CHAPTER 1

INTRODUCTION

1.1 GENERAL

Wireless Sensor Networks (WSNs) have gained worldwide attention in recent years, particularly with the proliferation in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. These smart sensor nodes as studied by Akyildiz et al (2002) are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio, and an actuator. Since the sensor nodes have limited memory and are typically deployed in difficult-to-access locations, a radio is implemented for wireless communication to transfer the data to a base station (e.g., a laptop, a personal handheld device, or an access point to a fixed infrastructure). Each node communicates directly (i.e., single hop) with a few other nodes within its radio communication range. A node may also transmit to distant nodes through multi-hop communication. Battery is the main power source in a sensor node. Secondary power supply that harvests power from the environment such as solar panels may be added to the node depending on the appropriateness of the environment where the sensor will be deployed. A variety of mechanical, thermal, biological, chemical, optical, and magnetic sensors may be attached to the sensor node to measure properties of the environment. Depending on the application and the type of sensors used, actuators may be incorporated in the sensors.
WSNs have great potential for many applications such as military target tracking and surveillance, natural disaster relief, biomedical health monitoring, and hazardous environment exploration and seismic sensing. In military target tracking and surveillance, a WSN can assist in intrusion detection and identification. Specific examples include spatially correlated and coordinated troop and tank movements. With natural disasters, sensor nodes can sense and detect the environment to forecast disasters before they occur. In biomedical applications, surgical implants of sensors can help monitor a patient’s health. For seismic sensing, ad hoc deployment of sensors along the volcanic area can detect the development of earthquakes and eruptions.

Most sensor networks today are deployed for a single purpose. They are designed for either data collection or a domain specific application. Application specific design has several drawbacks. First wireless sensor networks deployed for one or a few applications are often limited reusability and are therefore, inherently not cost effective. This translates into a low return on investment. Another drawback is the tight coupling between the application and the underlying WSN. The application is often designed as a monolithic, complex code of tightly coupled modules where each module implements a specific functionality, e.g., user interface, data access (i.e., retrieving sensor readings), actuator activation, etc. To develop these modules, programmers invoke functionalities at several layers in the WSN’s architecture. The reason behind this monolithic, application specific design is often optimization. By enabling programmers to manipulate parameters and mechanisms at different layers, the code may be tailored to achieve better efficiency for the application at hand. A consequence of this tight coupling between the application and the WSN is that considerable reprogramming efforts are often necessary to make the network able to serve new application.
All these drawbacks motivate a new programming model based on Service Oriented Architecture (SOA). SOA is a popular paradigm in the community of the web software developers. WSNs can be viewed in part as a reduced copy of Internet, where different nodes or their groups provide different services to the end user. Therefore as discussed by Delicato et al (2003) SOA has been explored in the context of WSNs by number of recent researchers. SOA consists of a set of design principles which enable defining and composing interoperable services in a loosely coupled way. It can bring enormous benefits to the WSNs because it can turn these networks into open, ubiquitous, interoperable, and multipurpose infrastructures. When using SOA, the WSN plays the role of service provider, while the application is its client. Thus, the application can request, find, execute and monitor the services provided by WSNs that can meet its requirements.

In Service Oriented Wireless Sensor Network (SOWSN), services are lightweight code units deployed directly on top of the operating system of nodes. Each service provides some sensing or actuation functionality supported by the local node. Services may be individually invoked or combined in complex ways with far richer sensing and actuation capabilities. Applications invoke services using a service oriented query model that offers a high abstraction level and, yet, enables a wide spectrum of low level optimization mechanisms. Thus the programming task becomes easier because sensor node capabilities are abstracted and defined as services and applications are written based on service requests issued to the network. Services are reusable and often generic. By implementing a service oriented approach at all levels of WSN, the rapid development of applications as well as the thorough testing of sensor networks will be possible. Also service oriented approach provides adequate abstractions for application developers, and that it is a good way to integrate the Internet with WSN.
Service composition as discussed by Brnsted et al (2007) refers to the method of constructing composite services with the help of small and simple executable services or components. It is used in situations where a client request cannot be satisfied by any single available service, but by a combination thereof. It constitutes an essential part of service provisioning, since it leads to novel service offering thus adding value that was not existent in the individual services. The value of SOA lies in assuring such compositions are easily and rapidly possible with low costs. Thus, service composition is a key to SOA. Especially, achieving an automatic service composition in WSN remains a major challenge.

Service composition can be made manually or (semi-) automatically using computational algorithms. The manual composition is a complex task and susceptible to errors, due to the dynamic nature of WSN. Thus automatic service composition is the most powerful method applied in WSN.

1.2 MOTIVATION

The basic service oriented architecture suffices to implement simple interactions between a consumer and a provider. If the implementation of a service needs the invocation of other services, it is necessary to combine the functionality of several services. In this case, a need for composite service arises. The process of developing a composite service in turn is called service composition.

Service composition which is the ability to aggregate multiple services into a single composite service that would provide a certain functionality, which otherwise cannot be provided by a single service. The motivation for service composition in wireless sensor networks is based on the requirement for developing value-added services and applications by
selecting and integrating pre-existing services. Such an approach has
tremendous benefits in terms of reducing the cost and effort for building
newer services from scratch, thereby promoting rapid application
development. Additionally, the resulting composite services may be used as
basic services in further service compositions.

