

Zone Hierarchical Routing Protocol with Data Aggregation

Kamal Beydoun¹

Department of Computer Science, Lebanese University, Beirut, Lebanon

Abstract

A wireless sensor network (WSN) is a network formed by a large number of sensor nodes where each node is equipped with a sensor to detect physical phenomena such as light, heat, pressure, etc... WSNs are regarded as a revolutionary information gathering method to build the information and communication system which will greatly improve the reliability and efficiency of infrastructure systems. Compared with the wired solution, WSNs feature easier deployment and better flexibility of devices. In the energy-constrained sensor network environments, it is unsuitable in numerous aspects of battery power, processing ability, storage capacity and communication bandwidth, for each node to transmit data to the sink node. This is because in sensor networks with high coverage, the information reported by the neighboring nodes has some degree of redundancy, thus transmitting data separately in each node while consuming bandwidth and energy of the whole sensor network, which shortens lifetime of the network. To avoid the above-mentioned problems, data aggregation techniques have been introduced. Data aggregation is the process of integrating multiple copies of information into one copy, which is effective and able to meet user needs in middle sensor nodes. In this paper, we will propose data aggregation solution to the routing protocol ZHRP (Zone Hierarchical Routing Protocol). This solution will efficiently improve the lifetime of the WSN.

Keywords:

Wireless Sensor Networks, Hierarchical Routing, Data Aggregation.

1. Introduction

Recent technological advances led to the development of very small and low-cost sensor devices with computational, processing, data storage and communicational capabilities. These devices, called wireless sensor nodes, when deployed in an area (indoors or outdoors) form a Wireless Sensor Network (WSN). The initial development of WSN was motivated by military applications such as enemy detection, battlefield surveillance, etc. As years went by, considerable amounts of research efforts have enabled the actual implementation and deployment of sensor networks tailored to the unique requirements of certain sensing and monitoring applications. Nowadays WSNs are a very promising tool of monitoring events and are used in many other fields, such as agriculture, environmental monitoring of air-water pollution, greenhouse, health monitoring, structural monitoring and more. Given the benefits offered by WSNs compared to wired networks, such as, simple deployment, low

installation cost, lack of cabling, and high mobility, WSNs present an appealing technology as a smart infrastructure for building and factory automation, and process control applications. WSN has many topics to deal with, the most important and challenging topics are the WSN structure and WSN routing. Routing allows sending packet from source to destination by detecting the optimal routing path taking in consideration energy consumption. Routing protocols should accomplish some objectives to be an efficient protocol. The main objectives are:

- Minimize the communication between nodes to decrease the energy consumption.
- Perform reliable multi-hop communications
- Find the optimal routing paths
- Provide auto configuration

Routing protocols can be flat or hierarchical. In Flat protocols, all nodes have the same roles. While in the hierarchical routing, some nodes may have specific roles in the routing to minimize communications and make energy consumption efficient. Sensor Nodes are tiny and cheap devices that use low energy. Each node mainly has three tasks: sense data, process data, and transmit data. Nodes can sense various types of data. They can sense temperature, humidity, pressure, presence and absence of an object, and can be attached to objects to get their characteristics like size, speed, and location.

In all of the three tasks, the sensor node will have to consume energy. Hence decreasing the energy consumption during these three stages will increase the WSN lifetime in a great way. According to [3] the battery consumption of transmitting data is higher than processing the same amount of data. Each sensor node consists of four main components as shown in Figure 1.

- Sensing Subsystem: It can sense data from the environment.
- Processor Subsystem: This is used to process and make some operations.
- Transceiver Subsystem: This is used to send and receive packets.

- Power Supply Subsystem: This is usually the battery.

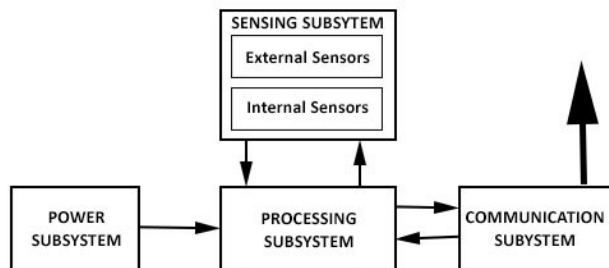


Figure 1: Sensor Node Architecture

1.2 Wireless Sensor Networks

Sensor nodes offer a powerful combination of distributed sensing, computing and communication. The ever-increasing capabilities of these tiny sensor nodes, which include sensing, data processing, and communicating, enable the realization of WSNs based on the collaborative effort of a number of other sensor nodes. They enable a wide range of applications and, at the same time, offer numerous challenges due to their peculiarities, primarily the stringent energy constraints to which sensing nodes are typically subjected. Wireless Sensor Network is a highly distributed and randomly deployed wireless network consists of large number of sensor nodes called Motes. These nodes work with each other to sense data from the environment and send them to the base station over a large area. A very important factor in the lifetime of the WSN is the energy consumption since sensor nodes are driven by small batteries; they have a limited energy resource. When sensors sense data, compute or communicate they consumes energy, hence the lifetime of WSN will decrease. Therefore, the battery consumption should be decreased efficiently to increase the network lifetime. Not only energy consumption is a challenge for WSN, there are some other challenges like limited memory, limited processing power, and limited communication range.

