Design Issues, Principles and Routing Challenges in Sensor Networks

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Abstract: *The sensor network is one the popular means of communication in today's era of networking. These networks which are formed using tiny battery powered sensor nodes are capable of sensing the parameters, doing computation and doing communication wirelessly. Researchers looked into the energy efficiency factor at the time of designing networks. To achieve greater energy efficiency, the importance must be given to routing protocols which might differ depending on the application area and the network architecture. In this paper, main focus has been put on the various routing techniques, design challenges of routing protocols along with the performance issues of each routing technique. Also paper highlights on comprehensive analysis of different routing techniques used in sensor networks to achieve better energy efficiency.*

Keywords: *Energy, Networks, Routing, Sensor, Wireless*

Received April 15, 2018; Accepted September 5, 2018

1. Introduction

Due to recent technical advancements in electronics, it is economically feasible to manufacture the tiny and low cost sensors. The sensors have immense potential to connect the nearby physical environment. The sensor nodes equip with transceivers which are going to collect information from nearby environment. Then, information gets pass on to the base station. The base station is responsible for storing measured parameters and to make them available to the end user.

The sensors are tiny devices with several constraints like the limited battery power, communication range, and computation speed and data storage capacity.

1.1. WSN Communication Architecture

The sensor nodes can route data by communicating with each other or with base station. The base station is an intermediate node that acts as a channel between deployed sensors and main communication network.

The deployment of a base station is very important in a network because sensor nodes are spread over the field area. They handover their data to the base station for processing and decision making purpose. The user can access the reported data and do further processing on it. The general communication framework of the wireless sensor network is shown in following figure 1.

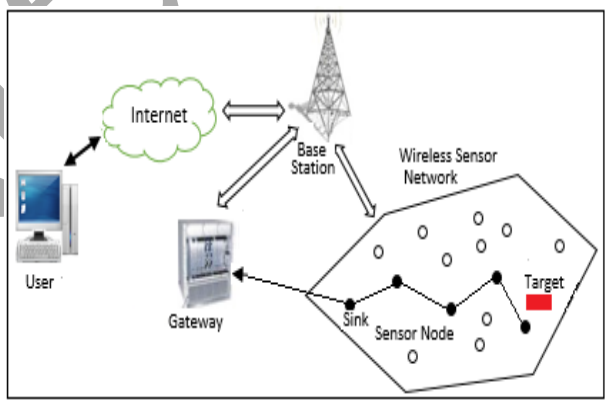

Figure 1. Generalized Communication framework in WSN.

During the deployment of base station in WSN, it has been taken care of some the important factors like energy conservation of node, coverage area and the reliability.

1.2. Sensor Node Units

Mainly, each sensor node involves sensing, processing and transceiver unit along with power unit. The sensor is a device which is used to measure changes in physical, environmental or health parameters of a person such as temperature, humidity, sound, vibration, pressure, health parameter like blood pressure, heartbeat etc. The analog to digital converters are used along with the processor and memory unit for processing input signals. The energy gets consumed to drive power amplifiers and radio transceiver electronics during

data communication. The following figure 2 shows the various units comprised in sensor node.

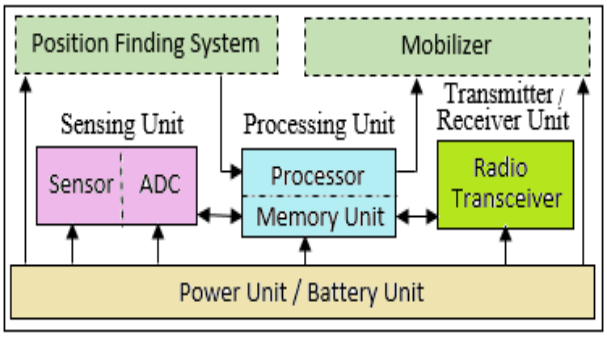

Figure 2. Sensor Node Units.

As sensor nodes are limited with power supply and bandwidth, novel techniques are highly recommended and required which will minimize energy waste. The deployment of increased number of such a constricted sensors increases design, management and routing challenges in WSN.

2. Related Work

Much of the research is done in align with the development of routing protocols in wireless networks. This subsection highlights literature survey on routing protocols and discusses the existing differences among them.

The authors, X. H. Wu, S. Wang discussed several design concerns in wireless networks as well as physical constraints on sensor nodes along with architectural attributes. Also they have proposed different protocols at network stack layers [11]. However, senor network surveys were not only devoted to routing but also emphasis on advancements in WSNs. The author S. Kim concentrated on the hardware components of a sensor node which are solely responsible for the energy consumption [5]. Also various architectural design solutions and power breakdown solutions have been discussed to reduce energy consumption in sensor networks. The characteristics and the organization of the energy saving schemes are also been explained by these authors.

