

A Survey on Middleware for Wireless Sensor Networks

Bhaskar Bhuyan¹, Hiren Kumar Deva Sarma^{1,*}, Nityananda Sarma²

¹Dept of IT, Sikkim Manipal Institute of Technology, Mazitar, Rangpo, Sikkim, 737136, India

²Dept of Computer Science and Engineering, Tezpur University, Napaam, 784028, India

Abstract The wireless sensor network is an emerging field and it offers a wide variety of applications that include habitat monitoring, object tracking, environmental surveillance, military systems, health care, precision agriculture, building monitoring etc. However, due to their unique characteristics and the constraints they suffer from, sensor networks pose considerable challenges and make application development quite complicated. There is a necessity of an intermediate software layer between the sensor hardware and the sensor network applications that may be termed as middleware. Middleware is necessary in order to fully meet the design and implementation challenges of wireless sensor networks. In this paper, we highlight the main design challenges of wireless sensor networks and present a study on the existing middleware approaches for wireless sensor networks. We also discuss the scope of Quality of Service support at middleware layer for wireless sensor networks. The paper is concluded with future research directions in the middleware level to meet the requirements of emerging applications of wireless sensor networks.

Keywords Wireless Sensor Networks, Middleware, Quality of Service

1. Introduction

Wireless Sensor Networks (WSNs) have emerged as a rapidly growing field in the recent years. It has attracted significant attention from the researchers involved in both academic and industrial communities. A typical wireless sensor network consists of a collection of tiny inexpensive sensor nodes. This collection may be in the tune of hundreds or thousands of sensor nodes and these nodes communicate through wireless media, i.e., radio. The sensor nodes are deployed randomly and typically in harsh environments. Depending on the application type, a sink node may be located in a remote corner which is connected to the sensor nodes through wireless channels. A typical sensor network setup is shown in Figure 1. The sensor nodes are resource constrained whereas the sink node is generally resourceful. Such an arrangement of sensor nodes and the sink node can be used for building distributed systems for data collection and processing. Thus, a wireless sensor network involves the tasks like on-field signal sensing and processing, in-network data aggregation and wireless communication. The wireless sensor networks are self starting and self organized in nature[1][36]. The technical advancements in the field of hardware and wireless communication are significant in recent times. Therefore, the features provided by computing and communication hardware require to be matched by an appropriate software layer in the wireless sensor network

system. This should enable programmers to easily and efficiently exploit the capabilities of the underlying hardware and other opportunities provided by the current communication technologies. The wireless sensor networks support a wide range of applications such as habitat monitoring, object tracking, environmental surveillance, military systems, health care, precision agriculture, building monitoring etc[1].

The term middleware refers to the software layer and tools that hides the underlying complexity and heterogeneity of the hardware and network platforms. The major responsibility of middleware is to make the management of system resources easier. This in turn should facilitate overall improvement in the system performance[2]. The main purpose of middleware in wireless sensor networks is to support the development, maintenance, deployment and execution of sensing based applications[23]. The middleware used in wireless sensor networks provides the desired services for sensing-based pervasive computing applications. These applications make use of wireless sensor networks as a system and related embedded operating systems or firmware of the sensor nodes. Generally, the middleware performs the role of a translator that fills up the gap between the high level requirements of different applications running on wireless sensor networks and the complexity of different operations in the underlying sensor node hardware. The various requirements of the wireless sensor network applications are flexibility, reliability and reusability[35]. The complexity of the operations with a wireless sensor network is characterized by the inherent properties of the wireless sensor network. Some of those properties are constrained resources, frequent changes in the

* Corresponding author:

hirenkdsarma@gmail.com(Hiren Kumar Deva Sarma)

Published online at <http://journal.sapub.org/jwnc>

Copyright © 2014 Scientific & Academic Publishing. All Rights Reserved

network topology and low level embedded operating system application programming interfaces (OS APIs)[3].

The middleware facilitates the programmer in developing applications for wireless sensor networks in several ways as mentioned below[3]:

- Middleware provides appropriate system abstraction. It hides the underlying hardware complexities. Therefore, the programmer can focus on the application logic without bothering too much about the lower level implementation details.
- Middleware provides reusable code services. Therefore, the application programmer can deploy and execute the applications without being troubled with complex and tedious functions.
- Middleware facilitates the programmer in network infrastructure management. This is achieved by providing efficient resource services, e.g., power management, bandwidth management etc and also system security related services.

Figure 2 shows the logical organization of the middleware layer with respect to the sensor node bare hardware and the user applications of wireless sensor networks. The middleware layer interacts with both the user application

layer and the sensor node hardware layer. The operating system is considered to be embedded along with the sensor node hardware layer. Thus the middleware layer performs the role of mediator between the user applications and the sensor node hardware. The major objective of having this middleware layer is to facilitate the interaction of user applications with the sensor node hardware. Although the major role played by the middleware is of mediator as mentioned above, it also facilitates various activities at user level. At a more detailed level of discussion, it may be summarized that there are several purposes behind the deployment of middleware in wireless sensor network system. These purposes may be enlisted as mentioned below in Figure 3.

The user application development in wireless sensor network needs support from the node hardware as well. Similarly, deployment, execution and maintenance of user applications too need hardware level interaction and support. On the other hand, the applications need various services from the underlying hardware. These are the various areas in which middleware plays different roles. And these are the purposes behind the design of middleware so that the middleware can support user applications in different ways.

