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Analytical Study of Hierarchical Routing Protocols for Virtual Wireless Sensor Network

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Abstract - *Nowadays more attention has been given to "Internet of Things" (IoT). By networking thousands of nodes, Wireless Sensor Networks (WSNs) can be used to observe remote environment, physical phenomena, and real-life applications such as health monitoring, smart home monitoring, military applications etc. Different applications require different WSNs configurations. To serve such applications, a dedicated WSN is needed per application where all nodes cooperate to achieve the required end results. Virtual Sensor Networks (VSNs) facilitate serving multiple application using the same WSN infrastructure. VSNs enable the same sensor nodes with the ability to play different roles at the same time serving multiple applications. This technique allows more than one application to share the same physical WSN. As a result, flexible and cost-effective solutions would be provided. Existing WSNs routing protocols need to be analyzed in the context of VSNs to measure it efficiency and compatibility. In this paper, LEACH, modleach, SEP, and ZSEP cluster-based routing protocols are analyzed. Multiple metrics will be studies such as network lifetime, load balance between nodes, and total residual energy of the network. The results provide insights on the different conditions needed to utilize the WSNs routing protocols for VSNs.*

***Key Words*: Virtualization Wireless Sensor network, Cluster based Routing, Leach Protocol, VWSN**

1. INTRODUCTION

Wireless sensor network (WSN) is one of the important technologies in our live nowadays as well as future communication. WSNs consist of tiny sensor nodes and a base station (BS). Due to the small size and low power capability of the nodes, the functionality of the nodes are restricted. A node can sense various types of environmental phenomena and sends data to other nodes or to BS.[1,2]. We can use WSNs with a single application where the network is dedicated for providing a single service for one application. This situation is imposes a limitation that prevents efficient utilization of the physical resources because no more than one application is able to utilize these resources at any single moment. For example, if we have two applications that need to run at the same time in the same geographical area, it would be a must to deploy two sets of the sensor nodes which means double the cost to operate these two applications. A good solution to this problem, is to virtualization of WSN (VSN).

Virtualization is an efficient technique used to allow the physical resources of the WSN to appear logically in such a way that let multiple applications to share and communicate with the same resources in an efficient way [1]. Virtualization in WSNs is a considered a new research area that needs to be investigated deeply. The existing routing protocols used with WSNs need to be analyzed and checked in terms of its performance when used in Virtual Wireless Sensor Networks (VSNs). Low Energy Adaptive Cluster Hierarchy (LEACH) is one of the famous routing protocols that has been used for clustering in WSN. In this paper, LEACH, modleach, SEP, ZSEP protocols are analyzed in order to investigate its compatibility with VSN. The rest of this paper is organized as follows. In section 2, Virtualization concept is presented. In section 3 the routing protocols related work is given. The results of simulation results are presented in section 4. Finally, we conclude this paper in section 5.

2. VIRTUALIZATION CONCEPT

Virtualization for WSN gained more attention nowadays as a means for efficient resources utilization in more computing and networking. The aim of virtualization is to do operations with lower cost, increased network manageability, flexibility, and improved administration and inter-operability within different sensors. The virtualization idea is to separate between the application layer and physical sensors layer, at the physical layer sensors nodes aim to sensing changes in some conditions and the area of operation, etc. Due to the limitation of the sensor hardware and low power sources of the sensor, is not efficient to run multiple OS at the level of the sensor infrastructure. To achieve virtualization in WSN some mechanisms must be developed for VSN nodes membership and network maintenance. This can be done by using dynamic reassignment of sensor nodes' roles in the network. A network can split or merge with other networks; add or remove sensor nodes from the VSN.

Many different middleware solutions have been proposed in the last few years for WSNs. Each of these solutions have different architectural design. Most of them are based on the supported application domain which separates the physical layer from heterogeneity and distribution of the infrastructure sensor network. The concept of Virtual machines is used with high-end servers and PCs to separate the hardware from the application layer. In WSNs, virtualization would give us the flexibility and dynamic change of the infrastructure without any impact on the application. Hereby, we propose a framework to produce a Secure Virtual Sensor Network. This framework includes three layers, Application Layer, Virtualization Layer, and WSN Physical Infrastructure as shown in Fig.1.

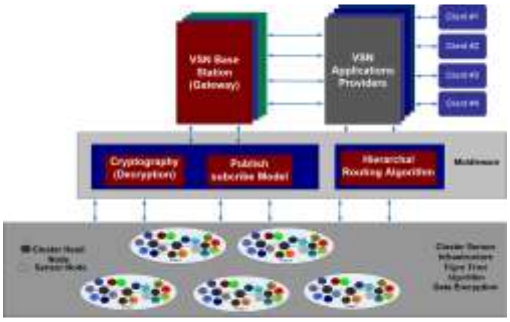

Fig-1: Building Blocks in VSN Framework

The Virtualization layer main components are WSN routing algorithm, cryptography(Encryption/ decryption) algorithm, and the publish/subscribe paradigm. In this paper we focus on the routing protocol component. Specifically, LEACH, modleach, SEP, ZSEP protocols [1] are implemented and analyzed in order to check out its compatibility with the proposed framework.