The current Service Oriented Wireless Sensor Network approaches
do not consider the automatic and dynamic integration and composition of
services. More precisely, the existing models specify only services and
operations that perform, but not the order of a flow specification of exchanged
messages between services. The composition is done static by a human expert
because the composition task requires an understanding about the service
semantics.

Achieving an automatic service composition remains a major
challenge. It is motivated by the following reasons.

- First, the user goal may be complex and its fulfillment requires
  multiple services to be involved. The manual creation of the
  composite service, by humans, can be a long-running, error-prone
  process, or even impossible. Moreover, it is expected that
dynamically varying user goals will have to be fulfilled, each
requiring different services to be composed on the fly.

- Second, the set of available services is dynamically changing.
  Useful services are added / removed. Hence, manual modification
  of the composition is not effective.

- Using an exhaustive search to find services which match each other
  is practical but ineffective.
• In addition, many services provided are the same or similar in function, so the ways of composing services are varied, with different QoS.

To handle the dynamism from different aspects, the automation of the composition process is essential.

1.3 PROBLEM STATEMENT

While the research on SOWSNs spans a variety of aspects, the goal of this work is to enable the use of pre-implemented services in a potentially heterogeneous sensor networks that can easily be combined to form an application in an energy efficient manner. Instead of re-implementing application logic each time from scratch, applications are implemented or adapted simply by composing existing services. By providing dynamic composition of services, users can be free from complicated configuration process, and specific knowledge is no longer a requirement as well. However, in the case of incoming services' types are not predefined, how do we know what services should be combined while others should not? What is the order? How to meet end user’s non-functional requirements? and how to get the final result with minimum energy expenditure? At present, mainly composition processes are designed in a static fashion therefore lack of the support for dynamic environment. The main objective is to deal with problems related to the following issues.

(i) Service graph generation: A service graph means a set of selected services in a specific sequence. Creating service graph requires a service discovery system for finding out the abstract services, the system should find out the order in which the services need to be executed.
(ii) **Service selection:** Service selection is the process of selecting one provider from among the set of all known providers that provide the desired service. It involves the consumer analyzing the properties of each provider, and selecting the one that it believes best meet its requirements.

(iii) **Service sharing:** Instead of running each request independently, if similar requests are merged or new request is rewritten in terms of currently existing requests, the overall energy consumption of the sensor network can be reduced because duplicate data requests can be eliminated.

(iv) **Routing service requests:** Since routing protocols directly access the communication module which consumes major portion of the sensor nodes energy, the design of energy efficient routing protocols is an essential task. In a SOWSN, it is necessary to find a query routing procedure which routes service requests towards service providers.

### 1.4 CONTRIBUTIONS

The aim of this thesis is to deal with the problem of energy efficient automatic service composition for SOWSN. The proposed approach allows service developers to specify an abstract and possibly incomplete specification of the composite (goal) service. This specification is used to discover, select and combine set of suitable component services such that their composition realizes the desired goal. In particular, the focus is on developing three main components: (i) automatic service graph generation, (ii) global QoS-aware service selection (iii) service sharing and routing service requests.

To achieve this, the WSN is first organized into hierarchy of service clusters. Service based, distributed and unequal clustering protocol is
used, in which transmission range of the node changes dynamically based on the residual energy and the distance from the base station. Then the following issues are addressed.

(i) Automatic service graph generation

An approach to create service graph on-demand for service composition in service oriented wireless sensor network is explored. The proposed Automatic Service Graph Generation (ASGG) algorithm discovers abstract services that satisfy user constraints and identifies the relationship between these services. Based on the input/output dependency between these services the algorithm generates service graph (work flow) automatically.

(ii) Global QoS-aware service selection

For services providing similar functionality, quality of service is the main factor to differentiate among them. This work proposes a global QoS-Aware multiobjective Service Selection algorithm for service composition (QASS). This algorithm uses convex hull method to optimize several objectives simultaneously. Based on different global constraints users set the QoS based service selection problem for composite services are divided into three categories. For each category, the mathematical model algorithms are presented.

(iii) Service sharing and Routing

Since the nodes in the wireless sensor networks are energy constraint appropriate routing protocol can drastically reduce the energy consumption and enhance the lifetime of the network. In order to achieve energy efficiency this chapter proposes two algorithms. The first algorithm identifies and merges set of similar and concurrent queries and the second
algorithm rewrites the new requests in terms of existing requests. Then the merged and rewritten queries are disseminated into the WSN using the proposed cluster based query routing protocol that routes the query based on the service requested.

1.5 **THESIS ORGANIZATION**

The rest of the thesis is organized as follows.

- Chapter 2: Presents a background for the research and a literature review of related work.
- Chapter 3: Presents detailed description about service based energy efficient clustering algorithm, distributed directory based service discovery algorithm and service graph generation algorithms.
- Chapter 4: Describes the need for global QoS based service selection. Based on the constraints set by the user service selection problem is divided into three categories. For each category this chapter presents mathematical models and algorithms for global QoS based service selection.
- Chapter 5: Describes the concept of service sharing to reduce number of service requests injected into the wireless sensor networks, which results in less energy consumption. Service sharing includes algorithms for service merging and service request rewriting. Then it presents algorithm for service request dissemination.
- Chapter 6: Contains conclusion and outlines some possible future research directions.