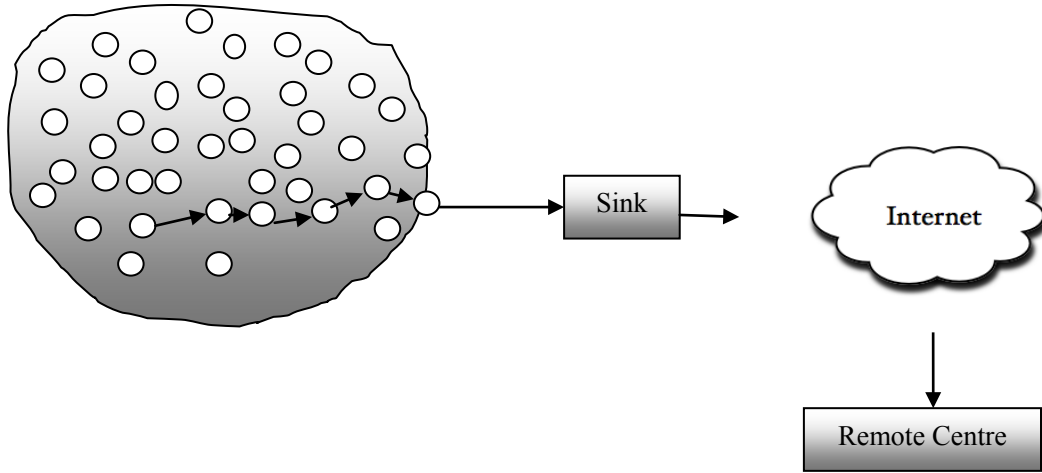


Figure 1. Wireless sensor network architecture

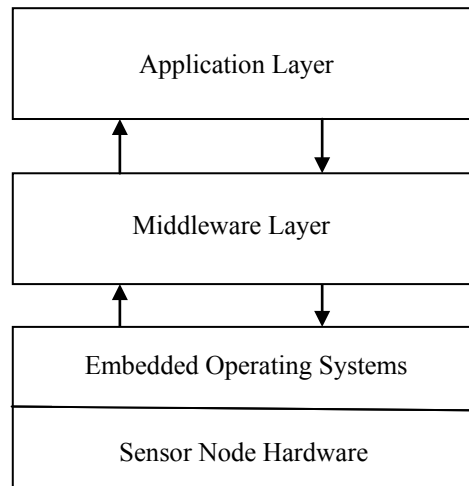


Figure 2. Logical organization of middleware

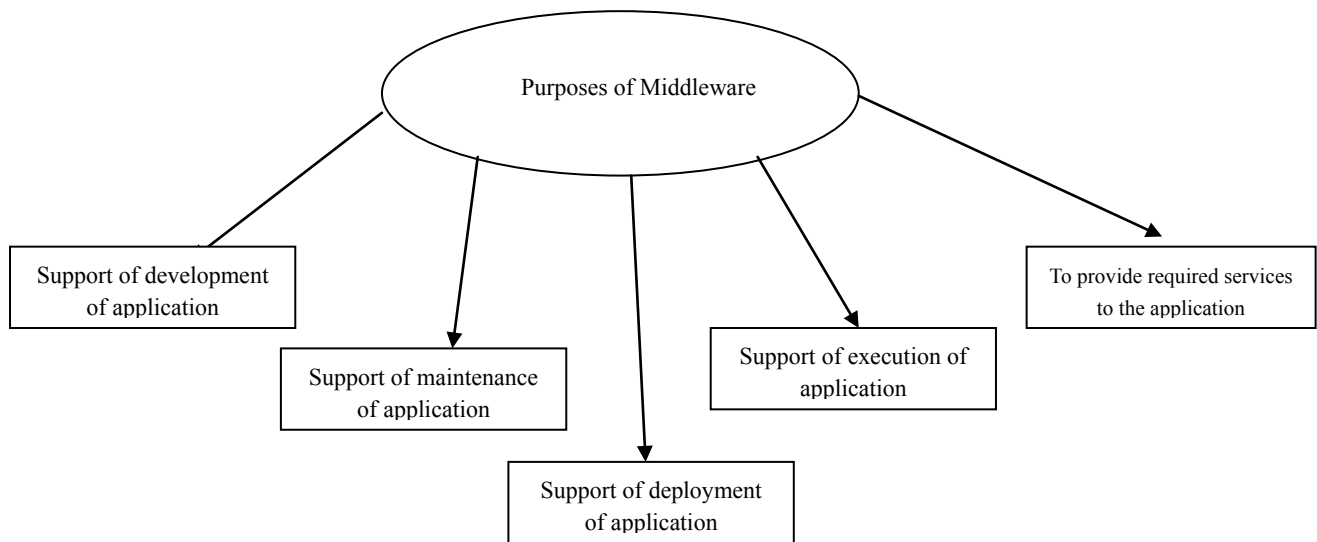


Figure 3. Purposes of middleware

2. Related Work

There are some reported works with respect to middleware technology in wireless sensor networks. W.B. Heinzelman et al presented the study related to the necessity of middleware support in wireless sensor network in[13], (2004). Salem Hadim and Nader Mohamed presented a study on middleware approaches in wireless sensor networks in[23], (2006). Wasim Masri et al presented a comparative study of different middleware technologies applicable to wireless sensor networks in[16], (2007). M.M. Wang et al reported a survey on middleware in wireless sensor networks in[3], (2008). N. Mohammed et al presented a survey on service oriented middleware for wireless sensor networks in[35], (2011).

3. Challenges in Designing Middleware for Wireless Sensor Networks

The traditional middleware used in distributed systems are generally heavy weight in the sense that they require huge memory space and also computation requirements are very high[4]. Since the sensor nodes are resource constrained, these solutions are not suitable for wireless sensor networks. The sensor networks suffer from limited energy, limited processing power and also limited memory. Therefore, the middleware solutions for wireless sensor networks should be light weight and these solutions should address the unique constraints such networks suffer from. Some of these constraints the wireless sensor networks suffer from are ad-hoc deployment of the nodes, limited computing and communication resources and also dynamic operating environments[1]. Some of the differences between traditional middleware used in distributed systems and the middleware used in wireless sensor networks are mentioned

below:

- Most of the distributed system middleware techniques proposed in[5][6] aim at providing transparency by hiding the context information. In contrast, wireless sensor network based applications should usually be context aware.
- Although many mobile computing middleware[7] support context awareness, their major concern is how to satisfy the interest of individual mobile node continuously taking into consideration the node mobility factor. On the other hand, wireless sensor network based systems are data centric and it reflects the whole application interest but not a single portion of it.
- Data aggregation or data fusion has no significance in traditional distributed system middleware. On the other hand, data aggregation in the intermediate nodes of the forwarding path in a wireless sensor network is highly desirable.
- The traditional distributed systems may be resourceful. Therefore, the middleware designed for such systems can be heavyweight which demands large memory space and high computing capability in the nodes. Unlike the nodes in such traditional distributed systems, the sensor nodes are simple with limited processing power, limited storage and finite as well as limited onboard battery power. Therefore, the middleware for resource constrained wireless sensor networks should be light weight so that these can be implemented in the simple sensor nodes. The middleware solution for wireless sensor network should be energy efficient. Moreover, the design of the middleware for wireless sensor networks should also take into consideration the factors like sensor node hardware, operating systems, routing protocols and applications[8][9][10].

The design and development of successful middleware solutions for wireless sensor networks need to address several challenges. Figure 4 shows different challenges in the middleware design for wireless sensor networks.

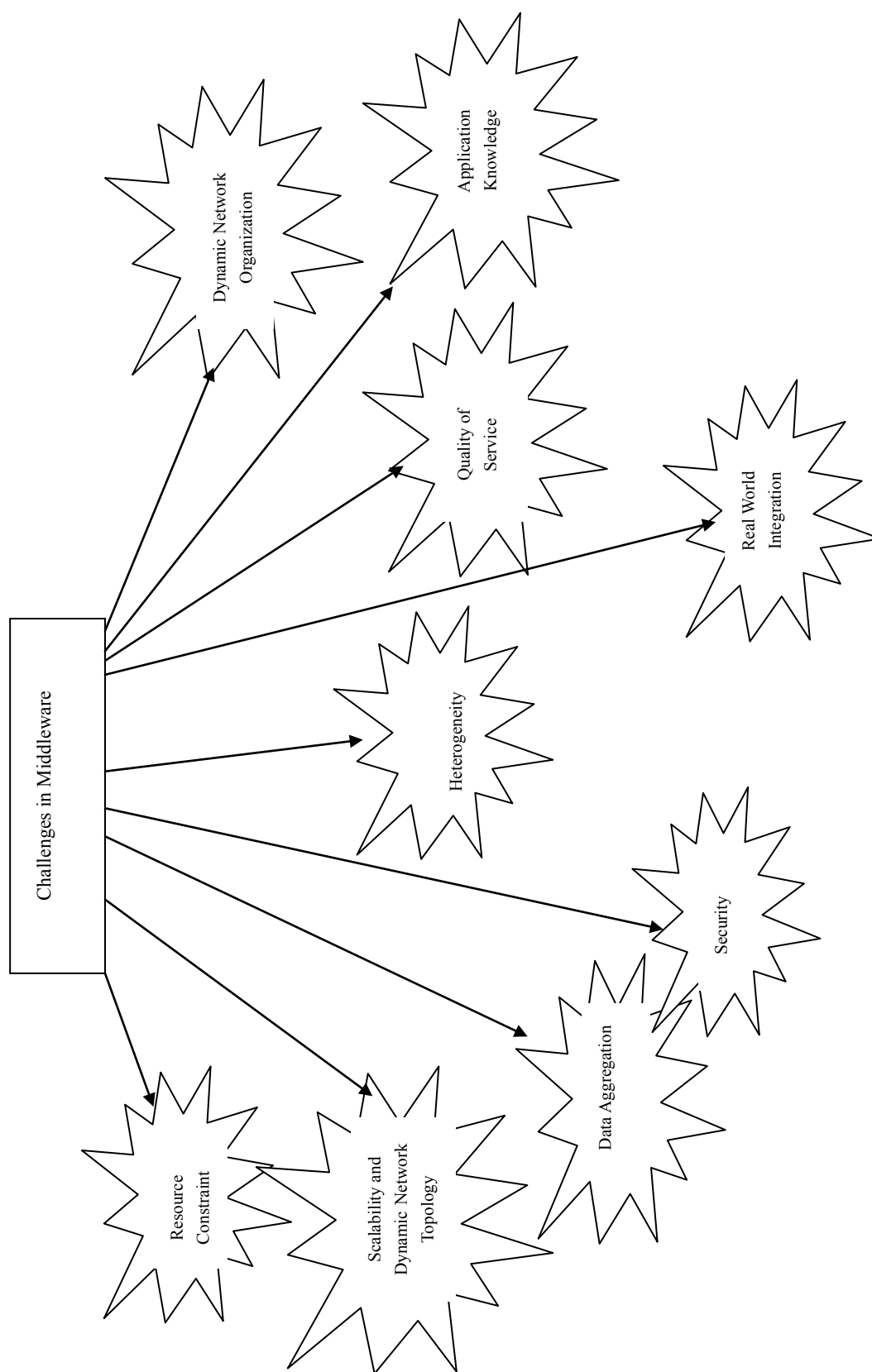


Figure 4. Challenges in middleware design for wireless sensor networks

The design challenges are discussed below.

a) **Managing limited battery power and resources:** Due to the advancement of microelectronics, the sensor nodes or the other embedded devices can be designed in the order of cubic centimeter[11]. Constrained resource is the major concern with these tiny devices. These nodes are equipped with very limited amount of storage space and very modest processing capability. Generally tiny inexpensive sensor nodes are deployed in the scale of hundreds or even thousands, and that too in a remote and hostile environment. The only possible way to access these devices is via wireless media. Therefore, the middleware designed for these types of devices should provide mechanisms for efficient use of limited processing capability and limited memory while enabling low power communications.