WSN nodes have a limited transmission range so they cannot communicate with the base station directly so they must cooperate with each other to deliver the data packets to the base station. The base station is responsible to collect data from the WSN. Nodes send data packets to their neighboring nodes which are in the range of the transmitting nodes, and then forward those packets to their 'neighbors' until the base station. This act will consume power because of packets transmission thus the communication should be decreased to a minimum in order to make the battery consumption lower and as a result increase the network's lifetime.

1.2 Wireless Sensor Characteristics

Any WSN have some common characteristics such as:

- Infra Structure less: WSN initially has no structure but it may define a structure after deployment.
- Large Area and Large Number of Nodes: WSN contains a large number of sensor nodes and can cover a very large area.
- Many Interferences: Nodes in the WSN may receive many packets at the same time. Packets may collide and lost.
- Security Issues: WSNs highly exposed to security breaches, and nodes can be hacked easily.
- Limited Transmission Range: Nodes are tiny and have small antennas and small battery so their transmission range is limited and small.
- Limited Memory: Because of the small size of the nodes, the nodes contain small and limited memories.
- Limited Computing Power: The Processing unit in the nodes is small and has limited resources due to the size of the nodes.
- Dynamic Topology: Nodes may die, added, or even move. Therefore, the WSN will dynamically change its structure.
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1.3 Wireless Sensor Applications

Wireless Sensor Networks (WSNs) are used in many applications that are divided into three categories:

- Monitoring of areas
 - Environment and Habitat: forest fire detection, animal monitoring
 - Military: monitor friendly forces, ammunition
 - Agriculture: farming
- Monitoring of objects
 - Structures: critical building monitoring, machine status
 - Medical Diagnosis: blood pressure monitoring
- Monitoring both areas and objects
- Asset Tracking: vehicle tracking
- HealthCare: monitoring patients
- Disaster Management: volcanic monitoring

2. Related Work

2.1 Routing Protocols in WSN

Energy consumption is one of the main challenges in wireless sensor networks. Energy saving assures a long lifetime for the system. Another main goal is reducing the size of the stored data (e.g. routing table) in each node of the network. Clustering is an important technique for prolonging the system lifetime and reducing the size of the stored data. In clustering, nodes are gathered in several groups, generally disjoint, which are named clusters. Each cluster has a cluster head (CH). The nodes collect data and send it to the CH that forwards this data to the final user or Base Station (BS). CHs can communicate with the Base Station directly or via other CHs. There are many existing clustering protocols.

LEACH [22] is a distributed clustering-based protocol that uses randomized rotation of the CHs to evenly distribute the energy load among the sensors in the network. LEACH assumes that the fixed sink is located far from the sensors and that all sensors in the network are homogeneous and battery-constrained. Lin's protocol [23] is a distributed clustering technique for large multi-hop mobile wireless networks. The cluster structure is controlled by the hop distance. In each cluster, one of the nodes in the cluster is designed as cluster head. Other nodes join a cluster if they are within a predetermined maximum number of hops from the cluster head. HEED [24] is a distributed clustering protocol that periodically selects cluster heads according to a hybrid function between their residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. In CES distributed protocol [25], each sensor computes its weight based on the k-density, the residual energy and the mobility features. Then it broadcasts the weight to its 2-hop neighborhood. The sensor node having the greatest weight in its 2-hop neighborhood becomes the cluster head and its neighboring sensors will join its cluster. SPAN [26] is a distributed, randomized protocol in which nodes make local decisions on whether to sleep, or to join a coordinator that rotates at times. Each node makes its decision depending on the amount of available energy on the node and on its degree (the number of its neighbors when the node is active). SPAN is a protocol that operates under the routing layer and above the MAC and physical layers. The routing layer uses information SPAN provides, and SPAN leverages any power saving features of the underlying MAC layer [26]. The centralized PEGASIS protocol [27] constructs chains instead of clusters. Each node delivers the sensed data to the nearest neighbor node. One sensor node on the chain is assigned as the cluster head node that delivers sensed data to the base station. The head node is selected by turns; this

technique allows even energy consumption in wireless sensor networks. However, the PEGASIS protocol causes redundant data transmissions since one of the nodes on the chain is selected as the head node regardless of the base station's location. In [28], authors propose the enhanced PEGASIS protocol based on the « concentric clustering » scheme to solve this problem. It means that clusters have the shape of concentric circles. Similar to PEGASIS, the SHORT protocol [29] adopts centralized approaches and requires powerful BS to take the responsibility of managing the network topology and to calculate the routing path and time schedule for data collection.

