A ROUTING PROTOCOL FOR SENSOR NETWORKS BASED ON POLICIES FOR *ENVIRONMENTAL* MONITORING SEASONAL

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ABSTRACT

This article presents the PBP (Policy-Based Protocol) for wireless sensor networks. Its main objectives are to increase the lifetime of the network and improve data delivery rate making efficient use of energy. This is achieved through the implementation of policies for managing the transmission intervals of observed events and the routing protocol that uses techniques from network optimization, through multiple pathways and clustering for data delivery to the sink in accordance with policy applied . The PBP was compared with routing protocols proposed in the literature using similar techniques. The results show that the PBP presents the best performance among evaluated protocols concerning the lifetime of sensor.

Keywords: Policy-based Protocol; Wireless sensor networks; routing protocol.

1. INTRODUCTION

Wireless Sensor Networks (WSN) are defined as a set of sensor nodes distributed in a field of observation, which are intended mainly to capture information (phenomenon) and forward it to an observer, which processes the information [1].

New research in microelectronics have collaborated to develop even smaller sensors, which are usually equipped with wireless communication systems and processing electrical signals into digital. Such sensors are used in many areas since such as: military, industry, health, agriculture and control of environmental phenomena [2].

Energy consumption is a major issue that has drawn interest in the academic community, and this specification in WSN is directly related to the lifetime of the same, because in many of these networks, sensor nodes are equipped with batteries and its cargo or replacement is not an easy task.

Managing such resources needed for survival of WSN can be run through a set of rules (policies) with procedures for implementation in sensor nodes, depending on the values of the observed phenomena, so adaptable to the needs,

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and these policies can be dynamically updated without human interference in the sensor nodes [3].

The objective of this paper is to evaluate use of policies for power management of the transceivers in wireless sensor networks, and operations of transmission and reception of messages to the largest consumers of energy between the components of a sensor node [4]. For this reason it was proposed protocol PBP (Policy-Based Protocol) adapted from the PEQ (*Periodic Even-driven, query-based*) [5] a protocol for low latency and fault tolerance for use in WSN.

2. CHARACTERIZATION OF THE PROBLEM

Energy consumption is an important factor to prolong the life of the sensor network, some projects of protocols that implement methods for energy savings in the reduction of communication of packets sent, show better network organization and timing data.

In [4], the authors classify the methods used to reduce the energy expended during the process of communication of sensor nodes. The amount of information transmitted to the collector can be reduced by methods of aggregation/fusion and data compression.

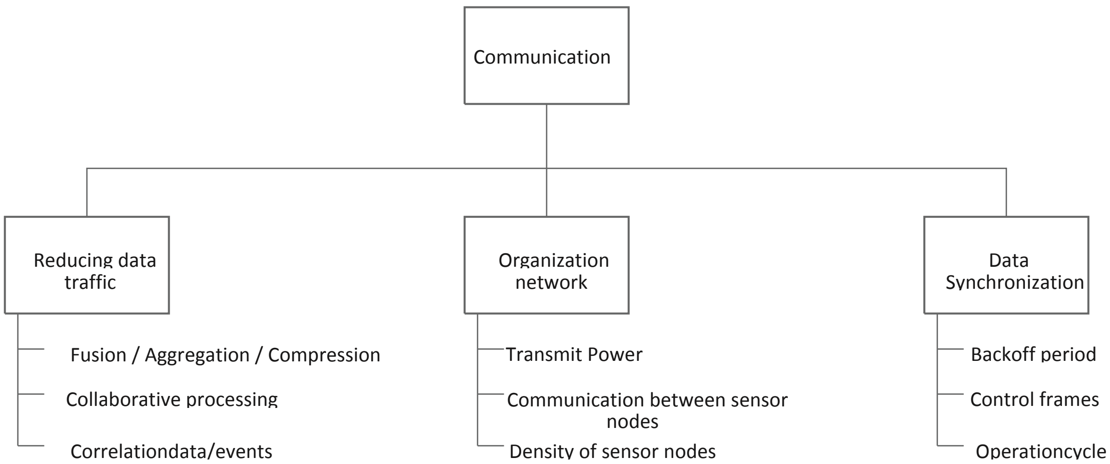

Figure 1. Operations Energy Reduction in Wireless Sensor Networks [4]

In Figure 1 extracted from [4], the authors classified the methods used to reduce the energy expended during the process of communication of sensor nodes, which are described below.