S. Dulman, T. Nieberg, J. Wu, and P. Havinga [4] had discussed categorization and design problems of routing protocols. Some routing protocols were also been presented to prolong the network lifetime based on the characteristics and mechanisms used.

The author P. Minet [6] highlighted strengths and weaknesses of MAC protocols along with challenges related to energy-efficient Medium Access Control protocol design [2].

3. Routing Protocols in WSNs

Based on the network structure, there are several routing techniques present which are grouped into flat based, location based and hierarchical based routing.

In flat based routing, equal functionality and roles are assigned to all sensor nodes. Whereas, data packets are routed by using the position of sensor node in location based routing. However, sensor nodes play diverse roles in hierarchical routing. In adapting routing protocols, certain system parameters are tuned to comply with available energy level and dynamic network conditions in adaptive routing protocols.

The sensor nodes are clustered together in hierarchical routing protocols and clusters are formed. Each cluster has cluster head. This Cluster head is chosen by applying various election algorithms. The traffic overhead is reduced at certain level using cluster heads in wireless communication at higher levels.

At this point, the comparison among the different routing approaches based on various parameters for flat and hierarchical sensor networks, which is shown in table 1.

Analysis of hierarchical based routing protocols based on various parameters can be given as shown in table 2.

Table 1. Flat based Vs. Hierarchical Based Routing.

Parameter	Routing Approach	
	Hierarchical Routing	**Flat Routing**
Scheduling	Reservation based scheduling	Contention based scheduling
Collision	Collisions are avoided	Collision overhead is present
Duty Cycle	periodic sleeping resulting reduction in duty cycle	Sleep time of nodes is controlled thereby resulting variable duty cycle
Data Aggregation	Data aggregation through cluster head	Sensor node aggregates incoming data from neighbours on multi-hop path
Routing	Non optimal simple routing	Routing can be made optimal but with an added complexity
Synchronization	Requires global and local synchronization	Links formed on the fly without synchronization
Route Formation	cluster formation throughout the network leads to extra overhead	Routes formation is done only in the region of data transmission
Latency	Latency is low	Latency increases in Multipath setting and waking up intermediate sensor nodes
Energy Dissipation	Uniform energy dissipation	Energy dissipation changes per traffic patterns
Control	No control on energy dissipation	Energy dissipation changes according to traffic pattern
Channel Allocation	Channel allocation is fair	Fairness is not guaranteed

Table 2. Comparison of Hierarchical Based Routing schemes.

Protocol	Merits	Demerits	Scalability	Mobility
Low-Energy Adaptive Clustering Hierarchy (LEACH)	Distributed, ad-hoc and Low energy protocol	Use of dynamic clustering results in extra overhead bits and not applicable to large network regions	Good	Yes with Fixed Base Station
Power Efficient Gathering in Sensor Information Systems (PEGASIS)	Sensor nodes distance of transmission gets reduced	Head node's selection based upon, location of base station's doesn't taken into consideration	Good	supported with the provision of Fixed Base Station
Threshold sensitive Energy Efficient sensor Network protocol (TEEN)	Works well in the conditions like sudden changes in the sensed parameters like temperature	Energy consumption and overhead is more with increase in network size	Good	Fixed BS
Two-Tier Data Dissemination (TTDD)	It can be used for multiple mobile sinks in a field of stationary sensor nodes	Source node builds a virtual grid structure of dissemination points to supply data to the mobile sink nodes	Low	No Mobility
Base-Station Controlled Dynamic Clustering Protocol	Energy Consumption is low	Decreased performance gain as the sensor field area becomes small	Limited	No Mobility
Sleep / Wake Scheduling Protocol (Sleep / Wake)	Identifies bottleneck and significantly extends the network lifetime	Synchroniz -ation and scheduling will both affect the overall system performance	Good	No
Scaling Hierarchical Power Efficient Routing (SHPER)	Energy balance of the network	It does not support mobility	Good	Fixed BS
Distributed hierarchical agglomerative clustering (DHAC)	Longer network lifetime	Performance is worse as the network traffic is getting high	Good	No

4. Routing Challenges in WSNs

There are several constraints imposed on WSN like, limited battery energy, fixed wireless communication bandwidth for connecting sensor nodes and computing power. One of the major design goal of WSN is to carry data communication with extended lifetime. The design of routing protocols is influenced by many challenging factors which must be overcome to achieve efficient communication in WSNs. In reality, the problem of routing is much complicated while designing a multi-hop wireless network.

