Adaptive Routing Protocol for Dynamic Wireless Sensor Networks

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Abstract**—**The main issue in designing a wireless sensor network (WSN) is the finding of a proper routing protocol that complies with the several requirements of high reliability, short latency, scalability, low power consumption, and many others. This paper proposes a novel routing algorithm that complies with these design requirements.

The new routing protocol divides the WSN into several sub-networks and each sub-network is divided into several clusters. This division is designed to reduce the number of radio transmission and hence decreases the power consumption. The network division may be changed dynamically to adapt with the network changes and allows the realization of the design requirements.

Keywords**—**Wireless sensor networks, routing protocols, ad hoc topology, cluster, sub-network, WSN design requirements.

I. INTRODUCTION

WIRELESS SENSOR NETWORK (WSN) is widely considered as an important technology in the twenty-first century. A WSN typically consists of a large number of low-cost, low power, and multifunctional wireless sensor nodes, with sensing, wireless communications, and computation capabilities. These sensor nodes communicate over short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control [1], [2].

In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful planning and engineering. Once deployed, the sensor nodes must be able to organize themselves autonomously into a wireless communication network.

Due to the severe energy constraints of large number of densely deployed sensor nodes, it requires a suite of network protocols to implement various network control and management functions such as synchronization, node localization, data transfer, and network security. The main needed network protocol is the routing algorithm, which is vital for the data transfer between the nodes.

The traditional routing protocols have several shortcomings when applied to WSNs, which are mainly due to the energy-constrained nature of such networks. For example, flooding is a technique in which a given node broadcasts data and control packets that it has received to the rest of the nodes in the network. This process repeats until the destination node is reached. This protocol implies that a very large number of data transmissions have to occur for each data transfer which in turn means large power consumption. To solve this problem, it is necessary to modify the flooding protocol to ensure low number of transmissions and this objective is realized by the current work described in this paper.

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II. ROUTING PROTOCOLS IN WSN

Routing in wireless sensor networks differs from conventional routing in fixed networks in various ways. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements. Many routing algorithms were developed for wireless networks in general. All major routing protocols proposed previously for WSNs may be divided into seven categories as follows [3]-[5]:

- **Location-based Protocols:** MECN, SMECN, GAF, GEAR, Span, TBF, BVGF, GeRaF.
- **Data-centric Protocols:** SPIN, Directed Diffusion, Rumor Routing, COUGAR, ACQUIRE, EAD, Information-Directed Routing, Gradient-
- Based Routing, Energy-aware Routing, Information-Directed Routing, Quorum-Based Information Dissemination, Home Agent Based Information Dissemination.
- **Hierarchical Protocols**: LEACH, PEGASIS, HEED, TEEN, APTEEN.
- **Mobility-based Protocols**: SEAD, TTDD, Joint Mobility and Routing, Data MULES, Dynamic Proxy Tree-Base Data Dissemination.
- **Multipath-based Protocols**: Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery.
- **Heterogeneity-based Protocols**: IDSQ, CADR, CHR.
- **QoS-based protocols**: SAR, SPEED, Energy-aware routing.

It is worth mentioning that the survey of the above routing protocols is not the objective of this paper and may be found in the literature.

III. FOUNDATIONS OF THE PROPOSED ROUTING PROTOCOL

The proposed routing strategy does not presume any restrictions on the WSN as it allows random deployment, mobility, failure, and high density of nodes.

The strategy makes standard assumption of the existence of a base station (BS) that is capable of collecting the data from all nodes and redirects them to a proper control center, which decides the actions to be taken. The BS is also capable of controlling, the functions of the nodes to make them act as normal sensors or as relaying stations. The functional assignment should ensure low number of radio transmissions and hence low energy consumption. In addition, it ensures an equal distribution of transmissions between nodes, which means no energy depletion of any node before the others.

For all the above features, the novel algorithm is called "ARDWSN" i.e. Adaptive Routing for Dynamic Wireless Sensor Network.

The implementation of ARDWSN assumes a physical address assigned to each node by the manufacturer. If not, the BS can assign this address to each node as follows: The BS, by using a proper control message, instructs each node to select a random number from defined domain and send it back to the BS. The BS examines all the received numbers to detect any duplication. If duplication is discovered, the BS sends the duplicated number to all nodes and instructs those who already use it to change randomly their choice. The BS keeps doing this until all nodes have different identification numbers, which become equivalent to physical addresses. This means that we can always assume that each node has an identification address whether it is physical or assigned by the BS.

