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Developing a Routing Protocol for Wireless Sensor Networks Using Fuzzy Logic and Focused on Optimal Route Election

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Abstract

Tracking is one of the most critical problems of networks. It is of more importance when considering of challenges present in wireless sensor networks. In this research, we will introduce a tracking protocol for wireless sensor networks based on fuzzy logic. To solve problem, first, we developed input parameters of fuzzy module and determined its membership functions. By using of these parameters, then, we designed our respective fuzzy module to perform the next selection step in the routing operation, as a fuzzy inference machine. After simulation of the proposed routing, we compared results with those of existing routing protocols based on fuzzy logic. The main purpose of this research was transferring data created in the original node to the base station. Results show that routing simulation of the proposed algorithm has more favorable retained energy than two other protocols. There are a lower number of critical nodes in the proposed routing protocol which extends network life time and submits more packs to the base station.

Keywords: Wireless Sensor, Fuzzy Logic, Routing Algorithms

Introduction:

The recent developments in the electronic industry and lowered energy use in electronic appliances have resulted in their furnishing with small sensors which use a low level of energy. These sensors sense their surrounding environment and convert received data to an electric signal. Signal processing is closely related to the event type and subject under study within the respective piece. Sensors present in environment send their data to a database or the same Sink[*]. [1]

The term routing in wireless sensor network is different from that of other wireless communication networks due to its inherent characteristics, and this poses some other challenges:

- Lacking of creation a unique and universal address for each node.
- Almost all of the programs based on wireless sensor networks need to transmit sensed data from a target environment to a specific unit referred to as base station.
- Data traffic created in these networks has significant redundancy.
- The message transmission energy, power level, calculation strength, and temperature memory are restricted.

Considering challenges of wireless sensor networks, implementation of other networks routing protocols is not possible in wireless sensor networks. So, there is a need to design specific routing protocols or to modify those of other networks, so they can be implemented in wireless sensor networks. [2]

A General Review on Routing Protocols

Traditional routing protocols have some limitations when they are used in wireless sensor networks, the most important of which is their energy limitation. We will discuss about an example of routing protocols designed for wireless sensor networks in the next section.[3]

Location-Aided protocols

There are many location- aided routing protocols for wireless sensor networks, such as Greedy Other Adaptive Face Routing (GOAFR), Greedy Perimeter Stateless Routing (GPSR), Most Forward within Radius (MFR)[4], Geographic Distance Routing (GEDIR)[5], etc. Although these protocols are designed for Mobile Ad-hoc Networks (MANET) and without energy considerations, they don't consider the specific energy needs of the wireless sensor networks and, then, aren't applicable in these networks.[6]

Data-Centric Protocols

In the common routing protocols for wireless sensor networks, which are known as address- aided protocol, when a base station sends a query to collect data, each source sensor which has its respective data, responds independent of other sensors by sending its data to the base station. The method of sending data from source sensors to base station is different between data- centric and address- aided protocols. For example, Sensor *Protocols* for Information via Negotiation (SPINs), Directed Diffusion, Rumor Routing, Cougar Approach, Active Query Forwarding in Sensor Networks, and Energy- Efficient Data-Centric Routing Protocol, etc. are some of the data-centric protocols. [7]

Multipath- based Protocols

There are two types of routing according to the ways of data diffusion between source sensors and base station: single-path and multi-path routing. In single-path routing each sensor sends data through a single best route to destination (base station) while in multi-path routing each source sensor finds k paths to destination and distributes load between paths equally. Disjoint Paths, Braided Paths, and N-to-1 Multipath Routing are some examples.[8]

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[*] base station

Mobility-based Protocols

Mobility has created some new challenges for routing and data diffusion in WSN, especially base station mobility which needs energy- efficient protocols to ensure data submission to mobile base station. There are some routing protocols offered for mobile WSNs including Joint Mobility and Routing, MULE-Data Protocols, Two-Tier Data Dissemination (TTDD), Unsynchronized Scalable Energy Efficient Dissemination, and Dynamic Proxy Tree-based Data Dissemination. [9]