b) **Scalability, mobility and dynamic network topology:** Efficient middleware services must be capable of maintaining desirable performance levels along with the growth of the network size. In a wireless sensor network setup, network topology changes very frequently. This is due to several factors such as node failure, moving obstacles, node mobility and interference. Middleware should support sensor network to do its basic operations like sensing, data processing and communication despite these dynamics present in the network. The middleware should be able to cope up with the changing network environment. Thus middleware needs to be adaptive and also should support mechanisms for fault tolerance. Moreover, the middleware needs to support sensor node self-configuration and self maintenance.

c) **Heterogeneity:** Middleware for wireless sensor network should meet the challenge of bridging the gap between heterogeneous hardware technology and the pervasive application level operations such as configuration, execution and communication[23][34]. Since the sensor nodes are deployed in large scale, the entire collection of nodes may come with different hardware components. The middleware must handle such heterogeneity.

d) **Real world integration:** Most of the sensor network applications are real time in nature where time and space are extremely important. Therefore, middleware should be able to provide real time services to adapt to the changes and to provide consistent data.

e) **Data aggregation:** Most of the sensor network applications generate redundant data specific to a particular region. This behavior of sensor network opens the scope of in-network data aggregation. The redundancy in the sensory data is eliminated through such data processing. Thus the volume of data to be transmitted to the sink node is minimized. This optimization approach helps in saving energy in the sensor nodes which is a very important and limited resource type in a wireless sensor network setup[12].

f) **Dynamic network organization:** Sensor network middleware must handle efficient utilization of the resources that are dynamic in nature such as energy, bandwidth, processing power etc. These resources keep on varying in their respective amount available in the network system. The

middleware also should give support to long running applications. The routing algorithms and other protocols and algorithms also need to be designed considering energy efficiency and resource efficiency as a whole as one prime design objective. Such protocols and algorithms along with the middleware should enable the network to run as long as possible.

g) **Node mobility:** Depending on the application type the sensor nodes in a wireless sensor network may be static or even mobile. The mobility of sensor nodes introduces more complexities in such network systems. Due to mobility of the nodes, the network topology becomes even more dynamic and under such dynamic topology the communication may become more complex. Again resource constraints like limited battery power, limited communication bandwidth etc shall pose more design challenges for designing middleware for mobile wireless sensor networks. In order to support long running applications in mobile wireless sensor networks the protocols and algorithms must be designed taking mobility of the nodes into consideration. The middleware layer also needs to consider the mobility of the sensor nodes.

h) **Application knowledge:** Wireless sensor network middleware must include mechanisms for injecting application knowledge of wireless sensor network infrastructure[13]. This allows developers to map application communication requirements to network parameters which enable them to fine tune the network monitoring process. Although middleware is intended to support a wide range of applications, most of the existing middleware are application specific. Therefore, the trade-off between the degree of application specificity and generality of the middleware are to be explored[13].

i) **Quality of service:** Quality of Service (QoS) can be viewed from two perspectives in wireless sensor networks. These are application specific and network specific[14]. Application specific QoS refers to Quality of Service parameters specific to applications such as data accuracy, aggregation delay, fault tolerance, coverage, optimum number of active sensors etc. Network specific QoS refers to how the supporting communication network can fulfill application needs by efficient usage of the network resources such as bandwidth and power consumption. The traditional QoS mechanisms used in wired network can not be directly applied to wireless sensor networks mainly due to their resource constrained environment. Therefore, middleware should be able to provide novel mechanisms to maintain and support QoS over a long period of time by taking the resource constraints in wireless sensor networks into consideration. The middleware should be able to adapt to the changes dynamically and in real time.

j) **Security:** Wireless sensor networks can also be deployed in applications that deal with sensitive and confidential information. For example, the military and surveillance applications as well as applications dealing with mission critical operations may demand high level of security of information. The unattended and large deployment of sensor nodes in harsh environments may

increase their exposure to malicious intrusion and attacks such as eavesdropping, denial of service attack etc[15]. The standard security algorithms are not suitable for wireless sensor networks due to the limitations like processing capability, on board battery power and memory space in the sensor nodes. Therefore, middleware developed for wireless sensor networks should address all these issues and give better security support with efficient utilization of sensor network resources. Thus there is a need of lightweight security algorithms suitable for wireless sensor networks.

4. Classification of Different Middleware Approaches for WSN

In this section, different classes of middleware approach followed for wireless sensor networks are discussed. There have been several research projects undergoing all around the world for design and development of middleware for wireless sensor networks. The classification of various middleware approaches for wireless sensor networks along with respective examples are enlisted below. Table 1 summarizes some major classes of middleware design approaches.

Table 1. Some middleware design approaches

Middleware Class	Example	Developed at / by
Database approach	SINA	University of Delaware, USA
Event based approach	Mires	University of Pernambuco
Application driven approach	MiLAN	University of Rochester, USA
Modular approach	Impala	Princeton University, USA
Virtual machine approach	Mate	University of California, Berkley, USA
Tuple space approach	Tiny Lime	Carlo Curino, Matteo Giani, Marco Giorgetta, Alessandro Giusti, Amy L. Murphy, Gian Pietro Picco.

4.1. Database Approach

In this approach, the whole sensor network is considered as a database. An application can make query to the database using structured query language (SQL) like language. This approach facilitates a simple and easy communication scheme between users and the network, but generally it lacks time space relationships between events[16].

An example of database approach based middleware is SINA (Sensor Information Networking Architecture). It was designed as part of a research project at University of Delaware, USA. In SINA[17], the sensor applications can make queries to the network and get the replies back from the network. It can monitor changes in the network. It basically comprises of three functional components namely *hierarchical clustering*, *attribute based naming* and *location awareness*. The hierarchical clustering consists of grouping of nodes based on their proximity or energy levels. The groups of nodes are called clusters. The attribute naming replaces the standard id-based naming by attributes of the

data. This mechanism is used for data centric routing in wireless sensor networks. Location awareness of the sensor nodes is achieved by using GPS (Global Positioning System) based techniques. When querying the network, collision may result from the large number of responses coming from different parts of the network. All such responses propagate to the enquirer node during a short span of time and it may create *response implosion problem*. To overcome this problem, SINA introduces the following three techniques: First, sampling operation, in which a node may not respond to a query when its neighbor is responding. Second, self orchestrated operation, in which some nodes may defer their responses for a certain period of time reducing the number of collisions. Third, diffused computation operation, which uses data aggregation to reduce the amount of data exchanged over the network. SINA provides scalability through hierarchical clustering.

