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ANALYSIS OF ENERGY EFFICIENCY IN SENSOR NODES OF WSN SCADA SYSTEMS USING COGNITIVE FUZZY LOGIC

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ABSTRACT

Wireless Sensor Networks (WSN) provides an effective way to sense, analyze and transmit the data with the collection of sensor nodes. The lifetime of the WSNs are prolonged by using adequate clustering process. In general, clustering forms an efficient way to reduce the energy consumption of the sensor networks. The main requirement of sensor network is to preserve energy by increasing the network lifetime and efficiency. SCADA systems are primary control systems which can organize variety of manufacturing operations and industrial environments. The data is captured by the WSN sensor nodes and is allowed to communicate within the central controller which evaluates the data and proceed towards appropriate actions. The main objective of this paper is to enhance the energy efficiency and network lifetime with use of fuzzy based systems. This system focused its attention on reducing the transmission paths between sensor nodes and sink nodes by maintaining minimum number of multihop communications. The use of cognitive fuzzy systems achieves multiparametric fuzzy decision routing. The simulation results show that the fuzzy based algorithm efficaciously increases the lifetime of the network and achieves high energy efficiency compared to other protocols.

KEYWORDS: WSN, SCADA, Multihop, Cognitive Fuzzy Systems, Energy Efficiency, Packet Delivery Ratio, Delay Time

INTRODUCTION

Wireless Sensor Networks (WSN) generally consists of more number of sensor nodes that commune with wireless sensor channels for conjunctive processing and information sharing [1]. Recently, WSN is regarded as an up growing technology based on its increasing applications in the field of military and civil sectors. A WSN SCADA system consists of maintenance unit, controllers, actuators etc. In this type system, nodes are compiled of sink node and sensor node. On the top of wind power generator the wireless sensor nodes are deployed with many sectors which tend to gather various monitoring information's such as direction, wind velocity and generator running status [2].The base station observers collect the information transmitted by using sensors. The energy efficiency is designed to be the main goal for the WSN systems mainly based on deployment nature of recharged node batteries [3]. Most of the existing solutions of fuzzy logic based on WSN tend to have centralized decision making procedures which can theoretically render optimal solution but also have few disadvantages. The centralized decision making principle tend to cover huge number of nodes with larger area with WSN [4]. The process of conveying subsequent sensor information to the base station may sometimes provide large number of retransmissions with large number of collisions.

To make decision regarding some actions sometimes it may take long time to gather information beside the total number of messages that are transmitted. The decision making among all the nodes are distributed by using localized solutions. Fault tolerance and good scalability are some of the major advantages of localized decision making solutions. Nevertheless the decisions may not be always be optimal. Based on locally available information the nodes tend to make decisions and so the decisions will be highly suboptimal [5]. The total number of messages that are sent can significantly be reduced by using localized solutions. The network traffic even further can be reduced by using localized decision making combined with fuzzy logic. Fuzzy logic is a mechanism which solves complex problems by reducing communication overhead without compromising reliability.

In this paper initially WSN focuses on SCADA systems which solves wide range of problems related to network security. Generally SCADA system refers to industrial control system which is used to collect data from the remote areas to transmit data at a central site. Covering remote monitoring and control, WSN SCADA systems have lots of merits based on distributed information processing. Based on disperse deployment and seasonal characteristics of wind power plant, WSN tend to produce high data acquisition rate and low energy efficiency. In order to increase the energy efficiency of the wind power systems, fuzzy strategy logical terminology is used. The cluster analysis of fuzzy logic tends to increase the energy efficiency of the systems through significant process of fuzzy logic [6].

The contributions of paper are termed as follows: section 2 deals with various researches related to the study. Section 3 deals with the comparative methodology protocols of both the WSN SCADA and fuzzy strategy. Section 4 deals with comparative analysis and section 5 deals with discussion and conclusion.