Most topologies based on clusters assume that cluster heads are high-energy nodes and their transmission power can be adapted in order to reach the base station at far distances and to communicate directly to other cluster heads. Another assumption is that nodes within a cluster can directly communicate to the cluster head. In SHORT, HEED, CES, PEGASIS and Enhanced PEGASIS all nodes are supposed to have the ability to modify the transmission power in order to control topology. The LEACH radio model [22] is used for these protocols. Requirement of adaptive and dynamic transmission power modification can be prohibitive, especially for sensors not equipped with transmission amplifier. SPAN uses the radio model of the Cabletron

Roundabout 802.11 card has fixed transmission range and does not support power control. Lin's protocol does not mention the radio model used for simulations. The transmission defines the set of neighbors for a sensor node, those able to receive the transmitted signals. Because variation of the transmission range consumes more resources, virtual topologies should be proposed for sensor networks that are made of sensors with fixed transmission power. The challenge addressed in this paper presents an approach of virtual structuring of networks without using topology control technique. Our contribution to topology construction addresses two main issues in WSNs: distributed approaches, and energy efficiency. Moreover, our approach is independent of the embedded sensor technology (being able to vary the transmission power or not); the only parameter considered is the current node's transmission range. The algorithm is executed simultaneously with the neighborhood discovery protocol for random sensor node deployments. In the next section, we will detail our work for structuring wireless sensor networks into zones, which is not a real clustering algorithm like the cited related work. Therefore, no cluster heads exist in our topology; no other information on the network (e.g. geographic position) is required.

1.2 Data Aggregation in WSN

Sensor networks are distributed event-based systems that differ from traditional communication networks in several ways: sensor networks have severe energy constraints, redundant low-rate data, and many-to-one flows. Data centric mechanisms that perform in-network aggregation of data are needed in this setting for energy-efficient information flow. Because of the requirement of unattended operation in remote or even potentially hostile locations, sensor networks are extremely energy-limited. However since various sensor nodes often detect common phenomena, there is likely to be some redundancy in the data the various sources communicate to a particular sink. In-network filtering and processing techniques can help to conserve the scarce energy resources. Data aggregation has been put forward as an essential paradigm for wireless routing in sensor networks [3, 6]. The idea is to combine the data coming from different sources— eliminating redundancy, minimizing the number of transmissions and thus saving energy. This paradigm shifts the focus from the traditional address-centric approaches for networking (finding short routes between pairs of addressable end-nodes) to a more data-centric approach (finding routes from multiple sources to a single destination that allows in-network consolidation of redundant data). Data Aggregation is the process of collecting and summarizing data from the sensor nodes in a way that the communications between nodes are reduced so the energy consumption of the nodes is decreased hence increasing the network lifetime.

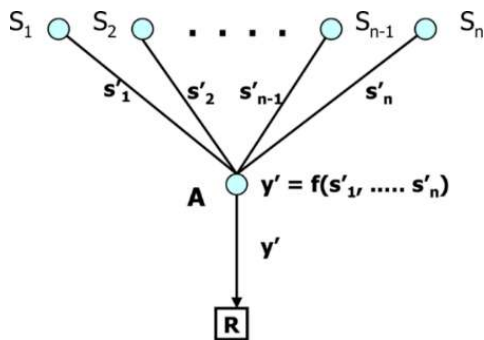


Figure 2: Data Aggregation

Figure 2 shows how sensor nodes $S_1, S_2 \dots S_n$ send their packets $S'_1, S'_2 \dots S'_n$ to a data collector node called aggregator node A , which indeed collects data and eliminates the redundant data. The aggregator uses some methods (f in

Figure 2) to remove redundant data and produce the aggregated filtered data y' . These methods could be statistical methods like in [13], probabilistic methods like in

[14], or artificial intelligence like in [15]. The filtered data y' is then sent to the base station R .

Data Aggregation protocols main goal is to gather and aggregate data in an energy efficient manner. These protocols can be classified as structure based and structure-free data aggregation protocols. In structure based protocols data are transmitted to the base station by creating chain [6], tree EIPDAP [2], cluster [16], tree-cluster [17], or hierarchy clustering [18].

3. EIPDAP

Efficient Integrity-Preserving Data Aggregation Protocol (EIPDAP) [2] is an aggregation protocol that can verify the integrity of aggregation result immediately after receiving aggregation result and the corresponding authentication information. The integrity verification is not done through another query-and-forward phase, for this reason energy, consumption and communication delay will be reduced significantly. EIPDAP needs some network assumptions to work. The first assumption is that the base station needs to be powerful with transmission range enough to cover the wireless sensor network in order to broadcast messages to all nodes directly, because the base station needs to broadcast authenticated query before the aggregation phase. The second assumption is that the wireless sensor network should form a tree topology with the base station as the root.

EIPDAP is based on the elliptic curve discrete logarithm with hierarchical aggregator topology. EIPDAP goal is to prevent stealthy attacks where the attacker tries to send wrong data to the base station and make it accepts them. Each node in the wireless sensor network should have a unique identifier s , private keys r and $l \in \mathbb{Z}_p$, and shares a private key sk with the base station and a private point $\Theta \in$ cyclic elliptic group $E(\mathbb{Z}_p)$ with the base station. Also the generator point $G \in E(\mathbb{Z}_p)$ is preloaded to all the nodes. In addition, two parameters α and β such that $\alpha = rG$ and $\beta = r\alpha$ are preloaded to all nodes. EIPDAP is accomplished after three main phases: query dissemination, aggregation-commit, and result checking.

