Chapter 2

Proposed Wireless Sensor Network Architecture
In this research plan, we are building scalable, reliable, robust and time-energy aware network architecture for sensor networks. We address scalability, robustness, real-time and energy conservation issues at different layers of the proposed architecture in this chapter. Some layers will only deal with one issue, while others engage in multiple issues simultaneously. From the application point of view, this network architecture provides a set of predictable and dependable higher-level service APIs for the programmer. From the system point of view, this network architecture is an integrated solution specifically tailored to the characteristics of sensor networks with a minimum overhead and high throughput.

The rest of the chapter is organized as follows. Section 2.1 presents the overview of the existing architecture for wireless sensor networks. Existing architecture and protocol stack is summarized in Section 2.2. Need of new architecture is presented in Section 2.3. In Section 2.4 we present our proposed architecture with details of all the layers. Finally, conclusions are provided in Section 2.5.

2.1 EXISTING SENSOR NETWORKS COMMUNICATION ARCHITECTURE

The sensor nodes are usually scattered in a sensor field as shown in Figure 2.1. Each of these scattered sensor nodes has the capabilities to collect data and route data back to the sink and the end users. Data are routed back to the end user by a multihop infrastructure less architecture through the sink as shown in Figure 2.1. The sink may communicate with the task manager node via Internet or Satellite.
2.1.1 Existing Protocol Stack for WSNs

Figure 2.2 presents the existing protocol stack for wireless sensor networks. This protocol stack combines power and routing awareness, integrates data with networking protocols, communicates power efficiently through the wireless medium, and promotes cooperative efforts of sensor nodes. The protocol stack consists of the application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane, and task management plane. Depending on the sensing tasks, different types of application software can be built and used on the application layer. The transport layer helps to maintain the flow of data if the sensor networks application requires it. The network layer takes care of routing the data supplied by the transport layer. Since the environment is noisy and sensor nodes can be mobile, the MAC protocol must be power aware and able to minimize collision with neighbors’ broadcast. The physical layer addresses the needs of a simple but robust modulation, transmission and receiving techniques. In addition, the power, mobility, and task management planes monitor the power, movement, and task distribution among the sensor nodes. These planes help the sensor nodes coordinate the sensing task and lower the overall power consumption. Function of these layers is described in detail. Table 2.1 summarizes layered protocols with open research issues.
Application Layer

This layer is involved in different types of application. Software can be built depending on sensing task. It provides the user software efficient interfaces for interest dissemination and is useful for lower layer operations. It also provides user application with interfaces to issue queries and respond to queries [1] [2] [3].

Transport Layer

Transport layer serves when system is planned to be accessed by external network or Internet. End to end communication are based on attribute based naming rather than global addressing [1] [2].

Network Layer

The following points are of consideration while designing Network layer [4]

- Power efficiency.
- Sensor network are mostly data centric.
- Attribute based addressing.
- Data aggregation.

Data Link Layer

Data link layer is used for multiplexing of data stream and medium and error control, data frame detection. MAC protocol creates communication link between sensor nodes for data transmission, but in sensor network power efficiency is of prime importance. In cellular network, primary goal of MAC protocol in such systems is high QOS and bandwidth efficiency. Power supply is of secondary importance because base stations have unlimited power, but in sensor network transmission, power is nearly 0 dbm and radio range is much less [5] [6] [7].

Physical Layer

Physical Layer is used for frequency selection, modulation and data encryption/decryption. In sensor network, we focus on signal propagation effects and
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power efficiency. Modulation scheme are Binary & M-ary modulation. M-ary modulation reduces the time because multiple bits are transmitted per symbol but increase power consumption and complex circuitry [13].

**Power Management Plane**

It is used to manage the power of sensor node. We can control the duplicate message by simply multicasting only to the neighbors (for low power consumption of power) instead of broadcasting to all nodes. We can also have provision that node become active only while receiving and transmitting the message and after that remain idle [8] [9].

**Mobility Management Plane**

It is responsible for keeping track of sensor nodes (i.e., getting exact location of node. We can also track neighboring nodes which can help in low power consumption, by transmitting the message to nearest possible node and also route back to user is maintained [7][8].

**Task Management Plane**

We do not require all the nodes at the same time to perform the sensing task, as a result some sensor node perform the task depending on their power level. The sensor nodes work together in a power efficient way and share the resources between sensors nodes [7][8].