Some other examples of database approach based middleware for wireless sensor network are as mentioned below.

- Cougar developed by Cornell University[18],
- DsWare developed by University of Virginia[19],
- TinyDB developed by University of California, Berkeley[20].

4.2. Event Based Approach

Event based, message oriented middleware provides asynchronous communication based on publish/subscribe paradigm[21]. In event based approach data acquisition support is focused on event definition, event registration/cancel, event detection and event delivery. The interest of the applications lies in certain changes of states of data. When such an event is detected, the middleware sends the event notification to the interested application. Publish/subscribe paradigm is the typical way of implementing event based middleware[3]. The basic entities of publish/subscribe system are event subscriber and event publisher. The event subscriber is the sink node and the sensor nodes are the event publishers.

An example of publish/subscribe based middleware is Mires[21], which was developed at University of Pernambuco. Mires middleware is built upon TinyOS[22]. TinyOS is an operating system built for wireless sensor network nodes. Mire is basically composed of the publish/subscribe service which has two main key services: routing services and aggregation service. The communication between the sensor nodes is consisting of three phases. Initially, the sensor nodes in the network advertise their available topics such as humidity, temperature etc. Next, the advertised messages are routed to the sink node. User applications connected to the sink node can now subscribe the desired application topics to be monitored. Finally, the subscribed messages are broadcasted to the sensor nodes in the network. In Mires, only the messages referring to the subscribed topics are sent and as a result, it reduces the number of transmissions and thus subsequent energy

consumptions.

4.3. Application Driven

In this approach, the applications are given more privileges by providing an architecture which reaches the network protocol stack and tunes the network on the basis of application requirements[23]. Therefore, the application dictates the management of the network by considering the Quality of Service issues as a matter of high priority.

MiLAN (Middleware Linking Application and Networks) is an example of application driven middleware. It was developed at the University of Rochester, USA. In MiLAN[13], application specifies its requirements, monitors network conditions and optimizes sensor network configurations. In order to do these tasks, an application specifies its requirements through some specialized graphs. MiLAN receives the application variables and the required Quality of Service parameters through these graphs. Then it determines which sensor or set of sensors can provide what level of Quality of Service for each variable. MiLAN can determine the set of sensors which can satisfy all the Quality of Service requirements. Due to energy constraints and dynamic network topology, the feasible set is constrained to subset of sensors. Subsequently MiLAN chooses the most suitable one to fulfill the required Quality of Service level. Although MiLAN supports Quality of Service and scalability, it has no support for node mobility. Moreover, due to its tight coupling with the network stack it does not support platform heterogeneity.

4.4. Modular Approach

In this approach, application is divided into some small program modules which save energy by allowing simple and lightweight software updates. This approach uses mobile agents or codes that are injected to sensor network for collecting local data. The agents can also move from one node to other.

An example of modular approach based middleware is Impala[24]. It was specially designed as a part of ZebraNet project, a wildlife monitoring project at Princeton University, USA. Impala is a middleware architecture that supports application adaptability, modularity and repairability in wireless sensor networks. It supports multiple applications by using event based modular programming model and provides a user friendly interface. It ensures application adaptation. The Impala middleware consists of two layers. The upper layer contains all the applications and protocols developed for ZebraNet project. These applications use various strategies to collect environmental information and to route the information to the base station. The lower layer has three middleware agents namely *event filter*, *application adapter* and the *application updater*. The event filter controls different operations which trigger a chain of processing. These events are timer event, packet event, data event and device event. The application adapter is armed with Application Finite State Machine (AFSM). The AFSM

handles application adaptation based on different scenarios such as energy efficiency and other attributes determined by the applications. On the other hand the updater agent is responsible for getting effective software updates by taking into account the tradeoff such as high node mobility, constrained bandwidth, wide range of updates and code management. In the case of software updates, as the first step, the nodes first exchange an index of application modules and then request the changed modules for transmission which saves network bandwidth. This happens before the actual software exchange. A program module is compiled into binary instructions before being injected into the network. The module is not linked to the main program for installation until the whole update is received. Although, Impala addresses issues like adaptability, software updates, energy efficiency, security but it does not give support for hardware heterogeneity and Quality of Service issues[16].

4.5. Virtual Machine Approach

Virtual Machines (VM) are used in sensor networks for various reasons. One of the advantages of implementing VMs in wireless sensor networks is that it allows the programmer the semantic like *write-once and execute many times* across a range of heterogeneous sensors. The modularity of VM code allows for concise bytecode. This reduces memory footprint and power consumption when dynamically updating applications via the network[25]. On the other hand the virtual machine based approach intrinsically provides security and synchronization models which simplify the programming task.

An example of virtual machine based middleware for wireless sensor network is Mate[25]. This project was developed at the University of California, Berkeley. It provides an abstraction layer to implement its operations and mainly focuses on a new programming paradigm to overcome the issues like limited bandwidth and higher energy consumption. Mate proposes a method of reprogrammability from simple parameter adjustments to upload complete updates using VM approach. It uses a byte code interpreter built on top of TinyOS[22]. The programs are broken into capsules of 24 instructions, each of which fits in to a single byte. This limitation allows a capsule to fit into a single TinyOS packet. There are five key components in Mate. Those are VM, Network, Logger, Hardware and Boot scheduler. Mate uses a synchronous model that begins execution in response to an event such as packet transmission or timer going off. With this it avoids message buffering and larger storage requirements. The synchronous model makes application level programming easier and less prone to error than dealing with asynchronous event. The concept of version number is used in this approach. In the event of network update, the update is carried out by adding a version number in the capsule and then comparisons are made with neighbors. Then if necessary, a new version capsule can be installed. Mate is energy efficient for simple and short running applications. But it incurs high CPU

overhead for long running applications. Mate also has mechanisms to deal with security related issues. Moreover, it can prevent programs from causing system failure[16].