RELATED WORK

An application layer promotion service that extends proportional differentiation by limiting the network load to protect high predictability and usage was explained by Ulf Bodin and Krzysztof Wolosz. [14]. Action Nechibvute and Courage Mudzingwa. [7] Analyzed about the sensor wired SCADA systems which increase the flexibility of the WSNs. various challenges and potential solutions were considered in this field area based on industrial condition and data network security systems. With new paradigms of WSN was developed by Joshi et al. [8] regarding the cognitive methodology of radio sensor WSN which was mainly used for timeserving spectrum analysis. The inquiry search in this field is gradually increasing towards a successful progress. In this paper, the basic cognitive radio wireless sensor networks are discussed to explore the uses of cognitive radio wireless sensor networks. The sensing methodologies suited for cognitive radio wireless sensor network scenarios are discussed with an emphasis on spectrum access methods and cooperation that ensure the availability of the required QoS. The most congenial data driven approaches and duty cycling schemes for energy saving in WSN was evaluated by Zahra Rezaei and Shima Mobininejad. [9]. some of the techniques include LEACH, STEM, ASCENT and MAC protocols were analyzed with its types. Based on channel access policy, these MAC protocols can be classified into hybrid based, contention based, TDMA based and cross layer MAC protocols. Each protocol tends to have its unique features with its functional implementations with energy and resource efficiency. Two energy efficient HERF algorithms were formulated by Zohre Arabi and Yaghoub Khodaei. [10]. This algorithm uses cluster based approach for information transmission.

Based on scrounging behavior of ants, the optimal routing protocol was proposed by Amiri et al. [11] to increase the efficiency of the network. To improve the appropriate solutions to various problems of WSN, Fuzzy Ant Colony Optimization Routing (FACTOR) was developed. Rault et al. [12] designed a top down survey to achieve the tradeoffs between wireless sensor networks to achieve multi objective optimization. Moya et al. [13] proposed unsupervised learning algorithm with distributive agents to attain fault tolerance with previously unknown attacks. Ahmed Ayadi. [15] Evaluated reliable transport protocols like RMST, PSFQ and ESRT for WSNs. These protocols tend to improve the congestion control, energy efficiency and reliability of various wireless networks. The efficient energy utilization method based on routing process was discussed by Tarique Haider and Mariam Yusuf. [16] For lower cost. The routing feature uses many attempts to utilize the energy consumption of the system. The simulated results of fuzzy logic represents soft and finely tuned network of changing shapes in fuzzy sets.

Based on the literature study it is researched that the energy efficiency and network lifetime of WSN can be increased by using certain protocols like LEACH, trust based strategies. The existing WSN SCADA systems were computed with future proposed fuzzy based systems. This methodology integrates data acquisition systems with data transmission approaches to promote control system and centralized monitoring for numerous process outputs and inputs. The SCADA systems reduce the energy efficiency of the WSN system. So to improve the efficiency based on energy consumption, a new fuzzy based logic approach is devised in this paper. This fuzzy logic with cluster based approach improves the efficiency of the system with high ranking accuracy.

METHODOLOGY

This section mainly deals with the study of WSN SCADA systems and fuzzy based strategy. This gives efficient comparative analysis based on the necessary related theory and methodology functions. Initially the challenges based on SCADA systems are discussed followed up with fuzzy based strategy. The fuzzy strategies tend to increase the energy efficiency of the system with the network lifetime [17].

SCADA Systems

A wireless sensor network is a substructure of networks that consists of communication elements, computing and sensing factors that gives the administrator the ability to observe and react in a specified manner [18]. The applications of wireless sensor networks (WSNs) are processed by means for control processing, data processing and process monitoring systems. WSN is the combination of CPU, sensing and Radio based systems. Over traditional wired monitoring systems, WSN provides various advantages based on rapid deployment, inherent intelligent processing and self organization. The association of miniature autonomous devices with sensors embedded with them is called as sensor node [19]. The typical node of wireless sensor networks consists of five basic components as designed in Figure 1.

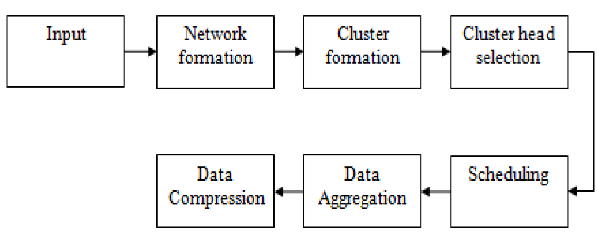

Figure 1: WSN Node Architecture

The architecture designed in Figure 1 mainly concentrates on total number of nodes which are going to be deployed through wireless sensor network. After the nodes are deployed a network is formed which collects the required amount of data and transmits data from one sensor node to another. Clustering reduces energy consumption but generally CH consumes large amount of energy while receiving the all aggregated data from all other sensor nodes and pass on the information to the Base Station. The CH is responsible for receiving the data from the cluster nodes.

