, Apr. 2006, pp. 64–72.
[7] L. Zhang and Z. Wang, "Integration of RFID into Wireless Sensor Networks: Architectures, Opportunities and Challenging Problems," *Proc. Int'l. Conf.Grid and Cooperative Comp. Wksps.*, Oct. 2006.
[8] A. Mason, A. Shaw, and A. Al-Shamma, "Asset Tracking: Beyond RFID," *Proc. Annual Postgraduate Symp. Convergence of Telecommun., Networking, and Broadcasting*, June 2006.
[9] T. S. Lopez, D. Kim, and T. Park, "Service Framework for Mobile Ubiquitous Sensor Networks and RFID," *Proc. IEEE Int'l. Symp. Wireless Pervasive Comp.*, Jan. 2006.
[10] http://www.xbow.com/Products/productdetails.asp
[11] http://www.tinyos.net
[12] http://www-903.ibm.com/kr/ubiquitous/sensor
[13] D. Gay *et al.*, *nesC 1.1 Language Reference Manual*, May 2003.
[14] J. Polastre, J. Hill, and D. Culler, "Versatile Low Power Media Access for Wireless Sensor Networks," *Proc. ACM Conf. Embedded Networked Sensor Sys.*, Nov. 2004.
[15] S. Pack *et al.*, "A Dynamic Load Balancing Scheme in Multi-Sink Wireless Sensor Networks," Technical-Report-mmlab-0612, Dec. 2006.

BIOGRAPHIES

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