4.6. Tuple Space Approach

A tuple space is an implementation of the shared memory paradigm used for distributed computing. It provides a repository of tuples that can be accessed concurrently. As an example, let us consider that there is a group of processors that produces pieces of data (i.e., producer). Again there is another group of processors that uses the data (i.e., consumer). Producers post their data as tuples in the space, and the consumers then retrieve data from the space that match a certain pattern. The tuple space model was pioneered by Gelernter and co-workers[26] in the Linda programming system for coordinating objects across a distributed computing environment.

An example of a tuple space based middleware developed for wireless sensor network is Tiny Lime[27]. It is a data sharing middleware built on TinyOS. Tiny Lime extends Lime[28]. Lime is a middleware developed for mobile ad-hoc networks. Lime breaks up the Linda tuple space into multiple tuple spaces. Each of these multiple tuple spaces is attached to a mobile component. The rules for sharing of

their contents i.e., tuple content, are defined. It is considered that the components are able to communicate. In a sense, the static global tuple space of Linda is rearranged as federated tuple space, which changes now dynamically. Tiny Lime is an extension of Lime which incorporates some suitable features required for sensor networks. For instance, reactions in Tiny Lime give the ability to specify the data freshness [27]. Tiny Lime reactions also accept conditions based on which a particular set of data can be fetched from the sensor nodes. Tiny Lime is designed for environments in which clients typically only need to query data from local sensors. Interestingly, Tiny Lime does not support multi-hop propagation of data through the sensor network. TS-Mid is another example of tuple space based middleware designed for sensor networks. Details of TS-Mid can be found in literature[29].

5. Comparative Study

In this section a comparative study is presented considering the major design approaches of middleware. The comparison based on our study about the different middleware approaches is shown below in the Table 2.

Table 2. A comparison on different design approaches of middleware

Design approach	Example	Power awareness	Mobility in the nodes	Heterogeneity	QoS support	Security	Scalability	In-network processing
Data Base approach	SINA	Yes	Less	Very Less or none	No	Nil	Vey Less or None	Yes
Event based approach	Mire	Yes	Less or partial	Less or partial	No	Nil	Yes	Yes
Application Driven	MiLAN	Less	Less or none	Less or none	Yes	Nil	Yes	Nil
Modular approach	Impala	Yes	Yes	Less or None	Nil	Yes	Yes	Nil
Virtual Machine approach	Mate	Yes	Yes	Partial	Nil	Yes	Yes	Nil
Tuple Space based	Tiny Lime	Yes	Yes	Partial	Nil	Nil	Nil	Nil

6. Middleware Layer Based Quality of Service Support in WSNs

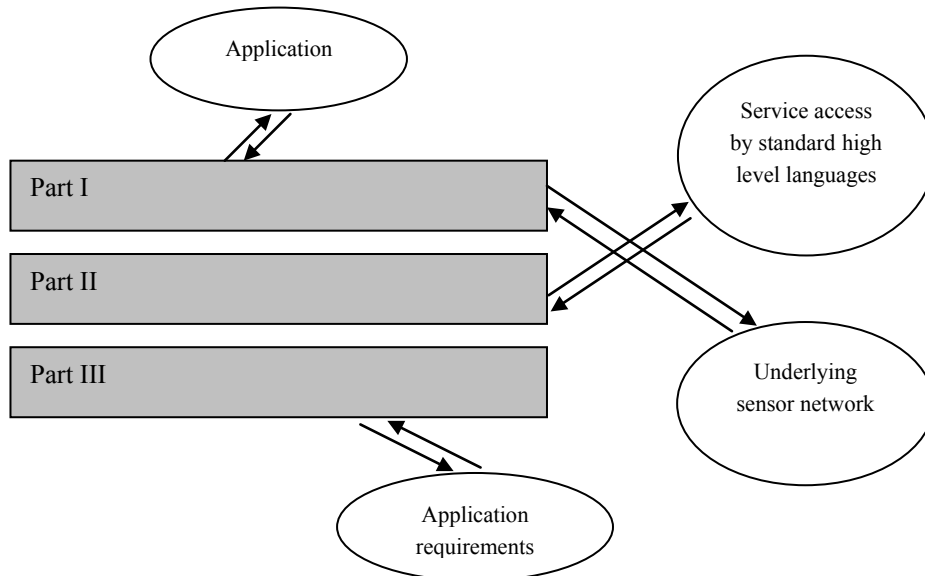


Figure 5. Three parts of service oriented middleware proposed in[33]