Data aggregation plays an essential role in WSN as the data aggregation involves in decreasing the amount of power consumed during data transmission between sensor nodes. The energy consumption in cluster Head is reduced based on scheduling and data compression technique.

SCADA Architecture for Wind Power Plant

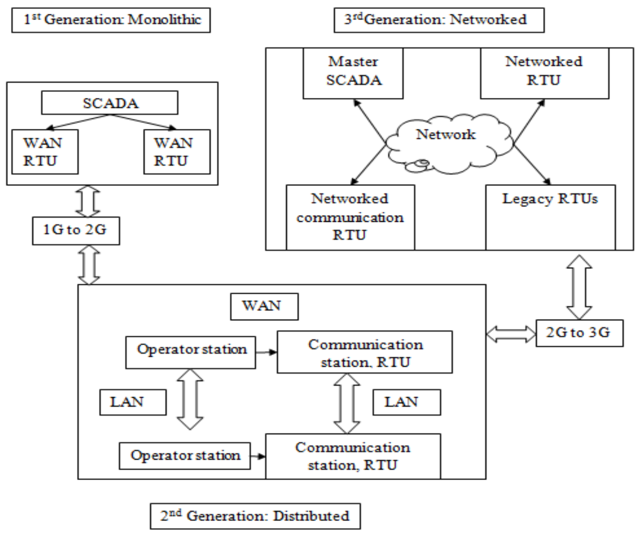

Figure 2: SCADA Systems Evolution

The data from one or more distant facilities are collected over with the SCADA based systems and the instructions are limited through this operation. The Figure 2 explains the evolution of SCADA systems which are projected mainly for controlled and closed industrial environments. To enhance the functionality by minimizing the overall cost there has been the combination of large scale services and enterprise systems [20]. Some of the basic subsystems of SCADA networks are communication infrastructure, central host computer, field data devices and HMI (Human Machine Interface).

Initially when SCADA systems were first generated based on the concept of computing it was evaluated with main framed systems. Networks are mainly said to be non-existent and each system is centralized based on the functional basis. The first generation SCADA systems were monolithic and standalone with practical no connectivity to other systems [21]. The WAN were enforced to commune with Remote Terminal Units (RTU) with the single aim on mind. Nevertheless the first generation systems were monolithic in nature with the system topological functions. The second generation SCADA systems were related to take advantage based on size by minimizing the system function terminologies with LAN connection. This LAN connection was mainly used to interconnect components with real time information sharing system.

The RTU units combined with WAN are processed with single aim in mind were simulate to communicate with necessary sensor network features [22]. Nevertheless, latter generation SCADA systems took advantage of improvements and developments of LAN technology and system miniaturization. This type of methodology is very cost effective and permits real time information sharing midst of the entities based on proprietary rules. As was the case with the first generation systems, the second generation SCADA systems were also limited to software, peripheral devices and hardware that were provided or at least selected by the vendor. The emergence of the next propagation moved towards employing the network as such, using not only WAN but also Internet, and featured open system architecture and open protocols. The distributed processing across physically separate locations has enabled the intention of SCADA systems that can outlast a total failure of any one location. For some organizations that see SCADA as a super-critical function, this is a real benefit [23]. The next generation will push further the limits in the network, assuming WSNs to develop the SCADA systems abilities.

Fuzzy Based Strategy

Fuzzy logic tends to produce many advantages based on the system function methodology. Many advantages were analyzed to carry out the system integration process of fuzzy based systems to increase the energy efficiency and confidence level of the systems [24]. The main advantage of fuzzy logic than crisp logic is determined based on following properties.

- Compared to other event classification algorithms based on probability theory, fuzzy logic is much more intuitive and easier to use.
- It can tolerate unreliable and imprecise sensor readings.
- It is much closer to our way of thinking than crisp logic.

