Routing Protocols in Wireless Sensor Network: A Critical Survey and Comparison

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ABSTRACT

Wireless Sensor Networks (WSNs) consist of small nodes with sensing, processing and wireless communications capabilities. Routing technique is one of the key concerns in the research area of wireless sensor networks now days. In this paper, important routing protocols and its various challenges such as energy efficiency, security, quality of service, scalability, storage and computation in WSNs are discussed. Wireless Sensor Networks a great opportunity for the researchers in the developing countries. The future developments in sensor nodes must produce very powerful and cost effective devices, so that they may be used in applications like underwater acoustic sensor systems, time critical applications, cognitive sensing and spectrum management and coordination in heterogeneous networks and so on.

***Keywords*—Wireless sensor network, routing, routing technique, challenges and design issues**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) is a great enabling technology that can revolutionize information and communication technology. In fact, it has the potential to significantly change the way we live – just like the Internet and World Wide Web – perhaps more so. WSN has opened up the challenge for distributed and cooperative computing and communication. A Wireless Sensor Network is a self-configuring network of small sensor nodes communicating among themselves using radio signals, and deployed in quantity to sense, monitor and understand the physical world. It is highly distributed networks of small, lightweight wireless nodes, deployed in large numbers and monitors the environment or system by measuring physical parameters such as temperature, pressure, humidity. A wireless sensor network (WSN) is a wireless network consisting of dispersed autonomous devices that use sensors to monitor physical or environmental conditions. These autonomous devices, or nodes, combine with routers and a gateway to create a typical WSN system. Data is collected at the wireless sensor node, compressed and transmitted to the gateway directly or, if required, uses other wireless sensor nodes to forward data to the gateway, which provides a connection to the wired world where it can collect, process, analyze and present the analyzed data. This paper is organized as follows: - Section II introduces the concept of architecture of wireless sensor network. Section III presents Wireless Sensor Node Communication Architecture: Protocol Stack. Routing Protocols in WSN are discussed in Section IV. Section V discusses routing challenges and design issues followed by future trends in development of WSN applications discussed in Section VI. Then analyzed and compared various papers proposed by the other researcher. Finally, Section VII concludes the paper followed by future work.

II. ARCHITECTURE OF WSN

Fig.1 shows the first look of wireless sensor network[1].
Sensor Field: A sensor field can be considered as the area in which the nodes are placed.
Sensor Nodes: Sensors nodes are the heart of the network. They are in charge of collecting data and routing this information back to a sink.

Sink: A sink is a sensor node with the specific task of receiving, processing and storing data from the other sensor nodes. They serve to reduce the total number of messages that need to be sent, hence reducing the overall energy requirements of the network. Sinks are also known as data aggregation points.

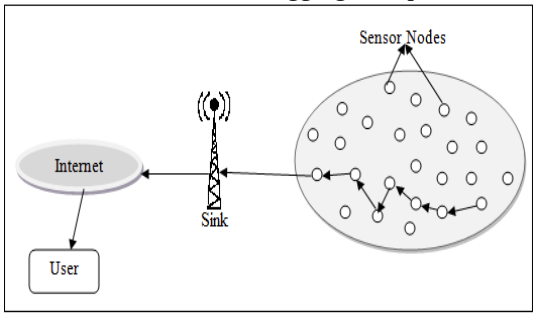

Fig.1 WSN Architecture

III. WIRELESS SENSOR NODE COMMUNICATION ARCHITECTURE: PROTOCOL STACK

Sensor network needs five layers: application layer, transport layer, network layer, data link layer and physical layer. The three cross planes or layers are; power management plane, mobility management plane and task management plane.

Fig.2 shows the sensor network protocol stack. These management planes make sensor nodes work together in a power efficient way, route data in a mobile sensor network, and share resources between sensor nodes.