QOS† Protocols

In addition to energy minimizing, it is important to consider some other requirements of quality of service such as delay, reliability, and fault tolerance for routing and data dissemination in WSNs. Some of the QOS routing protocols which help us in getting a balance between energy and quality of service requirements are Trade-off Energy with Delay (TED), Trade-off Energy with Resistance, and Trade-off Overhead with Reliability. [10]

Heterogeneity-Based Protocols

Up to now, all of the studied routing and data dissemination protocols consider a homogeneous network architecture in which all sensors have the same capability in respect of battery energy, communications, sensing, storage and processing. Recently, there has been a focused attention toward heterogeneous sensor networks, especially for real-time sensor networks.[11]

Routing Algorithms based on Fuzzy Logic

Implementation of fuzzy logic in routing sensor networks has often been focused on optimizing cluster creation in hierarchical routing, i.e. it can be developed better clusters by using of fuzzy logic. In this section, we will discuss about some fuzzy algorithms for the purpose of routing and cluster creation in sensor networks.

The majority of routing protocols using of fuzzy logic select inclusively the cluster head through fuzzy logic. Data transmission is a single step process in them meaning that, first, cluster heads are elected through fuzzy logic, and, then, nodes are added to the elected cluster heads and they form clusters with each other. During each round, the member nodes will send data to their respective cluster heads and, then, cluster head nodes, after data aggregation, will send them directly to the base station. [12]

FSCA‡ Routing Protocol

Energy resources constraint is one of the most important problems in wireless sensor networks, as many sensors use of battery to produce electromotive force. The highest level of energy consumption is when sensors communicate with each other, especially when transmitting data to the base station. To overcome this problem, there are developed some routing protocols such as Hierarchical Routing Protocols (ACE, LEACH, LEACH-C).

FSCA[13] aims to transmit the ACE's integrated exponential function with a module in each node. Fuzzy inference system is used extensively in control systems whose situation is unpredictable. Their classic design involved a mathematical complex system to create an appropriate state based on inputs. The fuzzy logic tends to replace these mathematical equations with some linguistic rules. FSCA is developed based on ACE. [14]

FSCA considers the node residual energy, regional density of each node within its sensed area, and time as inputs of fuzzy module, and this leads to an even distribution for cluster creation. Density refers to the

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† Quality of Service
‡ Fuzzy Self-Clustering

number of nodes present within the radio domain of a node, and time refers to the part of time a node is in the steady state protocol.
FSCA is a dynamic and distributed protocol that aims to increase the network lifetime. Firstly, FSCA divides network to a collection of clusters. Each cluster has a cluster head that aggregate data from the cluster members and send them to a database. This trend, i.e. direct communication with the center, is allowed just for a few of nodes. The second step of clusters distribution causes a redundancy in data on a target area, and so, wastes energy[15].

CHEF[§] Routing Protocol

The cluster head election has significant effect on reduced energy consumption and extended lifetime of the network. This section discusses about a fuzzy method to elect cluster heads. Algorithm makes its decisions in fuzzy module based on three parameters of energy, density and centrality. [16]
Cluster head (a node elected by base station) of clusters is one that have obtained the best value by using of three parameters of node density, energy level and centrality. We will discuss about this method and, then, compare it with LEACH. LEACH is based on statistical model and by using of regional clustering. The nodes select themselves as cluster head without any effect of base station on calculations. Other adjacent nodes of cluster heads attaches and transmit data to them.
In a common architecture of wireless sensor networks, each node send its data to the respective cluster head and, then, cluster head transmit data to the base station after aggregating them.
The following are some assumptions of our sensor network:

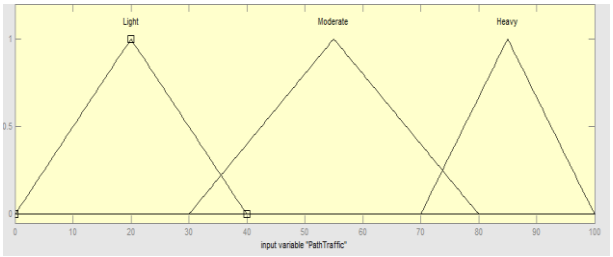
- The base station is located in a distant area of nodes,
- All nodes are the same,
- Diffusion is monotonous,
- The base station elects cluster head,
- Each node has situational data and sends them and energy level information to the base station.
- Nodes are fixed.