The following factors that make routing a more challenging task than just finding routing paths based on sink routes.

- **Inconsistency of Network Topology:**
  It is caused due to node mobility, joining or leaving of nodes in the network. Also links among sensor nodes can be up and down. This link variations causes an inconsistency in network topology.
- **Nondeterministic Routing Paths:**
  Selection of routing path is based on various components like network traffic, medium access control, channel allocation power control etc. So

finding most optimal solution for routing process is a challenging task.

5. Design Issues Related To Routing Protocols

Now a days, the design of an energy efficient routing protocol is an active research area in sensor networks. The following are some of the key issues faced during the design and implementation of routing protocols which affect routing process in wireless networks.

- **Node deployment:**
  The node structure deployment in WSN whether it is deterministic or randomized, varies as per the application and affects performance of the routing protocol. Generally deterministic node deployment involves manual placement of sensors and routing through predetermined network paths. On the other hand randomized node deployment encompasses randomized distribution in an ad hoc manner.
- **Data Aggregation:**
  In data aggregation, data is collected from different sources according to a definite aggregation function and also encompasses signal processing.
- **Energy consumption:**
  The energy constrained sensor nodes in WSN performs computation as well as also responsible for transmitting information in wireless sensor network.
  So there is necessity of energy conserving mechanisms for data communication and processing.
- **Node Heterogeneity:**
  Some application may demand diversified sensors for sensing different parameters of the environment like temperature, humidity, pressure, detecting motion, and capturing the image or video tracking of moving objects. This can be achieved by deploying special sensors independently or by incorporating these functionalities in a same sensor node. Whereas using heterogeneous sensor nodes leads to many data routing problems which needs to overcome further.
- **Connectivity:**
  Sensor nodes are expected to be highly connected and it is maintained by possibly random distribution of nodes.
- **Coverage:**
  The sensor nodes used in WSN records only specific view of environment. Mostly it constraints sensor's view in both range and accuracy also it covers only limited physical area of surrounding environment. This makes area coverage as an important design parameter for consideration.
- **Scalability:**
  Routing scheme can be design by considering huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to respond to events in the environment.
  Number of deployed sensor nodes in sensing area are in order of hundreds, thousands or even more than that. Any chosen routing scheme must comply with such huge number of nodes. Also routing protocols must also scalable enough for responding to external environmental events.
- **Fault Tolerance:**
  Physical damage, limited power, environmental interference etc. are some factors for node failure or blockage. The overall task of the sensor network should not get affected by the failure of sensor nodes. On multiple node failure, MAC and routing protocol should be flexible enough to formulate new links and routes.
- **Network Dynamics:**
  Some network framework works on the assumption of stationary sensor nodes which does not comply with the need of mobility in sensor nodes and base station. And in such mobile situation message routing is major challenge as there is no route stability.
- **Transmission Channel:**
  In a multi-hop sensor network, communicating nodes are linked by a wireless medium. Traditional problems of wireless channels can also have an adverse effect on operationalization of sensor network.
- **Quality of Service:**
  The routing protocols that are energy aware and reduces energy dissipation are necessary for extending lifetime of network. Also required to assure data delivery within certain period of time and need to maintain the quality of data sent.

6. Design Principles for Routing Protocol

In order to provide solution for the routing challenges, following heuristics needs to be taken into account while designing routing schemes.

- Development of new routing metrics.
- Emphasis on cross layer design.
- Performing dynamic and adaptive routing.
- Maintaining a stable and consistent network topology.
- Deriving fault tolerant distributed routing algorithms.
- Ensure scalability in routing protocols.

7. Conclusion

Now a days, routing in WSN is a new research area of many researcher with rapidly growing set of

research results. In this paper, while considering challenges in routing, we have carried out hierarchical based routing protocol's comprehensive analysis. Classification of routing protocols like flat, hierarchical, location based etc. are discussed. This analysis shows suitability of hierarchical protocols are for heavy load and wide sensor networks. Design issues in routing schemes, as well as the pros and cons of hierarchical routing technique are also discussed.

Although many of these routing techniques look promising, there are still many challenges that needs to be solved in the sensor networks. The enlisted some of the principles need to be considered in the design of routing protocols pinpointed future research directions in this regard.

Acknowledgement

I would like to express my sincere gratitude towards my research supervisor, Dr. Devendra Chaudhari, Professor, Research Centre for Computer Science and Engineering, Government College of Engineering, Amravati, for giving me the opportunity to do research and providing invaluable guidance throughout this research. His dynamism, vision, sincerity and motivation have deeply inspired me. He has taught me the research methodology for presenting the research work as clearly as possible.

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