- Power management plane
- Manages how a sensor node uses its power
- For example, the sensor node may turn off its receiver after receiving a message
- Mobility management plane
- Detects and registers the movement of sensor nodes
- So a route back to the user is always maintained
- The sensor nodes can keep track of who are their neighbor sensor nodes
- Task management plane
- Balances and schedules the sensing tasks given to a specific region
- Not all sensor nodes in that region are required to perform the sensing task at the same time

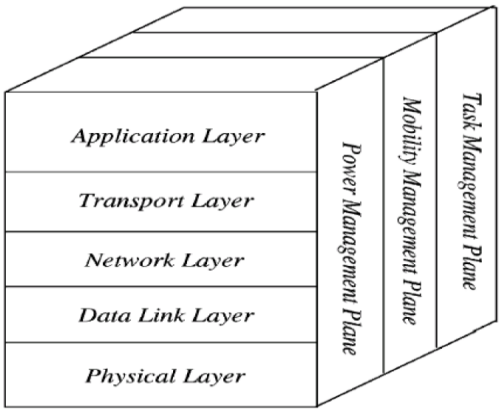

Fig.2 Sensor network protocol stack

1. *Physical Layer*

This layer provides an interface to transmit a stream of bits over physical medium. Responsible for frequency selection, carrier frequency generation, signal detection, Modulation and data encryption. The minimum output

power required to transmit a signal over a distance. In this layer multihop communication in a sensor network can effectively overcome shadowing and path loss effects. Energy-efficiency being pursued using binary and m-ary modulation.

2. Data link layer

The data link layer is responsible for the multiplexing of data stream, data frame detection, medium access and error control. Ensure reliability of point–point or point– multipoint, errors or unreliability. Co- channel interference at the MAC layer and this problem is solved by MAC protocols.

Multipath fading and shadowing at the physical layer and this problem is solved by forward error correction (FEC) and automatic repeat request (ARQ).

3. Network layer

The major function of this layer is routing. This layer has a lot of challenges depending on the application but apparently, the major challenges are in the power saving, limited memory and buffers, sensor does not have a global ID and have to be self organized.

The networking layer of sensor networks is usually designed according to the following principles:

- Power efficiency is always an important consideration.
- Sensor networks are mostly data centric.
- Data aggregation is useful only when it does not hinder the collaborative effort of the sensor nodes.

4. Transport layer

The transport layer is needed when the system is planned to be accessed through Internet or other external networks. The function of this layer is to provide reliability and congestion avoidance where a lot of protocols designed to provide this function are either applied on the upstream or downstream. These protocols use different mechanisms for loss detection ((ACK, NACK, and Sequence number)) and loss recovery ((End to End or Hop by Hop)). This layer is specifically needed when a system is organized to access other networks.

5. Application layer

Potential application layer protocols for sensor networks remain a largely unexplored region. Three possible application layer protocols.

- Sensor management protocol (SMP)
- Task assignment and data advertisement protocol (TADAP)
- Sensor query and data dissemination protocol (SQDDP)

Responsible for traffic management and provide software for different applications that translate the data in an understandable form or send queries to obtain certain information.

IV. ROUTING PROTOCOLS IN WSN

WSN Routing Protocols can be classified in four ways, according to the way of routing paths are established, according to the network structure, according to the generally, routing protocols are: Application specific; Data centric; Capable of Routing in Wireless Sensor Networks protocol operation and according to the initiator of communications. Fig.3 shows the classification of WSN routing protocols.

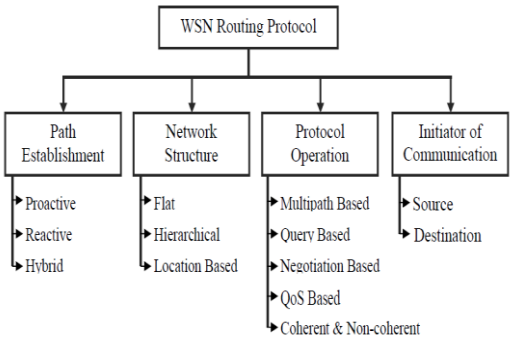

Fig 3. Classification of WSN routing protocols

Based on the network structure, routing in WSNs can be divided into three categories named as flat-based routing, hierarchical-based routing and location based routing

Flat Routing (Data Centric Routing protocols): In flat networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. In this type of network it is not possible to assign a global identifier to each node due to large number of nodes. Therefore, base station send queries to different part of the field and waits for the data from sensors in selected parts of the field.