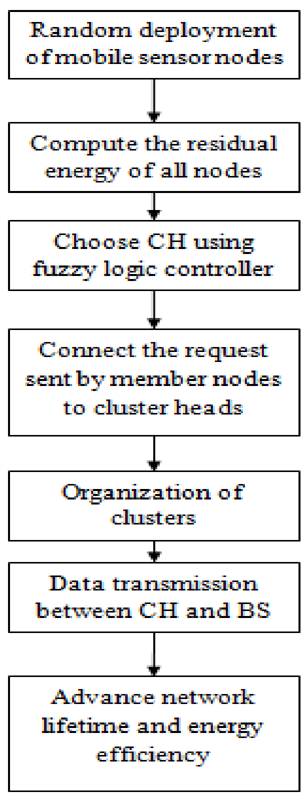

Figure 3: Proposed Trust Based Fuzzy Diagram

The normal fuzzy logic operation starts with the initial step of fuzzifier which converts the crisp input variables to fuzzy linguistic variables by utilizing the consequent membership functions. Linguistic variables are defined as “variables whose values are not numbers but words or sentences in a natural or artificial language”. An input variable can be associated with one or more fuzzy set values reckoning on the observed membership degrees. To take into consideration, a temperature value can be classified as both Low and Medium. The fuzzified values are further litigated by IF–THEN statements according to a set of predefined rules derived from domain knowledge rendered by experts [25]. In this phase, the inference scheme maps input fuzzy sets to output fuzzy sets. Finally, the defuzzifier computes a crisp result from the fuzzy sets output by the rules.

The control functions that should be taken are represented in the crisp output value. The above three steps are called fuzzification, decision making, and defuzzification, respectively. Generally, the sensor network architecture of fuzzy logic is classified into two types; they are clustered logic and layered architecture [26]. There are many types of protocols to generate fuzzy logic they are LEACH, trust based fuzzy, CHEATS, EAUCF, HEED and NECHS. Among all these types trust based fuzzy algorithms tend to produce high energy efficiency. As explained in Figure 3, the proposed fuzzy based logic starts with deployment level. The difference between initial energy and remaining energy is residual energy and this step is carried for further analysis. At this juncture the fuzzy set is applied to cluster head zones through 5 point liker scale membership functions. The cluster is formed with data transmissions which have lots of advantages in terms of energy consumption, power consumption, and cost with system management [27]. The proposed algorithm tries to adapt clusters and rotating cluster head positions to equally allocate the energy stack among all the nodes. This approach may sometimes lead to degree of uncertainty which is liked with the resulting data packet transmission rate to a variety of sensor nodes [28].

RESULTS AND DISCUSSIONS

The simulation results were computed in NS2 simulator which evaluates various research features based on wireless sensor network. The implementation results were carried out with the following features as multicasting delay time, overall Packet delivery ratio and simulation of wireless network

The delay time is one of the important features of SCADA systems based on time synchronization. Time stamping of these types of networks provides resolution of events to one million-second. Nevertheless there is a finite delay in transmission from master node to sink node by variety of devices along the transmission paths. Various delays due to lots of devices like intermediate repeater buffers, modem buffers etc are simulated with NS2 simulator and the results are compared with fuzzy based strategies.

Figure 4 shows the delay time comparison graph with SCADA system and fuzzy based system. The SCADA system exhibits system operation which involves real time data exchange from several frame relay packet networks with delays. The x-axis represents the total number of nodes and y-axis represents the average delay in seconds. For the total amount of 60 nodes, the SCADA system exhibits delay time of 0.06 seconds.