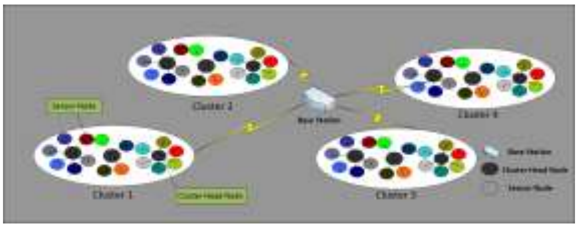

Fig-2: Cluster-based communication hierarchy

3. RELATED WORK

The most popular existing routing protocols for WSN will be discussed in this section. All these protocols are cluster-based hierarchy routing protocols. The three main ideas for cluster-based routing protocol are [5]: to increase network lifetime, decrease the network traffic towards the sink node and Simple data fusion. Each group of sensors nodes grouped into clusters, the selection of Cluster Head (CH) is based on the node with higher residual energy. The CH aggregates the data from all its members and forwards this data to the sink node, other nodes in the cluster perform the sensing task and send sensed data to its CH at short distance. This process reduces power consumption by the nodes as well as balanced traffic load and improved network scalability [4].

In WSN Hierarchical routing protocols consist of several clusters. Each cluster has only one CH and several non-cluster nodes. There are different election protocols for the election of a CH. The high-level communication done through cluster heads [7]. In the following paragraph list explains of these protocols:

3.1 Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is a single hop Homogeneous cluster based hierarchical routing protocol. LEACH performs every round re-clustering functions and self-organizing for the nodes. The sensor node organizes themselves into groups of clusters. The cluster heads in LEACH is selected randomly. The rotation of the CH among the sensors in a cluster distributes energy consumption. The communication between cluster groups and the sink node is done via the CH. All non-cluster nodes use the CH to communicate with the sink node. Fig.2 shows basic cluster-based communication hierarchy.

Cluster head (CH) node main function is to collect the data and compress it from all the cluster member. All the aggregated data packets from the CH are sent to base station. The amount of information transmitted as well as the power consumed will be reduced when the CH eliminates redundancy in data. To balance the energy over the cluster, the CH changes over the time in a random way between the sensor nodes. [5,7] The decision is made by choosing a random number between 0 and 1 by the node. The node becomes a CH depending on the threshold value for this node.

$$T(n) = \begin{cases} \frac{P}{1-P*(r \bmod \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where: P is the percentage of cluster heads, G is the group of nodes that non cluster head in 1 p rounds, r is the round that is currently working on it. The LEACH protocol cycle operation is done in rounds. Each round is divided into two phases. The first phase is called the setup phase while the second phase is called the steady state phase. During the setup phase, all nodes are arranged in hierarchical order. The CH have three functions data forwarding to BS, data compression, and data aggregation. Any single node can be chosen once to be the CH only once during any round P then it can't be chosen as the CH anymore. The duration of the steady state phase is larger than the duration of the setup phase and it starts after the data begins to be transmitted to the BS.

3.2 The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)

APTEEN is an extension to the TEEN protocol and can work on both reactive and proactive networks like LEACH. In APTEEN the parameters for CH selection is adjusted and broadcasted to start the transmission, as in TEEN protocol with the threshold value. TDMA schedule used to assigned a slot for each node to start transmission. [4, 8]. The user expects to get set of physical attributes such as Hard and soft threshold Operation mode for each node in the network (TDMA) and Counting time frame (CT).

3.3 Power Efficient Gathering in Sensing Information System (PEGASIS)

PEGASIS is an enhanced version of the LEACH protocol. In this protocol, communication is done only with the nearest neighbors sensors until data reach the BS to achieve the maximum network life time which is the main aim of this protocol. [5]

The main advantage of this protocol is the dynamic way of the CH selection to avoid communication consumption. The nodes use a greedy algorithm in order to send or receive data to its nearest neighbor nodes. The node structure is a chain structure which enables all the nodes to know the location of other nodes. [8]

After all the nodes communicate with the BS, a new round will start. That reduces the power required for data transmit during each round.[5] There are two main objectives of PEGASIS. First, to decrease bandwidth consumption in the communication between nodes. Second, to increase the network lifetime.