• *Reduction of data traffic*: as previously mentioned, the amount of information transmitted to the collector can be reduced by methods of aggregation/fusion and data compression, where the fusion data received by the sensor node are incorporated and sent information in a single data packet. In the aggregation method the node receives information from its neighbor and runs a processing from this information, by aggregating it to their data and sending the sink also reduces network traffic. The compression is the method where the sensor node makes use of compression algorithms to reduce data to be transmitted. Collaborative processing in sensor nodes fit to prevent invalid information to flow in the network. This adjustment happens through calibration of the sensor nodes in the network. In networks where there are several sensors near performing the same monitoring, there may be transmitting the same information observed by several nodes, the data correlation avoids this type of redundant information through suppression and filtering data to reduce traffic. In [6] technique of aggregation and fusion of sensor data are used as a means of reducing energy consumed by the network.

- *Network Organization:* topology influences the economy of energy expended of sensor nodes, so the transmission power is related to the range of the radio. The higher the power, the greater range and greater power consumption. The article [7] is about maximizing the lifetime of WSN. The communication between the sensor nodes can be direct when the sensor node communicates directly with the base station or sink, also called single-hop, or indirect, when sensor nodes communicate with each other to reach the sink, called multi-hop. According [8], the higher the density of the number of sensor nodes, the greater the accuracy of the data, yielding a better fault tolerance of the system. According to [9] this increased density contributes to the higher rates of collisions.

- *Data Synchronization*: methods used to avoid collisions on the network as the backoff periods, where the sensors detect that no transmissions from other sensors and they wait the time to convey their information. Already control frames defining times for each node to transmit and receive their information. In operation cycles sensor nodes switch their activity in transmission periods and sleep state, thereby reducing the power consumption. In [10] the authors present a method for synchronization of time and the ways to achieve this synchronization.

3. PBP - THE PROTOCOL-BASED POLICIES

Some authors such as [11], [12], [13] have used policies for managing wireless sensor networks for information of sensor nodes, verify and manage their resources message exchange between the sensor nodes.

These protocols serve a specific need for this which it was implemented, but these do not have an efficient mechanism for power control in their sensor nodes with respect to monitoring events. Because of this PBP was proposed by using techniques of management policies to control energy consumption in operations of transmission and reception of messages, so increasing the lifetime of the network, and can operate in periods of seasonality with different monitoring needs.

Figure 2 illustrates the components that compose the protocol PBP, where the first part is the sink who is responsible for deciding the policies to be implemented in sensor nodes and the storage of information collected, also called policy Decision Point (policy Decision point) - PDP. The second part consists of the sensor nodes, responsible for sensing and transmitting data to the sink, called the Policy Enforcement Point (Policy Enforcement Point) PEP.

Initially, the sink controls all information received from the sensor nodes via processor and stores them in a database for later retrieval by the coordinator, who is the person responsible for managing the system, and define the policies to be used in network and distributed by PBP protocol. Another function of the processor in the sink is the management of the network topology, assisting in the creation of routes between the sensor nodes and restarting the network in case of failures. The sensor node, which is the second part of Figure 2, consists of three basic components: sensing unit, processing unit and communication unit (transceiver/mobilizer). The sensing unit comprises sensors that capture the information and transfer the data observed to the unit of processing.