There are some difficulties in electing cluster heads based on regional information of nodes (for example LEACH). Firstly, as each node make decision whether it is cluster head based on calculations, it is likely that two cluster heads are adjacent to each other and this will increase total energy consumption of the network due to redundancy. Secondly, the number of created cluster heads is not fixed, so it may be higher or lower than optimal in some rounds. Thirdly, node election may be occurred in the network edges, so nodes need a higher level of energy to send data to clusters.
An expert knowledge is expressed by node energy, node density and node centrality.
To find centrality of each elected node, the base station calculates the square distance of other nodes from a node. Since transmission energy is proportional to d^2, the lowest value of centrality leads to minimized energy consumption of nodes to send data to cluster heads.

Fuzzy Input

The membership functions of fuzzy module are node residual energy, number of hops to base station, packet priority, and path traffic which will be discussed in this section.
Since each node in the path traffic membership function may, currently, have some data to send and receive new traffic requests from other nodes, so traffic situation of data reception path will be considered in the proposed routing protocol.

[§] Cluster Head Election Fuzzy Mechanism



Figure(1)Membership function of the route traffic[16]

Figure 1 illustrates this membership function and fuzzy parameters are defined as following:

$$0 < \text{Light} < 40$$

$$30 < \text{Moderate} < 80$$

$$70 < \text{Heavy} < 100$$

Fuzzy rules

According to the defined membership functions, fuzzy rules were developed for the

Table 1Fuzzy Rules [16]

Residual Energy	Number of Hops	Path Traffic	RSSI	Packet priority	node goodness
VeryLow	Very Low	Light	Very Low	Low	Low
Low	Very Low	Light	Very Low	Low	Low
Moderate	Very Low	Light	Very Low	Low	Medium
High	Very Low	Light	Very Low	Low	High
Very High	Very Low	Light	Very Low	Low	High

purpose of inference by fuzzy inference system, as shown in Table 1.

Defuzzification

Considering that we have used of Mamdani model to design fuzzy module, so we needs to defuzzify output parameter and submit it as a deffuzified value to the source node so it can select the best of all results as the best node for the next step.

The Proposed Routing Diagram

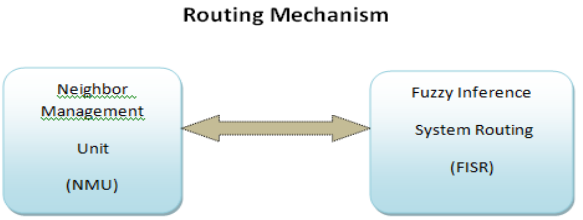


Figure2 diagram of proposed route

According to the above information, Figure2 shows diagram of the proposed routing

Simulation of the Proposed Routing and Results Review

Table2 Simulation parameters

Parameter	Value
Simulation area	100*100 m^2
Node number	150
Radio frequency	2.4GHz
Radio transmission radius	10m
Packet size	128b
The node's primary energy	5j
Heat distribution	random
Buffer size	4 packets
Energy consumption of a packet	0.2j
Traffic type	CBR**
Simulation time	100s

Table2 presents parameters used in simulation.
In the design of our proposed routing, the sensor network has a flat structure, routing is dynamic, classification is data centered and, as a result, based on query, the operation simulation is done as source initiator and sensor network is homogenous. In the following we will see interrelationships and membership function ratios implemented in fuzzy inference system.

** Constant bit rate

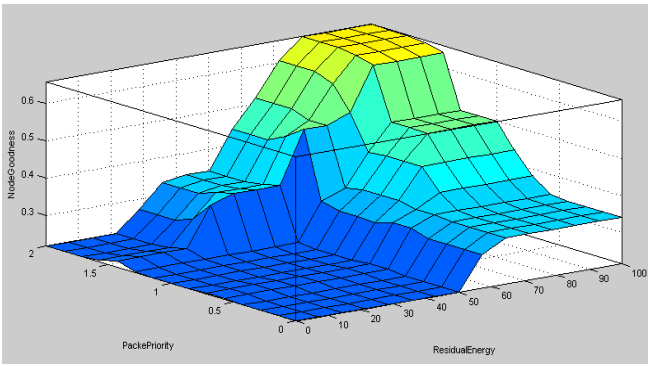


Figure3 residual energy to packets priority ratio to determine optimal node

As illustrated in Figure3 , an optimal node for high priority packets and high residual energy nodes has shown in yellow. According to the picture, low energy nodes and low priority packets are inappropriate and less favorable.