*Sensor Protocol for Information Negotiation (SPIN):*In [2] the author mentions that Sensor Protocols for Information via Negotiation (SPIN) that disseminates all the information at each node to every node in the network assuming that all nodes in the network are potential BSs. This enables a user to query any node and get the required information immediately.

These protocols make use of the property that nodes in close proximity have similar data, and hence there is a need to only distribute the data other nodes do not posses.

Directed Diffusion: Directed Diffusion is another type of data centric protocol for wireless sensor network [3]. There are four main features of this protocol: Interest, Gradient, Data, and Reinforcement. Interest message defines the data the recipient interested in. It is disseminated to all the applicable nodes in the network. The gradient message provides neighboring nodes with the information as to where the data is to be forwarded next.

An Energy Efficient Directed Diffusion Model for Wireless Sensor Networks [4], this paper emphasizes on a fact that the flooding procedure followed in interest diffusion phase will inevitably bring about heavy traffic load and affect seriously transmission performance of network.

Load-balance Directed Diffusion in Wireless Sensor Networks [5], this paper talks about the power consumption of the nodes considering in terms of load in the wireless sensor network. In DD, interest is disseminated through flooding process and path gradient is calculated as well as recalculated (while sending exploratory data) using the interest message.

Rumor Routing: Rumor routing [6] allows the routing of queries to nodes that have observed an event of interest. As a result, retrieval of data is based on events and not on an addressing scheme. An event is an activity related to the phenomena being sensed (e.g. increased movement in an area being monitored). In this paper, events are assumed to be localized phenomena which occur in fixed regions of space. A query is issued by the sink node for one of two reasons, as an order to collect more data, or as a request for information.

Minimum Cost Forwarding Algorithm (MCFA): Minimum Cost Forwarding has been defined by author in this paper [7] as an efficient protocol appropriate for simple WSN with limited resources. The aim of MCF is to establish a means of delivering messages from any sensor in a field of sensor nodes along a minimum cost path to an interested client node or base station. MCF exploits the fact that the direction of routing is always known, i.e. data always flows from sensor nodes towards a base station.

Hierarchical Routing: Hierarchical routing works in two layers, first layer is used to choose cluster heads and the other layer is used for routing. To make the WSN more energy efficient, clusters are created and special tasks (data aggregation, fusion) are assigned to them. It increases the overall system scalability, lifetime, and energy efficiency.

Low Energy Adaptive Clustering Hierarchy (LEACH): Among the current researches, the clustering routing technology is the most widely influential. Low-Energy Adaptive Clustering Hierarchy (LEACH) [8] is a classical clustering routing in wireless sensor networks .However the cluster-head selection in LEACH protocol is lack of balancing the whole network energy consumption, with the result that low energy nodes run out of energy prematurely and decline the network life. This paper analyses the effectiveness of LEACH protocol in cluster-head selection, and proposes an improved energy balanced clustering algorithm.

- LEACH C- It is a centralized clustering algorithm. The steady state used in LEACH C is similar to set up phase of LEACH and in Leach-C each node sends the information about the current location and the level of energy to the base station.

-LEACH-B – This algorithm to balance the number of cluster heads based on the residual energy of the sensor nodes.

Self Organizing Protocol (SOP): General self-organized tree-based energy-balance routing protocol [9] - GSTEB is a self-organized protocol, it only consumes a small amount of energy in each round to change the topography for the purpose of balancing the energy consumption.

All the leaf nodes can transmit data in the same TDMA time slot so that the transmitting delay is short. When lifetime is defined as the time from the start of the network operation to the death of the first node in the network.