The processing unit is responsible for the storage, management and implementation of policies forwarded by the PDP. These policies are stored in a repository. The data collected by the sensor nodes are processed and stored in a component for later transmission. The communication unit is responsible for transmission/reception of data (transceiver). The function of mobilizer the communication unit has the task to ”wake up” the sensor node to perform assigned tasks in accordance with the configuration by processing unit.

3.1. FUNCTIONING OF THE ARCHITECTURE

The flowchart in Figure 3 presents the phases and messages used by PBP protocol for control and management of sensor nodes. Where in the first phase the routing table is generated in the sensor nodes, initiated by a flood message for initial configuration of the

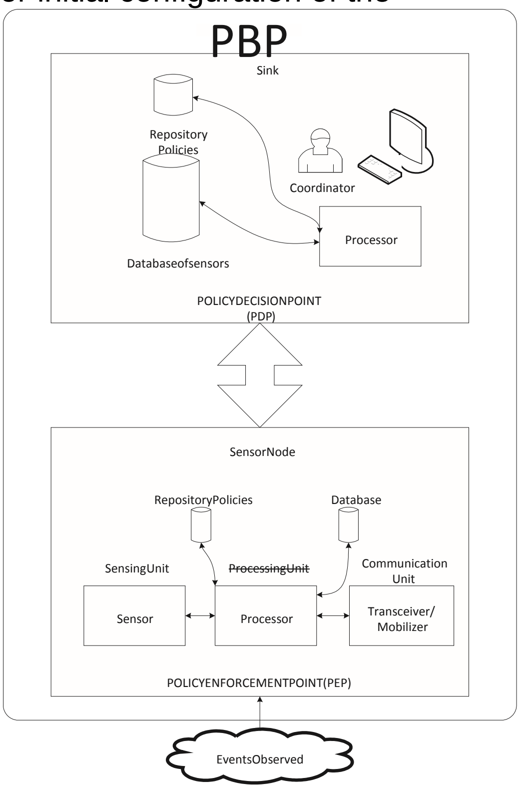

Figure 2. Components of the Protocol PBP

network, creating what it described as the PEQ protocol tree jumps [5], and a sensor node has only information from its nearest neighbors, without an overview of the network.

The tree starts in the sink, which sends a message to its neighbors of transmission the counter that is incremented every node that passes the counter. The sensor nodes in the network, besides collecting information, can act as replicators, relaying information from other sensor nodes, performing data aggregation and fusion.

The initial configuration algorithm 1 describes the initialization phase tree jumps. The data structure comprises table *configTable* and *routingTable*. The table *configTable* has associated parameter settings to collectors, since the table *routingTable* is used as the routing table of node.

As in the wireless sensor network communication is performed through radio frequency (RF), PBP uses rules similar to those used in the protocol PEQ to prevent congestion of messages, for example, in the network initialization phase, where a sensor node to receive a transmission counter for creating routing table of sensor nodes, this value compares with what you have stored. If the counter is greater than the received, the sensor node updates its value and transmits to its neighbor. Otherwise, this value is discarded and the message is deleted. This is done to create the routing table of the sensor node, as previously described, where the sensor node is route, thereby reducing the energy spent for transmission to the nearest sensor node.

At this stage startup also happens the creation of clusters of sensors, whose concept is used by hierarchical protocols as in [8], for information dissemination in large geographic regions it can be used cluster acting in different ways, avoiding the congestion of every network with the flood of messages to certain areas that are not interested.

Algorithm 1 - Algorithm initial configuration

```
//configTable (hop, sinkID, subTimeStamp);
//routingTable (nID, sID, sinkID, coord);
//Initial Phase Configuration
config.hop = 1;
config.sinkID = sinkID;
subTimeStamp = clock();
config.sendConfigMsg();
//When a sensor node receives a message,
//he table scan to see is configTable
entry = configTable.get(config.sinkID);
if entry then
    //entry exist?
    if entry.hop > config.hop then entry.hop = config.hop;
        config.hop = config.hop + 1;
        config.sendConfigMsg();
    end if
else
    // entry not exist!!
    entry.sinkID = config.sinkID;
    entry.hop = config.hop;
```