3.1 Query Dissemination

In the dissemination phase aggregation tree information is collected; if the aggregation tree is not constructed then it is constructed during this phase. Then the base station calculates path-keys and edge key for each node and encrypts them with the secret key shared between the base station and the node, and then the base station sends them to the corresponding node.

3.2 Aggregation-Commit

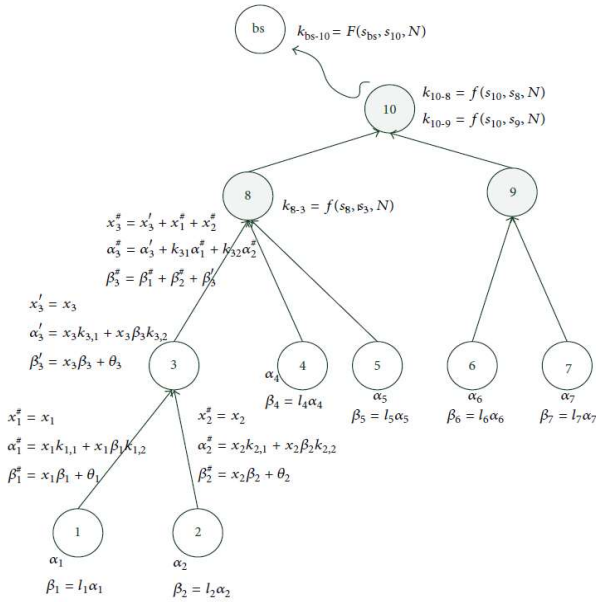


Figure 3: Aggregation Commit phase

3.3 Result Checking

In the result-checking phase, the base station verifies the integrity of the aggregated values with the two tags. As a result, the base station can preserve the integrity of the aggregated data immediately after receiving the aggregated data and their corresponding authentication information, so it will reduce the energy consumption not like other protocols which makes another query phase to check if the integrity of the aggregated data. EIPDAP is energy efficient because the result-checking phase is done in the base station hence no congestion in the aggregation tree during the result checking-phase.

4. Integration of EIPDAP in ZHRP

As we have described previously, ZHRP protocol splits the WSN into disjoint zones. Each zone has one Inviting node, Normal and Border Nodes. Each node has an Intra-Zone Routing Table that contains path cost to reach a destination node in the same zone. This path is the minimal between the paths. The Border nodes have Border Table to know their neighbor nodes from the neighbor zones. In addition, the Border nodes have the Inter-Zone Routing Table that contains the cost of passing through a zone when sending a packet. In ZHRP, the packet passes through the shortest route. Therefore, the packet will pass through fewer nodes until it reaches its destination. However, if there are x

nodes that wants to send data packets to their destinations, each packet will have a route to pass through, hence there will be x routes, therefore a lot of nodes will have to send and receive packets. To decrease the number of routes, packets must be combined as one packet as much as possible to reduce the number of packets and reduce the number of routes. Data aggregation is the process of collecting and summarizing data. This process will reduce the amount of data to be sent from one node to another, which will reduce communications and decreases the energy consumption to increase the WSN lifetime.

In ZHRP, if an event occurs, it may that many nodes in the same zone will send the same sensed data (event) to the same destination so there will be x packets each will have a path, and the packets may be redundant. This scenario will consume energy in a bad way. Therefore, to solve this problem we will build some aggregation trees in all the zones. These aggregation trees will collect data, summarize data, and sends them as one packet to the destination node. In this way, we will highly reduce the number of packets to be sent from one zone to another. The x packets may become one packet. This will decrease the number of send and receive actions at the nodes, so energy consumption will be efficient.

4.1 Aggregation Tree Construction Algorithm

Table 1: Tree Construction Packet Fields

SourceId	Node Id of the sending node
TreelD	Tree Id that the packet comes from
Level	Level of the sending node
ZoneId	Zone Id of the sending node

After finishing all ZHRP stages (zone construction stage, Intra-Zone Routing Table construction stage, and Inter-Zone Routing Table construction stage), each zone will start constructing the aggregation trees, each Border Node will be a root of a tree and start the construction of that tree, the tree will have treelD equals to the root nodeId. During the tree construction, a packet will be used with fields illustrated in

Table 1.

When a node receives a tree construction packet, if the node joins the tree, it must send a child packet to the sender of the construction packet to tell it that it is its child. Table 2 shows the fields of the child packet.