3.4 Threshold sensitive Energy Efficient sensor Network (TEEN)

TEEN is a homogeneous cluster-based routing protocol designed for reactive type of wireless sensor networks. [8] TEEN protocol senses the physical variation of the surround environment continuously. The CH nodes broadcasts two thresholds to non-cluster nodes. The two values are hard and soft thresholds. These thresholds are used to filter, and hence reduce, the amount of transmitted data to the cluster CH. [5,8] The hard threshold can be defined as the minimum data transmission.

The soft threshold can be specified as the change range of data detected. The first time the node finds the data exceeding the hard threshold, this data will be sent to the CH and set as the new hard threshold. Then, assign the monitor value to the sensed value. Soft and hard thresholds control and reduce the amount of data transfer by monitoring unexpected events and hot spots. Also, the use of a threshold can block not suitable data for applications that need a periodic reporting of data. [8]

3.5 modified LEACH (Modleach)

Modleach is a homogeneous cluster-based routing protocol with an efficient CH replacement scheme. Modleach also uses dual transmitting power levels with hard and soft thresholds. Hard threshold (known as MODLEACHHT) and soft threshold (known as MODLEACHST) are used as controls of throughput. Modleach improved its performance by using the same concepts (MODLEACHHT and MODLEACHST) utilized by the TEEN algorithm.

3.6 Zonal-Stable Election Protocol (ZSEP)

(Z-SEP) is a cluster-based routing protocol for heterogeneous WSNs. This protocol follows hybrid process for data communication. Direct communication data transmission and other way data transmission are routed via the CH to the BS. The network field in divided into three zone and nodes deployed based on energy levels and Y coordinate.

3.7 Stable Election Protocol (SEP)

SEP is a two-level heterogeneous-aware cluster-based routing algorithm based on weighted election probabilities for the choice of the CH based on the remaining energy level on each node. SEP clusters consist of two types of nodes: normal nodes and advances nodes. Normal nodes have lower energy level than advanced nodes. The probability of advanced nodes to become CH is more than the Normal nodes in order to balance energy consumption [2].

Table -1: Application Category

Environment specific	Task-specific	General
Beam forming antenna [3] Open field [44] Museum Network[46] CitySee large scale urban network [47] Underwater sensor network [13,49] telecom network [21] Renewable energy sources [28,50] Zigbee, Zwave [37] Sensor network for office [43] NoC [25]	Distributed video coding [22,24] Multimedia system [23,25] Video streaming [33]	Distributed Source Coding Based Applications [1] Multihop network [2] Distributed network [6] Hybrid network [8] Multihop network [12] Information centric network [15] Delay tolerant network of buildings and other landmarks [18] Seismic exploration [19] Core network [20] Heterogeneous network [32] Dynamic network [36]

Wireless sensor network classified routing protocols into two categories based on sensor energy level: homogeneous sensor network which include (Leach – Modleach- TEEN…..etc) as routing protocol. In this type, networks consist of sensor nodes with similar types and the same energy level while the second categories is heterogeneous sensor network which include (SEP-ZSEP,….etc) routing protocols. In this type, a network consists of different types of nodes with different energy level. Due to the different types of protocols and different types of application, the best routing protocol will be chosen from the above applications category table 1 based on the application deployment and application requirement.

4. SIMULATION RESULTS

The routing protocols LEACH, Modleach, SEP, ZSEP were implemented in a simulator. By performing analytical simulation, we could compare network performance with regard to different metrics. Those metrics are:

a. Network Stability period: the stable period for the network before the first node dies (FND).

b. Network lifetime: the time that remaining nodes still transmit data until all nodes die (AND) and stop transmission.

c. Energy consumption: the energy consumed during the transmission of a data packet from a non-cluster node or receiving data packet by the CH node in network lifetime.

d. Packets received at the CH node: the successfully received data packets at the CH node from non-cluster nodes network member.

Simulation parameters: A summary of the simulation parameters are show in Table 2. As shown in the table, some of the parameters are set to a fixed value such as parameters 1 to 8. While some other parameters, such as parameters 9 to 11, are set to different values in different experiments to evaluate their impact on the network performance.

The test parameters are:

- number of nodes in the range of 20 to 200.
- two different sizes of the monitoring area (50 m* 50 m) and (100 m* 100 m).
- different locations of the BS node that varies from (25,25) to (100,100).

Table -2 Simulation parameters

#	Parameters	Values
1	Percentage of cluster head (p_{opt})	0.1
2	Initial energy of nodes	0.5 joules
3	Data packet size	6400 bit
4	Transmission & receiving energy (E_{elec})	50 nJ/bit
5	Free space transmitter amplifier energy (E_{fs})	10 pJ/bit/m^2
6	Multipath fading transmitter amplifier energy (E_{mp})	0.0013 pJ/bit/m^4
7	Data aggregation energy (E_{DA})	5 nJ
8	Type of distribution	Random
9	Number of nodes	20, 50, 100, 200
10	Simulation area size	50m*50m 100m*100m
11	Base station position	(25,25), (50,50), (100,100)

Using the simulation and analysis of LEACH, Modleach, SEP, and ZSEP protocols, we could observe changes in network energy consumption and network life time with various number of rounds. The results showed that the optimal performance can be obtained using a small number of nodes per cluster which maximized survived nodes and network lifetime.