**Coordination Plane**

It determines how a node behaves according to the data received from communication plane and management plane. The existence of coordination plane may be much more critical for the actors than for the sensors, since actors may need to collaborate with each other in order to perform appropriate actions.[6][7][8]
TABLE 2.1: Summarizes of the layered communication protocols

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Open Research Area</th>
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<tbody>
<tr>
<td>Physical</td>
<td>Responsible for frequency selection, carrier frequency generation, signal detection modulation, and data encryption.</td>
<td>• Hardware design&lt;br&gt;• Minimize energy consumption&lt;br&gt;• Minimize power consumption&lt;br&gt;• Methods of improving the transmission rate</td>
</tr>
<tr>
<td>Data link</td>
<td>Responsible for the multiplexing of data streams, data frame detection, medium access, and error control. Ensures reliable point-to-point and point-to-multipoint connections in a communication network.</td>
<td>• Design-scalable MAC&lt;br&gt;• MAC/Physical Cross Layer Design&lt;br&gt;• Data aggregation&lt;br&gt;• Explore the possibility of other error control coding schemes&lt;br&gt;• Power saving modes of operation</td>
</tr>
<tr>
<td>Network Layer</td>
<td>Takes care of routing the data supplied from the transport layer.</td>
<td>• Improvements to existing protocols to address higher topology, scalability. Real-time communication challenges</td>
</tr>
<tr>
<td>Transport Layer</td>
<td>Helps to maintain the flow of data if the sensor network application requires it.</td>
<td>• Improve the existing transport protocols&lt;br&gt;• Sink can play important role in transport protocols</td>
</tr>
<tr>
<td>Application Layer</td>
<td>Different types; depends on the sensing tasks.</td>
<td>• Improve existing application-layer protocols&lt;br&gt;• Different application needs</td>
</tr>
<tr>
<td>Power management plane</td>
<td>Manages the way in which a sensor node uses its power.</td>
<td>• Introducing the rules related to data aggregation&lt;br&gt;• Turning sensor nodes on and off&lt;br&gt;• Optimizing power consumption and connectivity</td>
</tr>
<tr>
<td>Mobility management plane</td>
<td>Detects and registers the movement of sensor nodes.</td>
<td>• Exchange the data related to location finding algorithms.&lt;br&gt;• Location services</td>
</tr>
<tr>
<td>Task management plane</td>
<td>It balances and schedules the sensing tasks given to a specific region.</td>
<td>• Optimize the way a sensor node participates in a sensing task&lt;br&gt;• Control node communication activities</td>
</tr>
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</table>
2.2 NEED FOR NEW SENSOR NETWORK ARCHITECTURE

In sensor networks, nodes are deployed into an infrastructure free environment. Without any a priori information about the network topology or the global, even local view, sensor nodes must self-configure and gradually establish the network infrastructure from the scratch during the initialization phase. With the support of this infrastructure, nodes are able to accept queries from remote sites, interact with the physical environment, actuate in response to the sensor readings, and relay sensed information through the multi-hop sensor networks. Different from traditional networks, sensor networks do impose a set of new limitations for the protocols designed for this type of networks. Devices in sensor networks have a much smaller memory, constrained energy supply, less process and communication bandwidth.[2][4][8] Topologies of the sensor networks are constantly changing due to a high node failure rate, occasional shutdown and abrupt communication interferences. Due to the nature of the applications supported, sensor networks need to be densely deployed and have anywhere from thousands to millions of sensing devices, which are the orders of magnitude larger than traditional ad hoc mobile networks. In addition, energy conservation becomes the center of focus due to the limited battery capacity and the impossibility of recharge in the hostile environment.

With such a vast difference between traditional networks and sensor networks, it is not appropriate and inefficient to port previous solutions for ad hoc networks into sensor networks with only incremental modifications. For instance, the sheer number of sensor nodes makes flooding-based standard routing schemes (e.g. DSR [10] and AODV [11] for ad hoc networks undesirable. Although applications for sensor networks remain diverse, one commonality they all share is the need for a network infrastructure tailored for sensor networks.

Without a scalable routing service, broadcast storms caused by the route discovery may result in significant power consumption and possibly a network meltdown. Without a real-time communication service, applications cannot react to the changes of the environment quickly enough to be effective. Without efficient energy-aware design, nodes in the sensor networks could deplete themselves after only several rounds of burst activities. Without fault-tolerance and self-stabilization supports in
such a dynamic and faulty system, sensor networks could never converge and are unable to guarantee an effective transport service to the applications. We do not close the eyes to the importance of the killer applications, but we argue that without a new network architecture tailored to the characteristics of sensor networks, the popularity of sensor networks cannot be a reality in the near future.

2.3 PROPOSED WIRELESS SENSOR NETWORK ARCHITECTURE

From bottom up, the proposed network architecture has following essential layers: (Figure 2.3)

- **Power and Coverage Management Layer**: This *energy-aware* layer is responsible for node duty-cycle scheduling for power conservation and sensing coverage management, which provide full sensing coverage to a geographic area while at the same time minimize energy consumption and extend system lifetime by leveraging the redundant deployment of sensor nodes. The proposed feature of this layer is QDPRA (Quality of Service On-Demand power aware routing protocol) to provide on demand routing for power conservation.