IV. Formatting of WSN

The word "formatting" means the division of the WSN into "tracks" and "sectors". The track includes all the nodes that have equal distance from the BS. The distance means the least number of relaying nodes necessary to transfer data between the normal node and the BS. The nodes included in each track form a sub-network "subnet". The track is also named as "layer".

Each track (layer) is divided into several sectors. The sector includes several nodes that form a "cluster". The cluster node is the one with a radio transmission that can reach the "cluster head" directly without relaying. The cluster head is any node that is assigned this task by the BS. The cluster head is called a "router".

The formatting process is carried out by the BS whenever necessary to ensure low energy consumption and equal distribution of radio transmissions between nodes and hence longer lifetime of the WSN.

The concept of tracks (layers, subnets) and sectors (clusters) is two-dimensional (2D); however, it can be generalized to be three-dimensional (3D) as well which in turn makes the ARDWSN more general and more dynamic.

A. Layering (Sub-Netting) Implementation

The Base Station BS broadcasts a control message and requests each node to respond after adding its physical address (ID). The nodes that respond directly without relaying constitute subnet1 (track1 or layer1). Then, the BS broadcasts another control message and the nodes that respond via subnet1 will form subnet2 (layer2). The BS continues this operation until all subnets are defined. The subnets (layers) may look as in Fig. 1.

In order to allow the BS to detect the relaying nodes, each one of them should add its ID address to the response message before retransmitting it. The BS analyzes the received response messages and compares the IDs contained in them with its database of the IDs of each already formed subnet.

B. Sectoring (Clustering) Implementation

To divide the subnet into clusters, the BS selects one node in certain layer and assigns it to be a cluster head (router). The router broadcasts a control message and requests responses from the nodes in the same layer. These responses are analyzed by the BS and accordingly it decides the nodes that belong to the current cluster. Of course, the node that belongs to the cluster should have relayed response via the router only and lies inside the layer being formatted. After this, the BS selects another node in the same layer, and assigns it as a router and repeats the previous action until all nodes of the layer are incorporated in clusters and each cluster has a router.

It should be noted that the node should add it's ID before retransmitting the response and the formatting process might be repeated at different times to change the routers and hence ensures uniform power consumption between nodes.

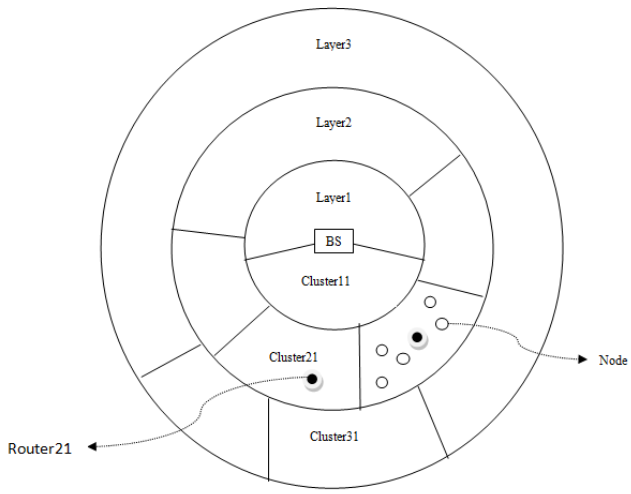


Fig. 1 Layers, Clusters, Routers, and Nodes in WSN

V. Directions of Data Transfer

The direction of data transfer is defined by a special field within the frame that is issued by the source node. In the ARDWSN, there are two directions:

- Forward: The BS, which lies in the lower layer, sends a message to the destination node in the upper layer. This means that any node that receives a message from upper layer during flooding process should discard this message. The relaying node retransmits only the messages that arrive from lower layer. Of course, each node should add its layer ID to the message before sending it and this inclusion is done in the frame field called "temporary source ID".
- Backward: The node, which lies in the upper layer, sends a message to the BS in the lower layer. This means that

any node that receives a message from lower layer during flooding process should discard this message. The relaying node retransmits the messages that only arrive from upper layer. Of course, each node should add its layer ID to the message before sending it and this inclusion is done in the frame field called "temporary source ID".

It is clear from the above definitions that the direction field in the frame will help in reducing the number of retransmissions in the flooding process, which in turn means less energy consumption.