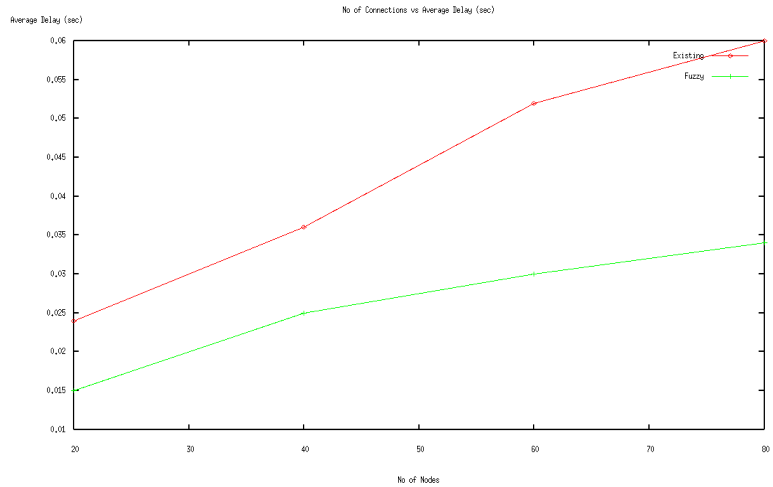

Figure 4: Comparison of Delay Time between SCADA and Fuzzy Based Systems

But for fuzzy based WSN system, the delay value is 0.034 seconds. The average delay or end to end delay value for existing work of overall amount of 60 nodes is represented as 0.026 seconds.

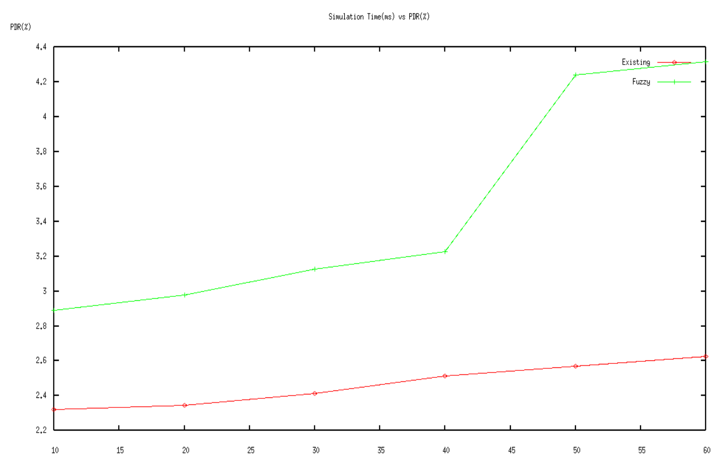

Figure 5: Comparison of PDR between SCADA and Fuzzy Based Systems

$$PDR = (\text{Number of packets received/ Number of packets sent}) * 100\%$$

Figure 5 shows the packet delivery ratio comparison of SCADA systems and fuzzy based strategy. The x-axis is represented as simulation time in millisecond and the y-axis represent the overall PDR. The gross packet delivery ratio of SCADA systems is 2.62%. While for fuzzy based systems the PDR is 4.3% which is greater than SCADA systems. This is one of the major features of the wireless sensor networks.

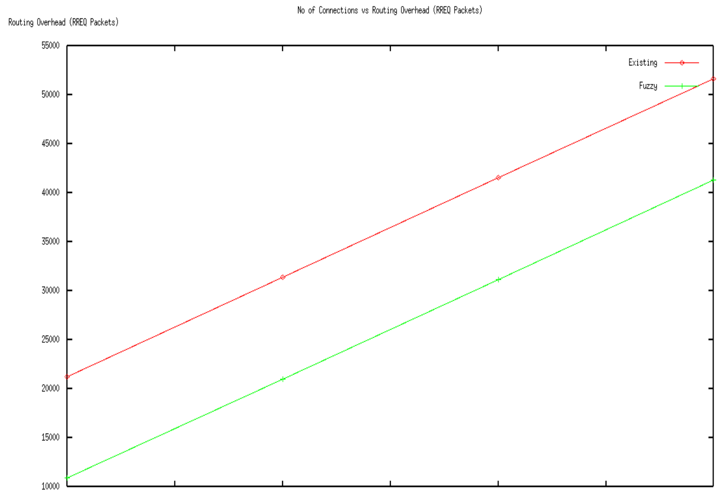

Figure 6: Routing Overhead Comparison of SCADA with Fuzzy Based Strategies

Network is responsible to route the packet properly and efficiently. Figure 6 shows the comparison of routing request sent with the routing overhead and total number of connections. The x-axis represents the routing overhead level for total number of routing request sent while the y-axis shows the total number of connections within the source to the destination. The total number for routing requests sent for SCADA systems is 51000 while for fuzzy based system it is reduced to 41000. This representation shows that the computation overhead of the WSN systems are highly reduced with the use of fuzzy based approach.