Table 2: Child Packet Fields

ChildId	The node Id of the child node
ZoneId	The zone Id of the child node

After Tree Construction, every node will compute some fields as shown Table 3:

Table 3: Fields at each node after Tree Construction

TreeId	The Id of the tree the node belongs to
Level	The level of the node in the tree
ParentId	Node id of the Parent node
ChildsList	List of Ids of the Children of the node

Figure 4 shows the trees in a zone with two border nodes:

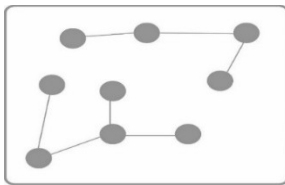


Figure 4.Trees Constructed in a Zone

Figure 5 shows the tree construction algorithm. Each Border node will broadcast a construction tree packet with TreeId same as Node Id and Level equals to zero, as it is the Root of the tree. Any node that receives the construction packet, if the node is already in a tree it will ignore the packet. However, if it is not already joined, it will join the tree and set the level to that from the packet added by one, and set its TreeId as the packets tree Id. Then the node will also broadcast constructing packets. The node must send a Child packet its parent to tell it that it is its child.

```

For Each Border Node Bn
Bn broadcast Tree Construction Packet p (Bn.nodeId, Bn.nodeId, 0, Bn.zoneId)

When Node n receives Tree Construction Packet p
IF (n.TreeId == NULL And n.zoneId == p.zoneId)
    n.TreeId = p.TreeId
    n.parentId = p.srcId
    n.level = p.level + 1
    Broadcast a Tree Construction Packet p' (n.zoneId, n.nodeId, n.level, n.zoneId)
    Send to parent node a Child Tree Packet cp (n.nodeId, n.zoneId)
End If
    
```

Figure 5: Tree Construction Algorithm

3.4 Tree Data Aggregation Algorithm

After trees are constructed, and when an event occurred near some nodes, those nodes must send their data to base station or to any defined node in the WSN.

Figure 6 shows how data aggregation occurs. Nodes that have sensed data must send their data to their parents in the aggregation tree. These packets should contain the data that the node wants to send. When a node receives a data packet from a child of it, it will wait for a specific time t (which is a parameter for our protocol) to receive more packets from other children. Then it will add its data and apply any aggregation algorithm on the collected data, such as filtering, addition, or subtraction. Then the node that received the data packets will send the result data as one packet to its parent, and the parent node will do the same task until the data packet reaches the root node, which is a Border Node.

When a Border node receives data from its children, then it will send the data using ZHRP routing to the destination node.

An event happens near some nodes; those nodes sends Tree Data Packet to their parents

```

When Node n receives Tree Data Packet p
If(p.treeId == n.treeId && p.srcId is child of n)
    Add p.data to received data
    Wait for time t and listen to other childs and add their data to received data
    Add Current Node Data to received data
    Make Aggregation Function on received data
    IF(n.nodeType == BORDER)
        Send the aggregated data via Zhrp Inter rouring
    Else
        Send Tree Data Packet with aggregated data to parent node
    End If
End If
    
```

Figure 6: Node activities when an event occurs

4 ZHRP vs ZHRP with Aggregation: Routing Scenario

Figure 7 describes what happens when an event occurs at zone Z1 and how the nodes that detects that same event sends their packets to the destination base station B using ZHRP routing (Table 4).

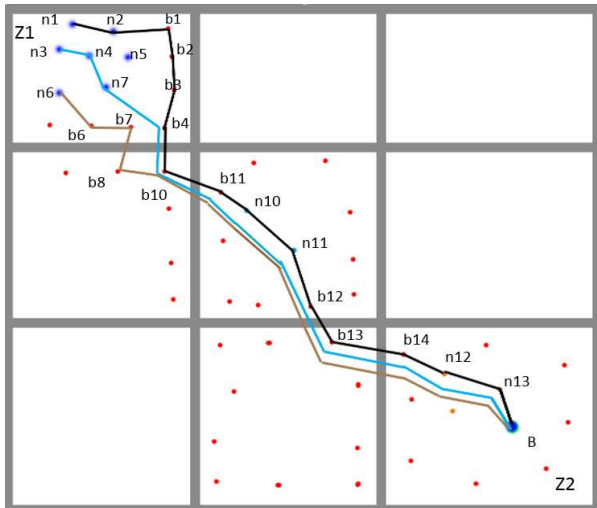


Figure 7: Routing Scenario with ZHRP

Table 4: ZHRP routing path of the same event

Node	Path	Sent Packets
n1	n1,n2,b1,b2,b3,b4,b10,b11,n10,n11, b12,b13,b14,n12-n13,B	15
n3	n3,n4,n7,b4,b10,b11,n10,n11, b12,b13,b14,n12,n13,B	13
n6	n6,b6,b7,b8,b10,b11,n10,n11, b12,b13,b14,n12,n13,B	13

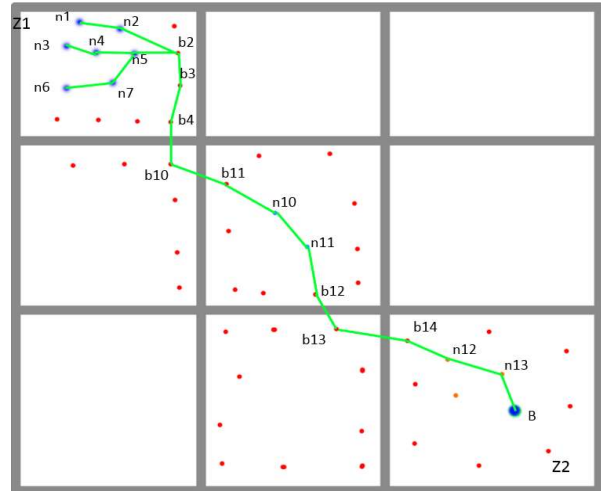


Figure 8: ZHRP routing scenario with aggregation

Figure 8 describes what happens when an event happens at zone Z1 and how the nodes sends their packets to the destination base station B using ZHRP routing and aggregation tree.