Virtual Grid Architecture: In this paper [6], a novel scheme called Virtual Grid based Dynamic Routes Adjustment (VGDRA) is proposed for periodic data collection from WSN. It aims to optimize them trade-off between nodes energy consumption and data delivery performance using a single mobile sink while adhering to the low-cost theme of WSN. The authors design a virtual infrastructure by partitioning the sensor field into a virtual grid of uniform sized cells where the total number of cells is a function of the number of sensor nodes. A set of nodes close to centre of the cells are appointed as cell-headers which are responsible for keeping track of the latest location of the mobile sink and relieve the rest of member nodes from taking part in routes re-adjustment.

Location-based Routing: In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Generally two techniques are used to find location, one is to find the coordinate of the neighboring node and other is to use GPS (Global Positioning System).

Geographical Adaptive Fidelity (GAF): The common approach for energy saving is to use sleep modes in nodes expecting no activity in a period of time. This is the main idea behind GAF. Proposed Scheme: The design of GAF [10] is motivated by an energy model that focuses on energy consumption due to the reception and transmission of packets as well as idle time. GAF is based on the mechanism of turning off unnecessary sensors while keeping a constant level of routing fidelity. GAF divides sensor field into grid squares and every sensor uses its location information to associate itself with a particular grid. Size of grid square is chosen in a way such that sensors within the same grid are equivalent with regard to routing and that sensors in adjacent grids can communicate with each other.

SPAN: Its goal is to reduce energy consumption. Span helps sensors to join a forwarding backbone topology as coordinators that will forward packets on behalf of other sensors between any source and destination .Span is an energy efficient coordination algorithm for topology maintenance in wireless ad hoc networks. Each node in Span does the local decision on whether to announce for or withdraw from coordinator. They modify coordinator withdrawal procedure of Span by adding average speed of node as one of the condition for withdrawing it from coordinator.

V. ROUTING CHALLENGES AND DESIGN ISSUES

Some of the important routing challenges in WSN are discussed in this section as follows:

Limited battery power: Wireless sensor nodes have limited energy storage and once they are deployed, it is not practical to recharge or replace their batteries as sensor nodes in WSN have limited battery power, it becomes challenging to perform computation and transmission while optimizing energy consumption. In fact the transmission of one bit of data consumes more energy than processing the same bit of data. Sensor node life time strongly depends on its battery life.

Security: Security is one of the major challenges in WSNs. Most of the attacks that are performed on WSN are insertion of false information by compromised nodes within the networks. Development of security schemes for WSN also faces challenges related to constrained environment.

Scalability: The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes. Scalability is one of the main design attributes of the sensor networks, and this must be encompassed by the protocols.

Node deployment: Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through pre-determined paths. However, in random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner.

Quality of Service: In some applications, data should be delivered within a certain period of time from the moment it is sensed; otherwise the data will be useless. Therefore bounded latency for data delivery is another condition for time-constrained applications. However, in many applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent.

Node Capability: Depending on the application, a sensor node can have different role or capability such as relaying, sensing and aggregation since engaging all these functions on the same node would drain the energy of that node more quickly. Different capabilities of sensor nodes raise multiple issues related to data routing and makes routing more challenging.

Fault Tolerance: Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations.

VI. FUTURE TRENDS IN WSN APPLICATIONS

The future developments in sensor nodes must produce very powerful and cost effective devices. Possibilities of further developments in WSN applications are studied in this section.

Cognitive Sensing: Cognitive sensor networks are used for acquiring localized and situated information of the sensing environment by the deploying a large number of sensors intelligently and autonomic ally. Managing a large number of wireless sensors is a complex task.

Spectrum Management: As application of low power wireless protocols is increasing, we can envision a future in which wireless devices, such as wireless keyboards, power point presenters, cell phone headsets, and health monitoring sensors will be ubiquitous. But the pervasiveness of these devices leads to increased interference and congestion within as well as between networks, because of overlapping physical frequencies. Cognitive radios and multi frequency MACs are some approaches that have been developed to utilize multiple frequencies for parallel communication.