- **Robust and Reliable MAC Layer**: This layer solves the issues related to *robustness* and *self-stabilization*. It can provide per-hop reliability if required by higher layer. Moreover, this layer deals with node failure and mobility issues internally as much as possible before signaling the network layer for further assistances. The Proposed protocol of this layer is Robust, reliable and real time routing protocol (RRRT).

- **Application Independent Data Aggregation Layer**: This *time-energy aware* layer provides data aggregation in order to reduce control overhead in MAC layer and energy consumption in radio communication. Adaptive control is provided in order to achieve aggregation without jeopardizing the end-to-end delay. This layer supports application independent data aggregation (AIDA) and the proposal of construction of lifetime maximizing trees is proposed in this layer.

- **Differentiated Packet Scheduling Layer**: This *QoS-time-aware* layer supports differentiated forwarding service among the packets with different priorities. The criterion for the differentiation includes not only the time constraints but also the spatial constraints. Real time scheduling (RTS) and...
real time communication capacity limits (RTCC) are the proposed features supported by differentiated packet scheduling layer.

- **Location-Address Soft Real-Time Routing Layer**: This time-aware scalable routing layer provides soft real-time communication for end-to-end packet delivery. Network congestion control is achieved by localized rerouting and traffic policing to the lower layer. Constant delivery speed is maintained through a combination of non-deterministic forwarding and neighborhood-based feedback control. The scalability issue is solved by the location-based routing and localized control scheme. RRTD is the proposed delivery mechanism to be used by real time routing layer to support real time communication.

- **Entity-Aware Transport Layer**: This layer abstracts communication endpoints into entities. This layer maintains robust connections between entities while both ends are mobile. Entity abstraction allows aggregation among a group of nodes in order to reduce the communication overhead and energy consumption. Left open for future research.

- **Localization Service**: Localization is a cross layer service for this network architecture as a whole. It provides location information for 1) the sensing coverage management, 2) the velocity calculation for the differentiated packet scheduling, 3) the location-address soft real-time routing, 4) the entity formation and 5) the location service for sensor network applications such as the enemy tracking and temperature mapping. Left open for future research.

### 2.4 CONCLUSION

Besides new research issues to be addressed inside individual layers, the major challenge is to build an integrated architecture, which takes care of scalability, robustness, real-time and energy conservation issues simultaneously. Since the point solutions we proposed for individual layers are conceived with this integration in mind, we expect this major challenge will be solved in this thesis research. In the following sections, five major components in Figure 2.3, namely real-time routing layer differentiated packet scheduling, application independent data aggregation, robust & self-stabilized Mac layer and physical layer with power management will be addressed in depth, respectively. Other proposed layers are left as open area for other researchers.
Figure 2.3: Proposed sensor network architecture
REAL TIME COMMUNICATION: INTRODUCTION

Real-time communications (RTC) is any mode of telecommunications in which all users can exchange information instantly or with negligible latency. In this context, the term "real-time" is synonymous with "live." RTC can take place in half-duplex or full-duplex modes. In half-duplex RTC, data can be transmitted in both directions on a single carrier or circuit but not at the same time. In full-duplex RTC, data can be transmitted in both directions simultaneously on a single carrier or circuit. RTC generally refers to peer-to-peer communications, not broadcast or multicast. In RTC, there is always a direct path between the source and the destination. Although the link might contain several intermediate nodes, the data goes from source to destination without having to be stored anywhere. In contrast, time shifting communications always involves some form of data storage between the source and the destination.

With real time communication, the application makes specific quality of service demands to the communication network with minimum delay and minimum data loss. This type of service is desirable for sensor networks. For data delivery in sensor networks, both hard as well as soft real time communications are required.

For achieving real time communication, we try to achieve four goals and divide our work in four directions:

1) RRTD: Robust and Real Time Data Delivery mechanism that deals with both hard as well as soft real time communication in data delivery in WSNs. Proposed data delivery mechanism of real time routing layer (Chapter 3).

2) RRRT: Robust, Real-time and Reliable Transport protocol that is responsible for data delivery with minimum energy consumption and with congestion avoidance in WSNs. Proposed protocol of robust and self-stabilized MAC layer of the proposed architecture (Chapter 4).

3) RTS: Real Time scheduling that is responsible for real time dissemination of data by defining delay bounds. Proposed real time dissemination algorithm residing at differentiated packet scheduling layer of the proposed architecture (Chapter 5).

4) Real Time Capacity: Real time capacity defines the amount of the information that can be carried in real time limits. These limits are defined at differentiated packet scheduling layer of the proposed architecture (Chapter 6).