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```
        configTable.add(entry);
        config.hop = config.hop + 1;
        config.sendConfigMsg();
end if
```

The use of clusters of sensors also has the objective of saving energy, it is very useful for WSN with large numbers of sensors and large geographic regions. PBP enables the use or not of clusters, and may be adapt to various types of networks.

As soon as after setting up the network topology by creating routes of sensors, adapted the second stage of the flowchart is initiated in Figure 3, where the network management policies are directed to the sensor nodes through forwarded messages by sink.

The policies can be disseminated to the entire network or groups of specific clusters. The sensor node, upon receiving this message and check ups in its repository policy if it exists. If positive it replaces the values received, otherwise the new policy is included in this repository. Section *B* deals with the protocol as PBP uses such network management policies.

The third step of the flowchart refers to the monitoring status of the network. In this process the protocol PBP makes a periodic monitoring network to verify if the sensor nodes are still active and can redo the routing of sensor data.

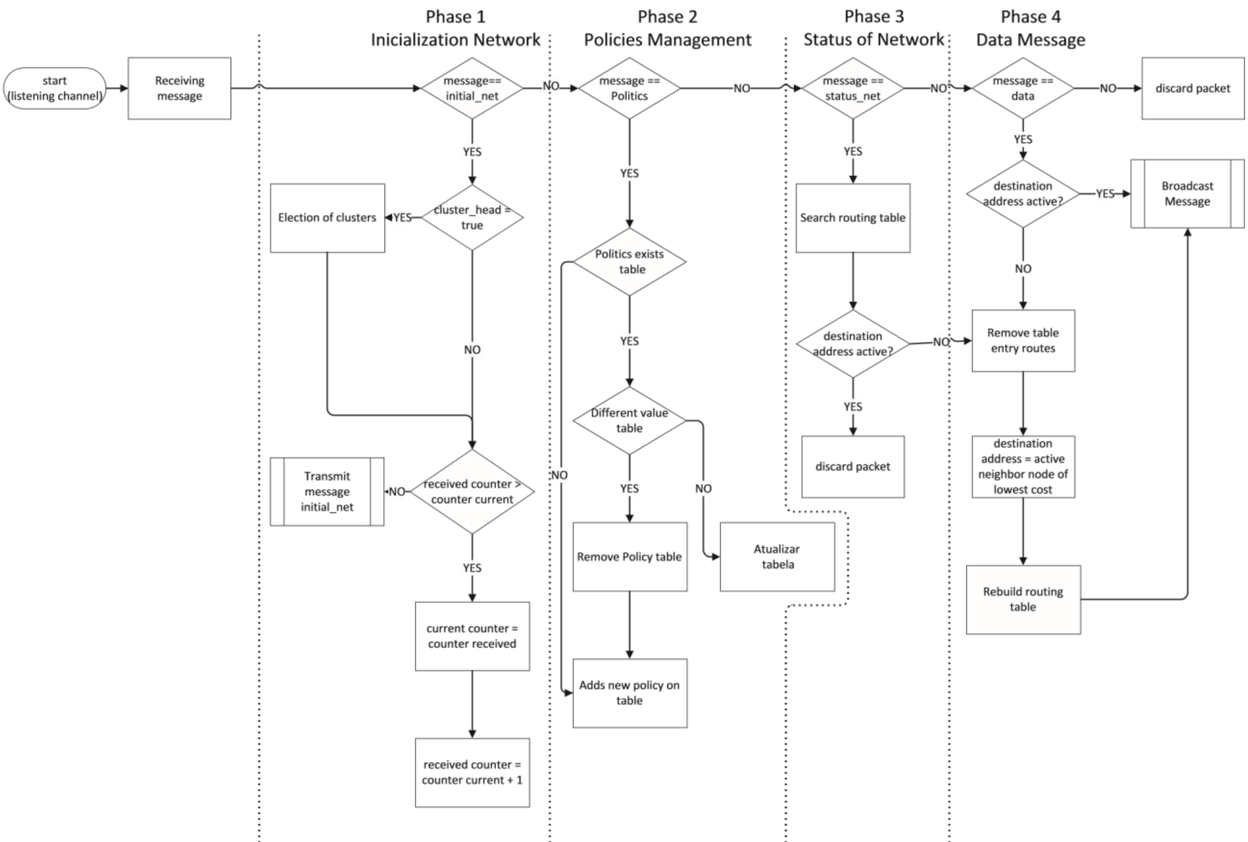

Figure 3. Diagram messaging protocol PBP

The fourth and final phase is the beginning of the process of collecting information of the phenomena observed by the sensor nodes, where data messages are forwarded. The observed values are compared to the conditions used by the policies and criteria as determined by the action that uses this policy. Upon receiving a message of the type of data, the sensor node can aggregate this information and transmit their data to the address of its active routing table, before transmitting it check ups if the address is active, otherwise can redo its route.

3.2. MANAGEMENT POLICIES NETWORKS IN PBP

As noted above, policies are rules to administer, manage and control network resources. The protocol PBP uses the Definition Language Policy Framework – PFDL, described by [14] to express the rules of network management. The PFDL expressed conditional lists, where the values observed by the sensor nodes are compared and actions on these values are assigned in the sensor node.

In Figure 4 observe the reference model which PBP used to deploy policy management in its architecture, where policies are defined by the administrator and stored in a database for later distribution by PDP to sensor nodes (PEP). The PDP distributes policies through messages according to Figure 3, where the sensor node receives a message identified as policy, in it repository to determine whether this policy will be storage.