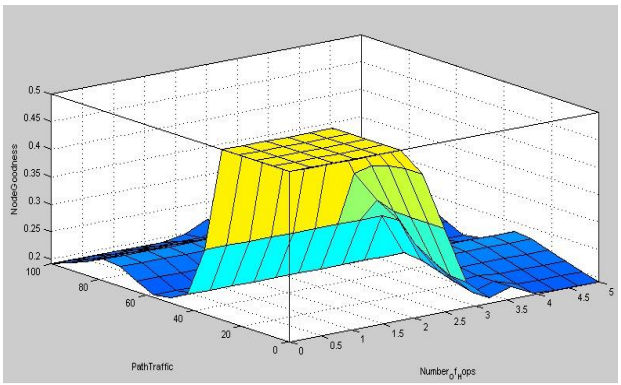


Figure4 number of hops to path traffic ratio

Figure4 shows that a lower number of node hops to destination and lower path traffic leads to more possibility for a node to be elected for the next hop and vice versa. This is shown in yellow.

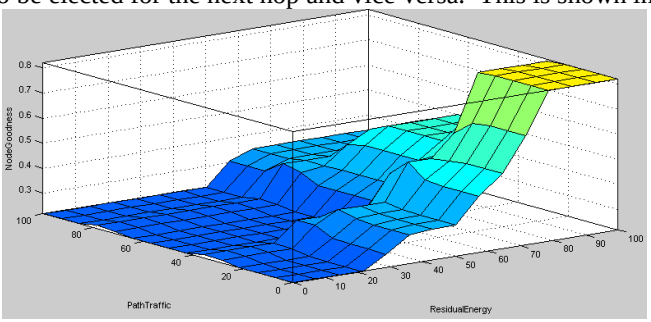


Figure5 : residual energy to path traffic ratio

According to Figure5 , when a node has a low level of energy, irrespective of the path traffic type and packet priority, it isn't an optimal hop. But, as shown, gradual increased energy results in its first election as the next hop for low traffic paths and then for paths with a higher traffic level.

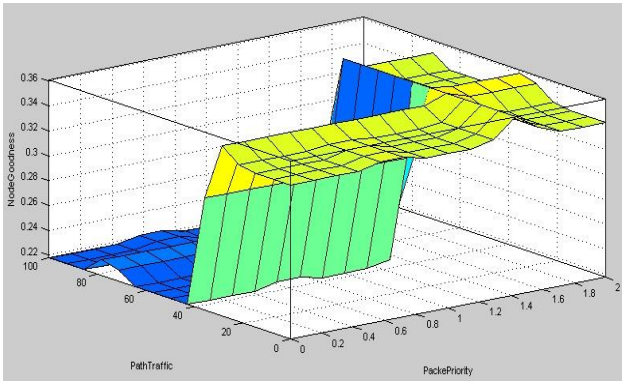


Figure6 packet priority to path traffic ratio

Figure6 indicates that in a low traffic path all packets will be crossed, irrespective of their priority, but in a higher path traffic there will be crossed just high priority packets.
Using of keywords defined for this routing protocol, i.e. Fuzzy Inference System (FIS), and routing (R), we named our proposed routing as FISR.