*Underwater Acoustic Sensor Systems***:** Underwater sensor networks are designed to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Underwater sensors are also being in use for exploration of natural undersea resources and gathering of scientific data. So a need of underwater communications among underwater devices arises. Underwater sensor nodes and vehicles should be capable of coordinate their operation, exchanging their location and movement information and hence relay monitored data to an onshore base station.

*Time Critical Applications***:** A new generation of distributed embedded systems, with a broad range of real-time applications, such as fire monitoring, border surveillance, medical care, and highway traffic coordination, can be represented by WSNs. Due to severe resource limitations in highly dynamic environments. These systems face new kinds of timing constraints. Many classical approaches to real-time computing like wireless networking protocols, operating systems, middleware services, data management, programming models, and theoretical analysis are challenged by WSNs.

Table 1.Comparison of routing protocols

	Classification	Power Usage	Localization	QoS	Scalability	Multipath
SPIN	Flat	Limited	No	No	Limited	Yes
Directed Diffusion	Flat	Limited	Yes	No	Limited	Yes
Rumor Routing	Flat	N/A	No	No	Good	No
MCFA	Flat	N/A	No	No	Limited	No
LEACH	Hierarchical	Maximum	Yes	No	Good	No
SOP	Hierarchical	N/A	No	No	Low	No
VGA	Hierarchical	N/A	Yes	No	Good	Yes
SPAN	Location	N/A	No	No	Limited	No
GAF	Location	Limited	No	No	Good	No

Table 2.*Comparisons analysis of various papers*

Researchers	Paper Title	Abstract	Analysis	Conclusion	Future Work
Abdul Waheed Khan, Abdul Hanan Abdullah, Mohammad AbdurRazzaque and JavedIqbalbangash	VGDRA : A virtual Grid based Dynamic Routes adjustment Scheme for Mobile Sink based Wireless Sensor Networks[6]	Aims to minimize the routes reconstruction cost of the sensor nodes while maintaining nearly optimal routes to the latest location of the mobile sink	VGDRA scheme partitions the sensor field into a virtual grid and constructs a virtual backbone structure comprised of the cell header nodes	Reduced routes reconstruction cost and improved network lifetime of the VGDRA scheme	Analyze the performance of VGDRA scheme at different sink's speeds and data generation rates of the sensor nodes.

Mrs. T. Nagamalar, Dr. T. R. Rangaswamy	Energy Efficient Cluster based Approach for Data Collection in Wireless Sensor Networks with Multiple Mobile Sink[11]	New cluster based approach using controlled flooding is proposed with multiple mobile sink for prolonging the life time of WSN	WSN lifetime is prolonged with optimal routes and limited flooding of update message to the restricted number of cluster heads.	Multiple mobile sink with reduced reconstruction of route has improved the energy efficiency and increased lifetime of WSN	Link failure due to the mobility of sink and node failure could also be taken into Consideration for maintaining the reliable path
NaliniJori. Neeta Thune	An Sensor Node Energy Improvement In-Network For Wireless Sensor Network[12]	Improves the data fusion and aggregation protocols to save energy efficiently, builds the effective routing tree, overlapping routes increases and eliminates the redundant data	Improves the routing path and builds the efficient routing tree, aggregation quality, the communication cost, delivery efficiency, calculate the energy utilization of each node	N-DRINA shows improved results along the use of energy-wake-up mechanism	Spatial and temporal correlation of aggregated data will also be taken into consideration as well as the construction of routing tree that meets application needs
Jenq-ShiouLeu , Tung-Hung Chiang	Energy Efficient Clustering Scheme for Prolonging the Lifetime of Wireless Sensor Network With Isolated Nodes[13]	a new regional energy aware clustering method using isolated nodes for WSNs, called Regional Energy Aware Clustering with Isolated Nodes (REAC-IN)	CHs are selected based on weight which is determined according to the residual energy of each sensor and the regional average energy of all sensors in each cluster	improves the cluster head selection process and solves the problem of node isolation, lifetime and stability of a network is more favorable	
Prerna, Sanjay Kumar	Energy Efficient Clustering Algorithm for WSN[14]	based on static clustering concept and dynamic cluster heads selection technique, which divides the entire network area into a number of fixed regions	CH is selected that it reduces communicating distance bet-ween nodes, hence reduces energy consumption while transmitting the data from one node to another and increases network efficiency as energy consumed	the proposed (EECA) algorithm is better than the LEACH, LEACH-C and DR scheme in respect of throughput and stability	