VI. Routing Algorithms in ARDWSN

The data transfer in any direction can be made using different routing algorithms. The algorithm type should be indicated inside the transmitted frame. The adopted algorithms are:

- Flat flooding: Each node rebroadcasts the received message until the message lifetime is over. The lifetime can be defined in several ways as shown later. This method ensures the arrival of any message from the source to the destination; however, it causes a lot of congestion. This strategy is used in some special cases e.g. network formatting and sending control messages [6], [7].
- Local flooding: The message is transferred between the node and the router in the same cluster. Any node receives such a message should not rebroadcast it and hence the flooding congestion is reduced.
- Router flooding: The message is transferred between the source and the destination using the assigned routers only. The normal node in any cluster should not rebroadcast any received message unless the following conditions are fulfilled:
- A timeout has elapsed. The timeout is defined by the BS at formatting stage. During the timeout, the router should broadcast the message to the next router. Of course, each message has an ID that consists of source address and creation time.
- No other node has made the retransmission of that message. If any other node has made the retransmission then the router would have received it and no need for another retransmission.
- The message has been received from a router and not from a normal node. The type of transmitting node is declared inside the frame field called "temporary source address".

It should be noted that the normal data transfer is initiated by the normal sensor node that uses the local flooding to transfer its data to its cluster router, which uses the router flooding to transfer the message to the BS destination.

A. Routing Tables

To ensure the least number of radio transmissions for any data transfer, it is necessary to build routing tables to define the message route in the forward and backward directions. These tables may be built by the BS during the formatting process. The BS, using router flooding, sends a control message to certain router and requests it to send a reply. Each router should add its ID before retransmitting the control message. Upon receiving the returned control message, the BS analyzes the message contents and decides the proper route to that router. The BS repeats this action for each router until building full routing tables for all routers. The contents of these tables are then distributed to all routers to be used when directed flooding is used.

It should be noted that the routing table for each router is a lookup table where each entry includes the next router that enables the message to reach the final destination.

B. Directed Routing

In the previous mentioned types of flooding, we notice that multipath routing may occur i.e. the message may follow different routes which in turn means more radio transmissions. To avoid the multipath transfer, it is possible to add another type of flooding called "directed flooding". In this case the routers use the routing tables when retransmitting their messages and hence there will be no multipath and hence less radio transmission.

C. Error Control

The error control can be implemented using the Automatic Repeat reQuest technique ARQ where an error may be detected and the sender resend the erroneous message. The ARQ may be implemented on two levels:

- Link level between the neighboring nodes
- End to end level between the node and the BS

The used level of ARQ is determined by the importance of data; however, an end to end ARQ is quite adequate. The error detection may be carried out using the Cyclic Redundancy Check CRC algorithm.

D. Addressing

The proposed ARDWSN uses the following types of addresses:

- Physical address defined by the manufacturer or assigned by the BS.
- Logical address that consists of layer ID, cluster ID, and node ID. This address is assigned by the BS during formatting stage. The node ID is a random number selected by the node and confirmed by the BS. When two selected numbers are duplicated, the BS requests them to change.

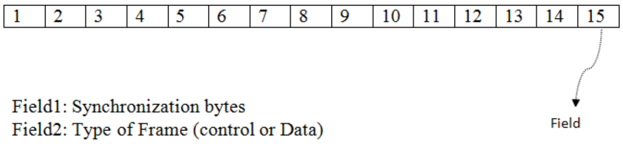
VII. Frame Format

The proposed ARDWSN requires a message format "frame format" as shown in Fig. 2. In this figure, we notice that there are different types of fields, which allow the ARDWSN to be multipurpose and it may be customized to application needs.

The lifetime field is responsible of discarding the frame when this lifetime has expired. The lifetime can be measured by different metrics such as:

- Actual creation time
- Number of crossed nodes
- Number of crossed layers
- Number of crossed clusters

The maximum limits of these metrics are decided by the BS and distributed to all nodes and routers.



Field1: Synchronization bytes
Field2: Type of Frame (control or Data)
Field3: Original Source Address
Field4: Original Destination Address
Field5: Temporary Source Address
Field6: Temporary Destination Address
Field7: Life Time
Field8: ARQ Sequence Numbers
Field9: ARQ Level
Field10: Data Transfer Direction
Field11: Routing method
Field12: Error Detection Code FCS
Field13: Length of Data in Bytes
Field14: Real Sensor Data
Field15: Type of node (router or normal)

Fig. 2 Frame Format for the ARDWSN

VIII. Modeling and Evaluation

A mathematical model has to be devised for the ARDWSN evaluation. This model is a subject of future research.

IX. Conclusions and Future Research

The proposed routing strategy ARDWSN is a general purpose and can be modified to suit many WSN applications. In addition, it is adaptable to network changes and hence more compliant with the network design requirements.

The proposed ARDWSN is a new approach in the WSN routing and requires more investigation for the purpose of evaluation and adaptation to specific applications.

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