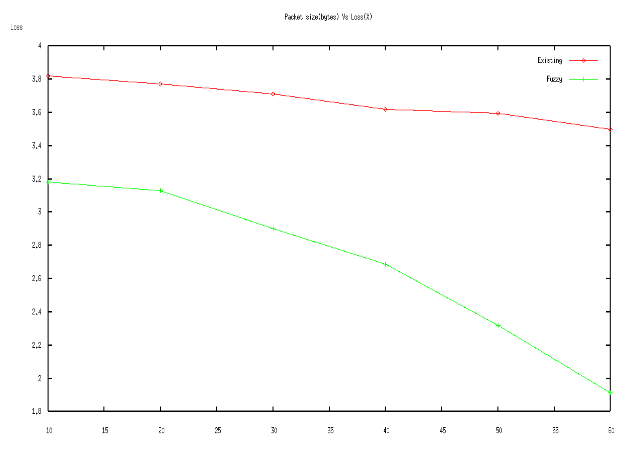

Figure 7: Packet Loss Comparison of SCADA System with Fuzzy Based Strategy

Figure 7 shows the total number of packet losses between SCADA and fuzzy based systems. The packet loss is defined as the difference between total numbers of packets sent to the total number of packets received. LEACH protocol is also used to calculate packet loss within the networks. The overall packet loss for SCADA system is 3.5% while for WSN fuzzy based system it is 1.91%.

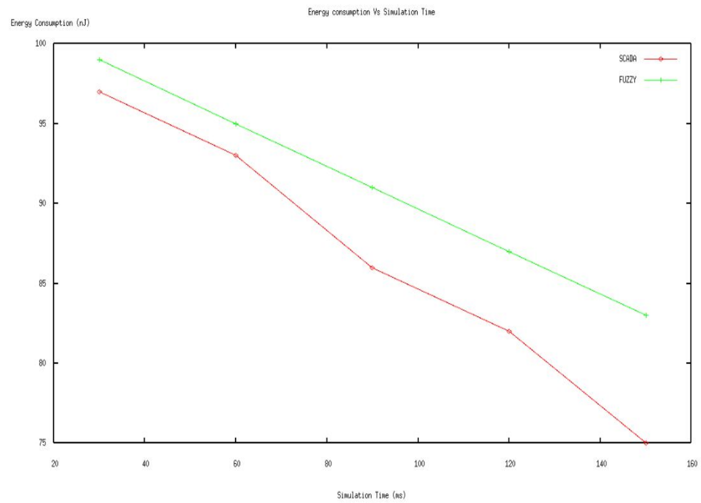

Figure 8: Energy Efficiency Comparison of SCADA with Fuzzy System

The energy efficiency of the SCADA and fuzzy systems is represented in the above figure 8. The difference between total energy to the energy consumption is known as energy efficiency.

Table 1: Comparison Table between SCADA and Fuzzy Based Values

Parameter	SCADA	Fuzzy Based
Delay time	0.06sec	0.034sec
PDR	2.62%	4.3%
Routing overhead	51000	51300
Packet loss	3.5%	1.91%
Energy efficiency	75nJ	83nJ

The overall energy efficiency of the SCADA systems is 75nJ. The energy efficiency of fuzzy based system is 83nJ. To calculate the overall energy consumption of the system, the energy consumption value should be subtracted from overall energy level. The SCADA system exhibits energy consumption value of 25nJ while fuzzy system exhibits consumption value of 17nJ which is lower than SCADA systems. Table 1 explains the comparative analysis of SCADA with fuzzy based strategy. Thus the average difference in energy efficiency between SCADA system and fuzzy based system is 8nJ, which leads to increase in network lifetime and overall performance of the system.

CONCLUSIONS

One of the major critical sources of WSNs is energy conservation systems. For wind power plant, WSNs are applied to SCADA systems. The wireless sensors designed SCADA architecture in this paper tends to provide copious real time data for wind power generators. This furnishes a great challenge of steady running of wind power plant. The fuzzy based cluster scheme with best chosen cluster head efficiently reduces the overall energy consumption value. Thus the use of cognitive fuzzy systems accomplished multiparametric fuzzy decision routing. The simulation results show that the proposed fuzzy based algorithm effectually increases the lifetime of the network and attains high energy efficiency compared to SCADA protocols. Finally it is persuaded that this class of strategy will get a greater attention and significance within the research group in the upcoming years.

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