Simulation results comparison

Energy consumption

The average value of consumed energy suggests an appropriate viewpoint on the energy efficiency of this network. Consumed energy involves energy consumption to send and receive k bits in a d distant path which is calculated as follows:

$$_{tx}(d) = (d^{\alpha} + E_{elec})k \qquad (1)$$

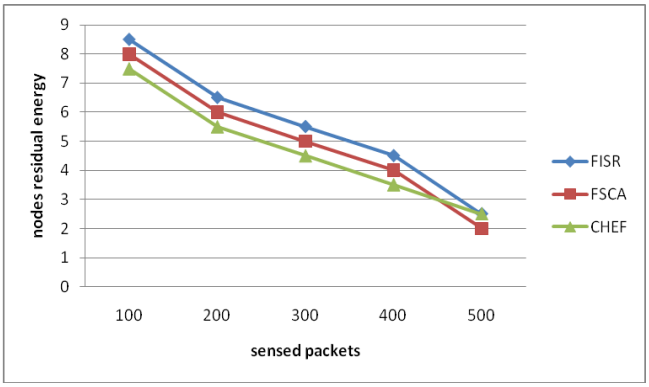


Figure7 comparison of FISR, FSCA and CHEF from the energy consumption viewpoint

In Figure7 The simulation results comparison with those of FSCA and CHEF shows that the nodes residual energy in less sensed packets of our proposed algorithm is better than its counterparts.

The Network Lifetime

We will consider number of sensed packets and the percent of nodes located in critical area as a parameter which shows the number of critical nodes

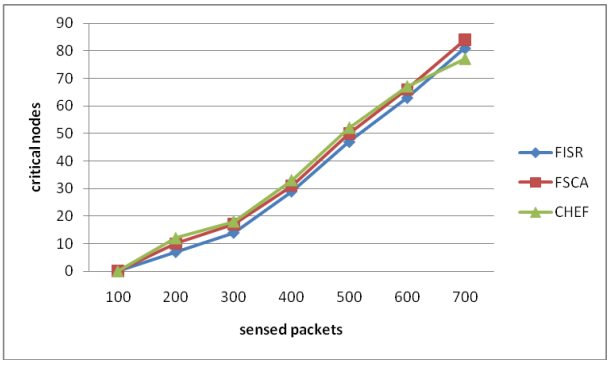


Figure8 comparison of the number of critical nodes in FISR, FSCA and CHEF

Figure8 compares our proposed routing protocol with FSCA, and CHEEF. Their greater critical nodes, the lower are their lifetime. The critical area equals to the energy level requires for sending 10 packets.

Delivery Ratio

Delivery ratio shows the capability of the routing protocol in packets submission, which equals to the number of packets received successfully by the base station to packets sent by the source node.

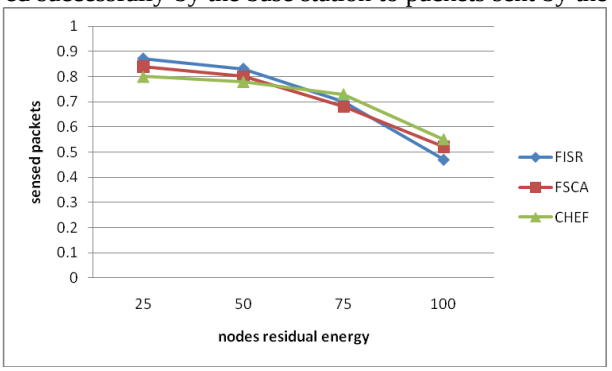


Figure9 delivery ratio of FISR, FACA and CHEF

Delivery ratio of the proposed protocol, CHEF, and FSCA is illustrated in Figure9 .

Discussion and conclusion

According to the simulation results and those of comparison between FISR, FSCA and CHEF (figures 3, 4, 5 & 6), we observed that FISR routing have more favorable residual energy than two other protocols.

Firstly, because it considers more inputs for the fuzzy inference system, so benefits of more accuracy due to more details and parameters for the election of the next node. Secondly, there are more membership functions in fuzzy module. And, finally, our protocol routes those packets which are of priority level 1 & 2 and belong to high and medium energy nodes. Also, FISR have fewer critical nodes and, as a result, a more favorable lifetime. So, it delivers more packets to the base station.
According to the above considerations, the following are recommended as the subject of the future researches:

- To consider parameters such as delay, jitter and load balance in the design of the proposed routing,
- To consider fault tolerance parameter in the design of the proposed routing,
- To offer solutions for error recovery after its occurrence and the possibility of reconstruction of the main route.
- To offer a modification mechanism to manage the neighbors.

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