Quality of Service in wireless sensor networks is application dependent. Suitable design of middleware may be helpful in achieving application specific Quality of Service in wireless sensor networks. Middleware based Quality of Service (QoS) support is a very new and an open area of research in the field of wireless sensor networks[3]. If the required application specific Quality of Service can not be supported by underlying wireless sensor network then the middleware can play a role. The middleware may negotiate between the application and underlying sensor network to provide appropriate Quality of Service. Figure 4 shows such a scheme between the middleware and the application level Quality of Service. Middleware based Quality of Service supports may also give an implementation framework in order to simplify the development of wireless sensor network applications[3]. Some of the important Quality of Service parameters at the middleware and the application layer are accuracy, aggregation degree, aggregation delay, coverage, and optimum number of sensor nodes in a region. On the other hand the Quality of Service parameters at the network layer are delay, jitter, bandwidth, and packet loss[30]. In[14], it is emphasized that for wireless sensor networks the collective Quality of Service metrics should be considered. This is because, the wireless sensor networks are generally densely deployed and single sensor accuracy or time delay between two sensor respective sensor nodes may not be meaningful. Therefore, collective behavior and effect of a group of logically related sensor nodes may be more meaningful. During middleware design, it is necessary to consider collective behavior of the sensor nodes and implement collective QoS metrics in the middleware layer. Quality of Service (QoS) support at wireless sensor network middleware depends on the middleware services[3] for example, resource discovery and resource management service. QoS support at the middleware may also have impact on some other services such as data acquisition in the data management service. In[31] a framework is proposed which uses services and function for fault detection without recovery. It is framework with fault tolerant algorithms. MiLAN[16], discussed in the previous section is a middleware approach to provide QoS between the application and the underlying sensor network. MiLAN allows the applications to specify their quality requirements and adjust the network characteristics for longer lifetime of the application and also meeting the QoS requirements. In[32] a middleware architecture called MidFusion, is proposed which makes use of Bayesian theory to support information fusion by the sensor network application. It selects and discovers the best possible set of sensor nodes based on the QoS requirements and the QoS that can be provided for the applications. In[33] a reflective and service-oriented middleware is proposed. It provides an abstraction layer between application layer and the underlying sensor network infrastructure. It uses QoS parameters such as data accuracy and energy awareness in its evaluation. It keeps a balance between application QoS requirements and the network life time. The main features of

this middleware are divided into three parts[33] as shown in Figure 5. Firstly, an interoperable layer is provided by the system between different applications and the wireless sensor network. Secondly, the services provided by the middleware are accessed in a flexible way by some standard high level languages. And finally, the provided service for network configuration and adaptation increases the overall lifetime of the network meeting the application requirements. In[30] a cluster based mechanism of QoS support at the middleware level is proposed. The middleware is based on publish/subscribe[21] model of communication and provides real time and fault tolerant services to its application.

- i) part I, interoperable layer between application and underlying sensor network,
- ii) part II, service access by standard high level languages,
- iii) part III, increase in lifetime by network configuration and adaptation services meeting the application requirements.

7. Future Research Directions

Based on our study it is observed that there are very little work that have been reported for middleware layer based QoS support in wireless sensor networks. In the previous section (section 6), we have cited some of the middleware based QoS support examples in wireless sensor networks and most of the projects we have mentioned here are at their initial stages. QoS provisioning at middleware layer is an open area of research and needs significant contributions from the research community. Another important observation is that almost all the middleware we have discussed are application specific. However, designing a middleware for a particular application has certain limitations such as limited reusability, tight coupling between application and the sensor network etc. Current state of the art middleware for sensor network have several drawbacks. This is why such middleware solutions can not be used for emerging pervasive applications[34]. Some of the drawbacks are:

- i) It is assumed that in most of the cases wireless sensor networks consist of homogeneous and resource constraint sensors.
- ii) Lack of Quality of Service management and control.

To overcome these drawbacks, the design and development of service oriented generic middleware for wireless sensor networks can be adapted as a solution. Service oriented generic middleware is a new direction of research in the middleware level. MiSense[34] is an example of service oriented component based middleware for wireless sensor networks. Again provisioning Quality of Service in such a service oriented middleware for wireless sensor network is yet another promising area of research. Defining and implementing collective Quality of Service metrics in wireless sensor networks is another open research issue.

8. Conclusions

In this paper, we have discussed the main challenges faced by the designers during the design and development of middleware for wireless sensor networks. We surveyed the existing middleware design approaches for wireless sensor networks. Suitable examples of these approaches are mentioned and a comparative study among them is presented. We also stated the scope and status of QoS support at the middleware level for wireless sensor networks and cited some of the examples in this direction. Though middleware is a stable technology in distributed systems and distributed computing environments, there is scope and need to develop this technology for wireless sensor networks. Finally, we highlighted the limitations of the current middleware technologies in wireless sensor networks and outlined a new direction of research based on the concept of Service Oriented Architecture (SOA) for the design and development of middleware in wireless sensor networks to meet the requirements of emerging pervasive applications.