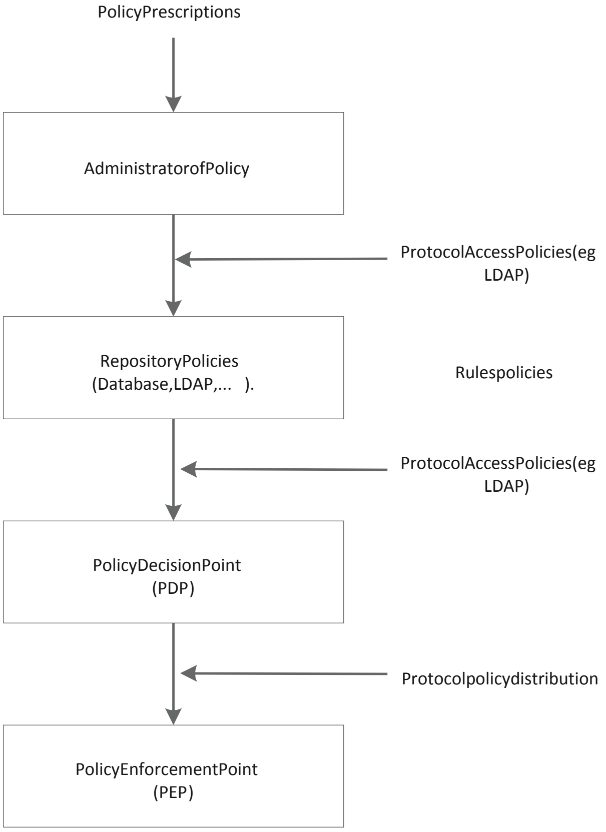

Figure 4. Reference Model of PFDL [14]

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If the policy already exists in the repository, PBP eliminates existing data and inserts new records, the algorithm 2 describes this functionality, which has been the identification data of the policy, the condition for use policy which is a statement of decision, the action to be applied and the scope is the address at which the policy will be applied.

The policy rules are often simple conditions that do not require much processing by the sensor nodes, requiring no further processing and therefore lower energy consumption. Such rules are formed by:

- **Condition:** IF *observed value* ≥ *z* and *observed value* ≤ *y* THEN
- **Action**: *range* = transmission time
- **Scope**: LOCAL

In the above example, as observed phenomena, the sensor node compares the *"observed value"* to the limits set by the PDP (*z, y*), and changes the *"transmission interval"* the transceiver between a message and another, in this way efficiently managing the power consumption of the network.

Another important feature in the architecture proposed by PBP concerning policies is the dynamically updated by sensor node, without human interference, different protocols that have these values fixed limits on programming the sensor node and such changes require human intervention to replacing these limits.

Algorithm 2 Receiving Message Policy

myaddress ← $nsaddr_t$;
myclusterid ← *clusterid*;
Require: receive(msg type);
if msg type == "policy msg" **then**
    if myaddress == scope OR myclusterid == scope OR scope == NETWORK **then**
        //stores the values received in the message object policy
        policy.policyID = policyID;
        policy.condition = condition;
        policy.action = action;
        policy.scope = scope;
        //verifies that the policy exists in the table
        pid = policyTable.lookup(policy.policyID);
if pid **then**
policyTable.rm entry(policy.policyID); // remove item da tabela
end if
//enter values in the policy table
policyTable.add entry(policy.policyID, policy.condition, policy.action, policy.scope);
end if
end if

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4. METHODOLOGY AND RESULTS

This section describes the investigation of the performance evaluation of the protocol PBP through a set of simulation experiments, where the NS-2 simulator [15] was modified and implemented protocols. The results are compared to other protocols used in sensor networks, such as PEQ [5] and LEACH hierarchical protocol [16].