Kyung Tae Kim, Man Youn Kim, JiHyeon Choi, Hee Yong Youn	An Energy Efficient and Optimal Randomized Clustering for Wireless Sensor Networks[15]	decides optimal number of clusters by employing a new approach for setting threshold value, including the probability of optimum number of cluster heads and residual energy of the nodes	Introduces a new threshold value used in selecting the cluster heads in the network. Also introduced a new tree construction approach inside each cluster to minimize the energy consumption of sensor nodes	the proposed scheme can significantly reduce energy consumption and increase the lifetime of the network compared to the existing schemes	Extension of the proposed scheme to cope with the mobility and the related challenges is yet another important issue remaining as future work
Suraj Sharma, Sanjay Kumar Jena	Cluster based Multipath Routing Protocol for Wireless Sensor Networks[16]	Uses the clustering and multipath protocols to reduce energy consumption and increase the reliability. The basic idea is to reduce the load of the sensor node by giving more responsibility to the base station (sink)	All the paths are computed prior to its requirement. It is suitable for the static network. It requires route from cluster head to the base station. The base station is responsible for computing the routing path and monitoring the energy level of each sensor node in the network.	The multipath gives more reliability to the network, and it increases the throughput and decreases latency. In addition to that, cluster based data collection reduces the traffic and energy consumption and also increases the lifetime of the network	
Noor M. Khan, Ihsan Ali, Zubair Khalid, Ghufran Ahmed, Alex A. Kavokin	Quasi Centralized Clustering Approach for an Energy-efficient and Vulnerability-aware Routing in Wireless Sensor Networks[17]	QCCA, in which WSN partition into disjoint and equal-sized cells. This approach reduces both energy consumption and communication bandwidth requirements and prolongs the lifetime of the WSN. Provides automatic adaptation to different routes when network condition changes	In the proposed approach, there are two phases of operation: setup phase and steady-state phase. In the setup phase, control information is flooded in the entire network. In the steady-state phase, whenever a source node wants to send data to its CH, it chooses that neighbor from its routing table who has lowest IPvalue	A large amount of energy is saved using this strategy. QCCA not only focus on the shortest path, but also on energy awareness and vulnerability factor of nodes	Extending the routing protocol to allow fault recovery of gateway. Introducing fault tolerance in the protocol while ensuring robustness in an energy-efficient and vulnerability-aware manner will increase the capability of WSN

AshishUpadhyay, Raghvendra Kumar, Sujeet.K.Tiwari	Modified LEACH Protocol for Sensor Network[8]	proposed algorithm solves the extra transmissions problem that can occurs in LEACH algorithm	The energy consumption in proposed algorithm increases and network lifetime decreases. The reason is that sensor nodes that are not included in any cluster have to transmit their data directly to the BS over long distance.	eliminated the extra transmissions that can occur in LEACH algorithm	Future proposed energy efficient protocol that will work on the less energy consumption

VII. CONCLUSION AND FUTURE WORKS

This paper conducts a critical survey of the wireless sensor networks architecture, design issues, different routing techniques and their challenges. Various existing routing protocols are compared and contrasted in the table 1 and table 2. Final findings of our this paper is that in case of Data centric routing in WSN, naming rules such as attribute-value pairs will not work for complex queries that are application dependent. In case of Hierarchical routing, the nodes are grouped together to form clusters. Cluster heads are responsible for data aggregation and relay of messages to the sink. In case of Location based routing protocols, energy efficient and intelligent utilization of location information.

There are substantial challenges that need to be solved in the sensor networks. In the future, our research work focus on to propose energy efficient routing algorithm based on clustering.

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