Table 5: ZHRP routing path with aggregation for the same event

Node	Path	Sent Packets
n1	n1,n2,b2	2
n3	n3,n4,n5,b2	3
n6	n6,n7,n5,b2	3

When an event happens in Z1, nodes n1, n3, and n6 receives the event. Each node must send data packet to its parent in the aggregation tree. The tree root is b2. Packets are traveling as shown in Table 5. From b2 to B normal ZHRP routing occurs hence we have 12 Sent packets. Therefore, the total number of packets is 20, which is less than the ZHRP routing alone. Hence, energy consumption is decreased and the network lifetime increased.

Note that when a node n in source zone Z1 wants to send data packet to a destination d in destination zone Z2. At first, node n will send it to its parent in the aggregation tree. The parent then will send it with data from other children to its parent, and so on. Until the data packet reaches the root of the tree, which is a Border node in the source zone Z1. When the data packet is received by the Border node, the Border node will forward the packet to the destination zone Z2 using its Inter-Zone Routing Table.

When the packet is received by a Border node at the destination zone Z2, this node will use its Intra-Zone Routing Table to forward the received packet to the destination node d in Z2.

5. Simulation and Results

In this section, we will show the implementation of all stages of the protocol ZHRP, the tree construction and ZHRP with aggregation. The implementation has been done using a simulation framework called Omnet++ [19]. Omnet++ is not a simulator; it is a discrete event network simulation framework. In other words, it provides infrastructure and tools to build network simulations. A simulator based on Omnet++ is used in building the simulation, which is called Castalia WSN simulator [20]. In this simulation, an ideal configuration was assumed: no interference, no interruptions, and no packet loss as we are simulating in the network layer. The simulation takes place in a field of size 200m x 200m. The sensor transmission range is 15m.

5.1 Sent and received packets – Aggregation Tree Construction

During Aggregation Tree Construction as shown in Figure 9 and Figure 10, the number of Sent and Received packets in each node is very small. This number does not increase when R and number of zones change because nodes will be able to communicate with their direct neighbors only.

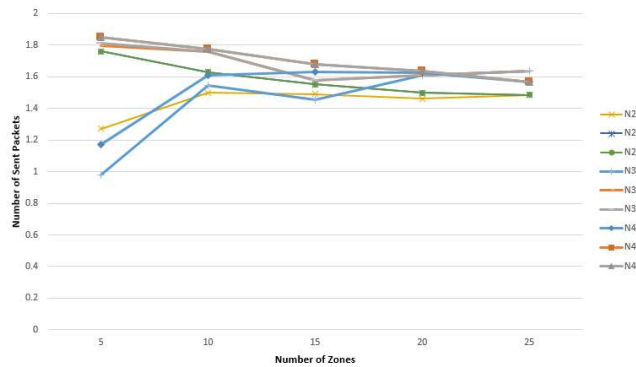


Figure 9: Aggregation Tree Construction - Sent Packets

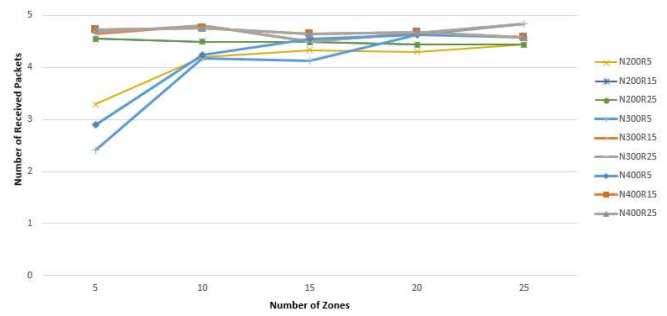


Figure 10: Aggregation Tree Construction - Received Packets

5.2 Sent packets– Routing

In this comparison, a variable number of events will take place over the WSN. Nodes that receive those events will send their data to a destination node in another zone. Therefore, we are simulating the routing of sensed data. The total number of events will vary between 300, 400, 500, and 600. The number of nodes is 400. The number of zones will change between 10, 20, and 30.