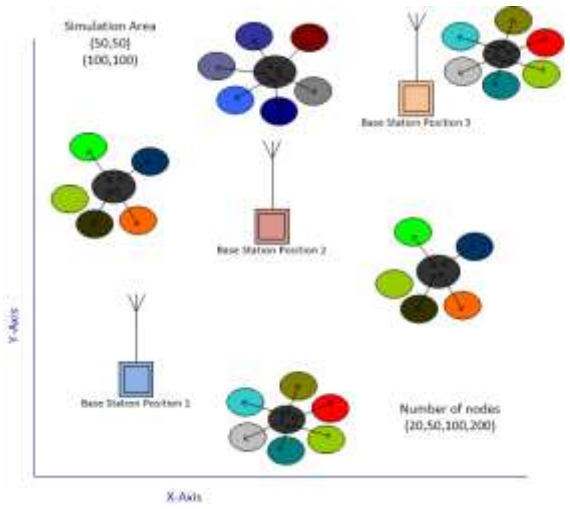

Fig-3: Sample diagram of the simulation setup

Fig. 3 shows a simple diagram of the simulation setup. The diagram illustrates some of the simulation parameters such as the simulation area and the BS location. The diagram also shows a sample Cluster Head (CH) node.

Table 3 summarizes the simulation results with different BS location. As can seen from the table, ZSEP had the best network stability periods in the smaller simulation area, while MODLEACH had the best network stability periods. Although ZSEP suffered from lower network stability periods with larger simulation area, it could maintain good network lifetime in most of the cases with the larger simulation area.

Table 4 summarizes the simulation results with different number of nodes. As can be seen from the table, ZSEP had the best network life span and network stability periods in the smaller simulation area (50,50) with different number of nodes in the range from 20 to 200 nodes. Meanwhile MODLEACH had the best network life span and network stability periods in the large simulation area (100,100) with different number of nodes. Although ZSEP suffered from lower network stability periods with larger simulation area, it could maintain good network lifetime in most of the cases with the larger simulation area.

For virtualization support and enabling different applications to share the same resource infrastructure, different routing protocols should be used depending on certain parameters such as simulation area and number of nodes. The right choice of the routing protocol will have a huge impact on network life span, load balance and network stability.

Table -3: FND vs. AND for different BS locations

		simulation area (50*50)		simulation area (100*100)		
	base station position	(25, 25)	(50, 50)	(25, 25)	(50, 50)	(100, 100)
First Node Dead	**Leach**	**997**	**870**	**845**	**905**	**500**
	Modleach	**1037**	**1002**	**3980**	**4396**	**3345**
	SEP	**1256**	**1162**	**1078**	**1178**	**1054**
	ZSEP	**1668**	**1570**	**1077**	**1572**	**583**
All Node Dead	leach	1850	7790	2080	2045	1960
	Modleach	1678	1619	6374	6094	6591
	SEP	4599	5046	6511	5195	4708
	ZSEP	6668	6003	6752	6273	5491

Table 4: FND vs. AND for different number of nodes

		simulation area (50*50) & BS position (25,25)				simulation area (100*100) BS position (50,50)			
	# of Nodes	20	50	100	200	20	50	100	200
First Node Dead	**leach**	**1100**	**950**	**940**	**920**	**1100**	**830**	**860**	**830**
	Modleach	**1180**	**992**	**956**	**1727**	**5339**	**4377**	**3893**	**3975**
	SEP	**1449**	**1294**	**1228**	**1146**	**1293**	**1179**	**1138**	**1103**
	ZSEP	**1723**	**1613**	**1689**	**1647**	**1631**	**1569**	**1543**	**1546**
All Node Dead	leach	1900	1950	1850	1700	2500	2150	1950	1580
	Modleach	1688	1599	1727	1699	6091	5776	6158	6354
	SEP	4760	4036	5532	4070	4683	5178	5286	5636
	ZSEP	6670	6559	6807	6638	6368	6442	6135	6147

5. CONCLUSION

This paper analyzed and described the process and characteristics of the work for LEACH, Modleach, SEP, ZSEP wireless sensor network routing protocols and discussed the impact of the number of nodes randomly spread on a different areas versus the network lifetime and stability period for the network. This paper concluded that LEACH, Modleach, SEP, ZSEP routing protocols could support virtualization under certain conditions for the design parameters such as the simulation area, number of nodes, the base station position. Controlling these parameters have a positive impact on the network performance, network life span, the number of survived nodes, and amount of data packet received by the base station.

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