REFERENCES

- [1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless sensor networks: a survey", *IEEE Communication Magazine*, 40(8), 2002, pp. 102-114.
- [2] Cecilia Mascolo, Stephen Hailes, "Survey of middleware for networked embedded systems", Technical Report for Project: Reconfigurable Ubiquitous Networked Embedded Systems, University College London, 2005.
- [3] M.M. Wang, J.N. Cao, Jing Li, Sajal K.Das, "Middleware for Wireless Sensor Network: A Survey", *Journal of Computer Science and Technology*, 23(3), May 2008, pp. 305-326.
- [4] Yang Yu, Bhaskar Krishnamurthy, V.K. Prasanna, "Issues in Designing Middleware for Wireless Sensor Network", *IEEE Network*, Jan-Feb 2004.
- [5] Java Soft., "Java Remote Invocation specification". Revision 1.5, JDK1.2 Edition, Oct. 1998, <http://java.sun.com/j2se/1.4.2/docs/guide/rmi/>.
- [6] OMG, "The common object request broker: Architecture and specification", Rev. 2.2, 1998, <http://en.wikipedia.org/wiki/CORBA>.
- [7] Licia Capra, Wolfgang Emmerich, Cecilia Mascolo, "Middleware for mobile computing, Technical Report", Department of Computer Science, University College London, 2005.
- [8] Kay Roomer, Oliver Kasten, Friedemann Mattern, "Middleware challenges for wireless sensor networks", *Mobile Computing and Communications Review*, 6(1), 2002, pp. 12-17.
- [9] Matthew Wolenetz, Rajnish Kumar, Junsuk Shin, Umakishore Ramachandran, "Middleware guidelines for future sensor networks", Technical Report 30332-0280", College of Computing, Georgia Institute of Technology, Atlanta Georgia 2004.
- [10] Bartolome Rubio, Manuel Diaz, Jose M. Troya "Programming approaches and challenges for wireless sensor networks", in proceedings of the 2nd International Conference on Systems and Networks Communications (ICSNC'07), Cap Esterel, French Riviera, France, August 25-31, 2007.
- [11] D. Estrin et al., "Next Century Challenges: Scalable Coordination in Sensor Networks", in proceedings of 5th Annual ACM/IEEE Int'l. Conf. on Mobile Computing and Networking (Mobi Com'99), ACM Press, 1999, pp. 263-270.
- [12] B. Krishnamachari, D. Estrin, and S. Wicker, "Impact of Data Aggregation in Wireless Sensor Networks," in proceedings of 22nd Int'l Conference on Distributed Computing Systems (ICDCSW 02), IEEE CS Press, 2002, pp. 575-578.
- [13] W.B. Heinzelman et al., "Middleware to Support Sensor Network Applications", *IEEE Network*, vol. 18, no. 1, 2004, pp. 6-14.
- [14] D. Chen and P.K. Varshney, "QoS Support in Wireless Sensor Networks: A Survey," in proceedings of Int'l Conference on Wireless Networks (ICWN 04), CSREA Press, 2004, pp. 227-233.
- [15] A. Perrig, J. Stankovic, and D. Wagner, "Security in Wireless Sensor Networks," *Communications ACM*, vol. 47, no. 6, 2004, pp. 53-57.
- [16] Wassim Masri, Zoubir Mammeri, "Middleware for Wireless Sensor Networks: A comparative Analysis", *IFIP International Conference on Network and Parallel Computing Workshops*, September 18-21, 2007, pp. 349-356.
- [17] C.C. Shen, C. Srisathapornphat, C. Jaikao, "Sensor Information Networking Architecture and Applications", *IEEE Personal Communications*, August 2001, pp. 52-59.
- [18] P. Bonnet, J. Gehrke, and P. Seshadri, "Towards Sensor Database Systems," in proceedings of 2nd Int'l Conf. on Mobile Data Management (MDM'01), 2001, pp. 314-810.
- [19] S.R. Madden, M.J. Franklin, and J.M. Hellerstein, "TinyDB: An Acquisitional Query Processing System for Sensor Networks," *ACM Trans. Database Systems*, vol. 30, no. 1, 2005, pp. 122-173.
- [20] S. Li, S. Son, and J. Stankovic, "Event Detection Services Using Data Service Middleware in Distributed Sensor Networks," in proceedings of 2nd Int'l Workshop on Information Processing in Sensor Networks (IPSN 03), LNCS 2634, Springer, 2003, pp. 502-517.
- [21] E. Souto, G. Guimaraes, G. Vasconcelos, "A message-oriented middleware for sensor networks", in proceedings of the 2nd Workshop on Middleware for Pervasive and Ad-hoc Computing 2004, (MPAC'04), pp. 127-134.
- [22] J. Hill, et al., "System architecture directions for networked sensors", *ACM SIGPLAN Notices*, vol. 35, issue 11, November 2000, pp. 93-104.
- [23] Salem Hadim, Nader Mohamed, "Middleware: Middleware Challenges and Approaches for Wireless Sensor Networks", *IEEE Distributed Systems Online*, vol. 7, no. 3, March 2006.
- [24] T. Liu and M. Martonosi, "Impala: A Middleware System for Managing Autonomic, Parallel Sensor Systems," in proceedings of ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming (PPoPP' 03), 2003, pp.

107–118.

- [25] P. Levis and D. Culler, “Mate: A Tiny Virtual Machine for Sensor Networks,” in Proceedings of 10th Int’l Conf. on Architectural Support for Programming Languages and Operating Systems (ASPLOS-X), ACM Press, 2002, pp. 85–95.
- [26] David Gelernter. “Generative Communication in Linda”, In ACM Transactions on Programming Languages and Systems, vol. 7(1), January 1985, pp. 80-112.
- [27] C. Curino, M. Giani, M. Giorgetta and A. Giusti, “TinyLIME: bridging mobile and sensor networks through middleware”, in proceedings of 3rd IEEE Int. Conf. on Pervasive Computing and Communications, Hawai, March 2005.
- [28] A. L. Murphy, G. P. Picco, and G.-C. Roman, “LIME: A middleware for physical and logical mobility”, in proceedings of the 21st Int. Conf. on Distributed Computing Systems, Phoenix, April 2001.
- [29] Rita de Cassia Acioli Lima et al, “TS-Mid: Middleware for Wireless Sensor Networks Based on Tuple Space”, in proceedings of 22nd International Conference on Advanced Information Networking and Applications, March 25-28, 2008, pp. 886-891.
- [30] M. Sharifi, M.A.Taleghan, A.Taherkordi, “A Middleware Layer Mechanism for QoS Support in Wireless Sensor Networks”, in proceedings of ICN/ICONS/MCL, 23-29 April 2006.
- [31] Ruiz L B, Siqueira I G, Oliverira L B, “Fault management in event-driven wireless sensor networks”, In Proc. the 7th ACM/IEEE Int. Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems, Italy, 2004.
- [32] Alex H., Kumar M., Shirazi B., "MidFusion: An adaptive middleware for information fusion in sensor network applications," Information Fusion, vol. 9, issue 3, July 2008, pp. 332-343.
- [33] F.C. Delicato et al., “Reflective middleware for wireless sensor networks”, in proceedings of ACM Symposium on Applied Computing 2005, (ACM SAC’05), pp. 1155-1159.
- [34] K.K. Khedo, R.K. Subramanian, “A Service-Oriented Component Based Middleware Architecture for Wireless Sensor Networks”, International Journal of Computer Science and Network Security, vol.9, no.3, March 2009, pp. 174-182.
- [35] N.Mohamed, J. Al-Jaroodi, “A survey on service-oriented middleware for wireless sensor Networks”, SOCA, vol. 5, no. 2, 2011, pp. 71-85.
- [36] Feng Zhao, Leonidas Guibas, Wireless Sensor Networks an information processing approach, Morgan Kaufmann Publishers, An imprint of Elsevier, 2005, ISBN 81-8147-642-5.