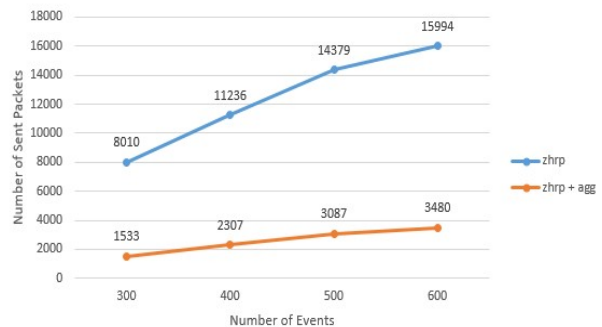


Figure 11: Number of zones Z = 10

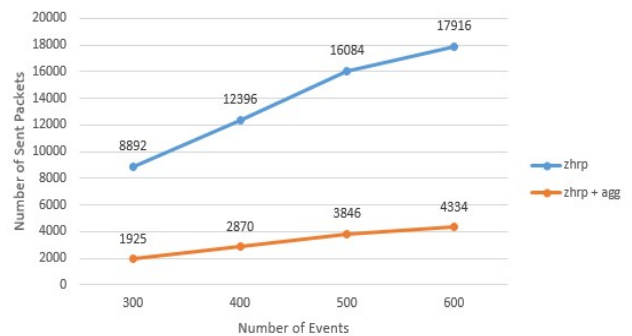


Figure 12: Number of zones Z = 20

Figure 11, Figure 12, and Figure 13 show that when events happen the number of packets Sent in ZHRP is much higher than that of ZHRP with tree aggregation. The results show that the number of Sent packets decreased from 15994 to 3480 which signals that the number of sent packets is decreased by about 80%. Therefore, the integration is very efficient, it will decrease the energy consumption, and the WSN lifetime will increase.

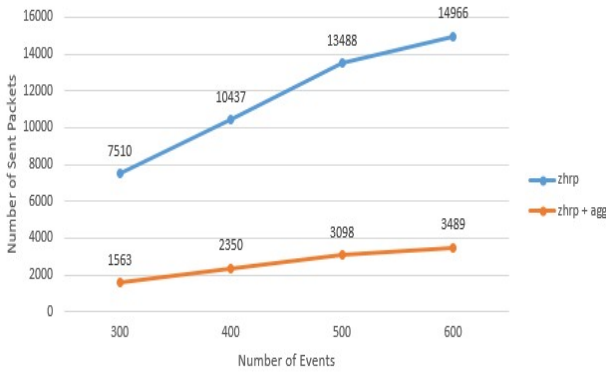


Figure 13: Number of zones Z = 30

5.3 Received packets - Routing

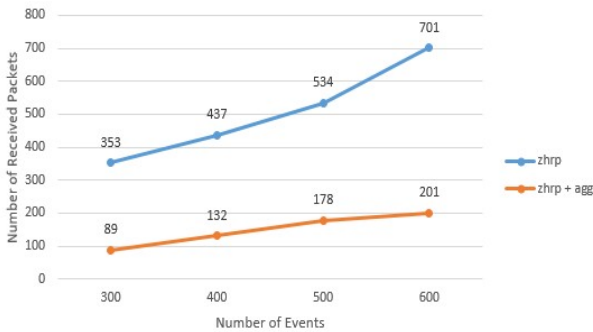


Figure 14: Number of zones Z = 10

Figure 14, Figure 15, and Figure 16 show that when events happen the number of packets Received in ZHRP is much higher than that of ZHRP integrated with tree aggregation. The results show that the number of packets Received decreased from 701 to 201, which means that the number of packets Received is decreased by about 75%. Therefore, the integration is very efficient, it will decrease the energy consumption, and WSN lifetime will increase.

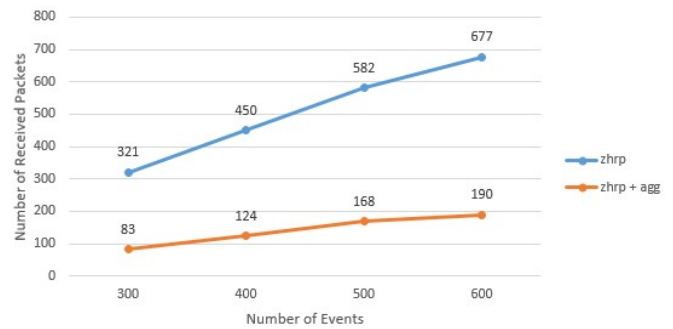


Figure 15: Number of zones Z = 20

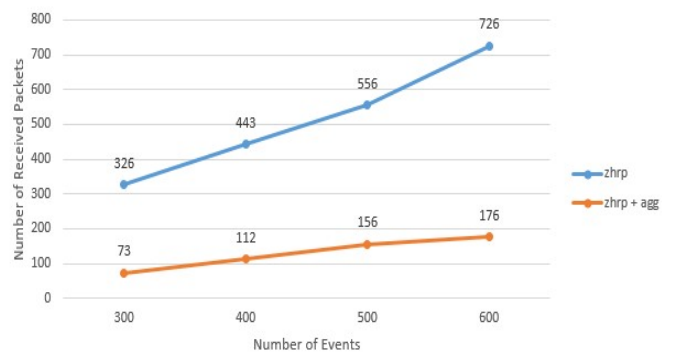


Figure 16: Number of zones Z = 30

5.4 Energy Consumption Results

Energy Consumption has been calculated based on the characteristics of the MICA2 [21] sensor node shown in Table 6. We have calculated the battery consumption during Aggregation Trees Construction. We also calculated the battery consumption during the routing scenario of ZHRP compared to ZHRP with aggregation. We change the number of nodes between 200, 300, and 400, and the number of zones between 5, 15, and 25, and for R we used 5 and 25.

Table 6: Characteristics of MICA2 Sensor

CPU Consumption	8 mAh
Receiving Consumption	10 mAh
Transmitting Consumption	27 mAh
Initial Energy	2900 mAh
Voltage	3 V
Data Transfer Rate	38400 bits/s
Communication Range	500ft

Energy consumptions for the Aggregation Tree Construction are shown in Figure 17 for the sent packets and in

Figure 18 for the received packets. It is clear that the energy consumption decreases when the number of nodes increases because the density of network (number of

nodes/m²) increases so that the algorithm of construction demands less energy.

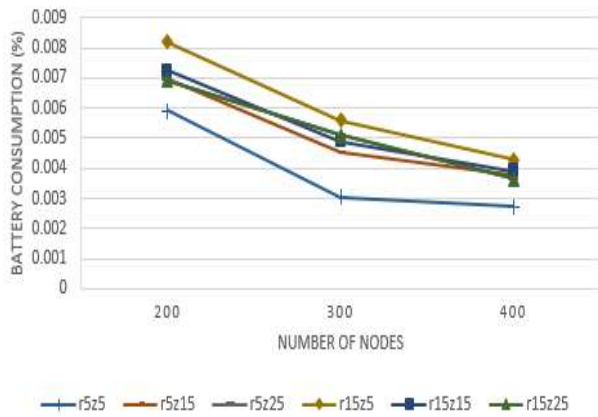


Figure 17: Aggregation Tree Construction - Sent Packets

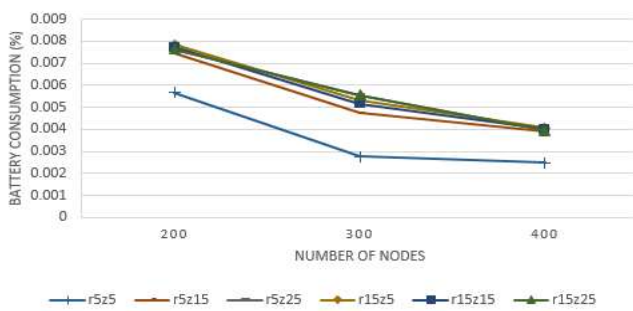


Figure 18: Aggregation Tree Construction - Received Packets

Battery consumption in ZHRP with Aggregation Tree routing are shown in Figure 19 for the sent packets, and in Figure 20 for the received packets.

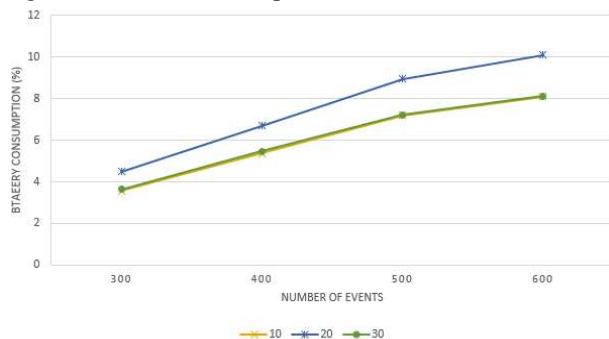


Figure 19: ZHRP with Aggregation Tree Sent Packets

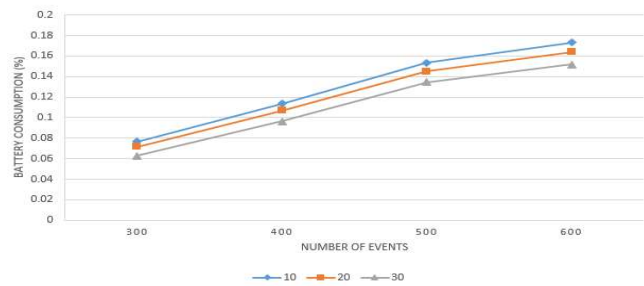


Figure 20: ZHRP with Aggregation Tree Received Packets

6. Conclusion

The introduction of data aggregation benefits both from saving energy and obtaining accurate information. The energy consumed in transmitting data is much greater than that in processing data in sensor networks. Therefore, with the node’s local computing and storage capacity, data aggregating operations are made to remove large quantities of redundant information, to minimize the amount of transmission and save energy. As previously proved, the addition of aggregation to the ZHRP has reduced the number of sent and received packets in a route from source to destination. This addition decreased the number of sent and received packets from 41 to 20. Results prove the energy efficient. The simulation also shows how the aggregation trees are constructed with small number of packets; hence the addition of aggregation tree will not consume a lot of energy. During scenario of routing with aggregation, sent and received packets decreases by 80% and 75% respectively. Hence, aggregation trees will increase the WSN lifetime by a noticeable value. Results clearly show that the battery consumption during ZHRP with Aggregation trees construction does not more than 1% of the battery energy.

For the routing scenario the battery consumption energy percentage decreased (in the worst case) from 40% to 10% after adding the aggregation to the ZHRP.

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