The Periodic, Event-driven, query-based (PEQ), suggests a protocol for monitoring the critical conditions, which uses an algorithm fault tolerant and low latency, such as the monitoring of security areas in a home detention. The protocol uses the fastest way to deliver data and has a network reconfiguration mechanism that ensures fault tolerance. The routing algorithm implements a tree of sensor nodes, where a sensor node only has information from its closest neighbors, with no overview of the network. The PEQ algorithm showed good results compared with the paradigm of Direction Difusion presented in [17] to monitor situations involving emergency.

Low-Energy Adaptive Clustering Hierarchy (LEACH) is one of the most popular hierarchical routing algorithms for sensor networks. It relies on the premise of forming groups of sensors based on the received signal strength and use of head-clusters, which make the aggregation/fusion processing and transmission of data to the sink, functioning as a kind of router, thus saving energy of others. These cluster-head is chosen randomly, using a distribution Bernolli, over time in order to balance the energy dissipation between nodes. LEACH shows good results regarding the use of energy by the sensor nodes, as it is distributed not need to know the entire network, but makes use of mechanism for single-hop routing and each sensor node can transmit directly to the cluster-head.

Table 1. Study of correlation Rain x Landslide [18]

LEVEL	RAIN CUMULATIVE (72h) mm		EVENTS
	de	a	
NORMAL	0	100	Low possibility of the occurrence of landslides, the possibility of occurrence of small landslides / rock located.
ATTENTION	101	120	Great possibility of the occurrence of landslides and localized spot and may be aggravated in areas of risk.

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ALERT	121	150	High possibility of occurrence of landslides of medium ratio and may be aggravated in the areas of risk.
MAXIMUM ALERT	above 151		Great possibility of the occurrence of large landslides with high destructive power, especially in the areas of mapped risks.

4.1 SCENARIO SIMULATION AND METRICS

The simulation scenario presented is formed by a network of 100 sensor nodes randomly distributed in an area with defined boundaries. Change the policies of events so that the network behavior was equivalent to the real environment studies in the city of Jaragua do Sul/Brazil, with respect to the amount of rainfall that occurred for one year, ie simulation time was divided in 52 parts equivalent to weeks, sensor nodes were simulated.

The threshold values used by the policies in the experiment were based on actual studies conducted by the city Civil Defense to monitor hillsides suffering action rains. These correlation coefficients of *rain X landslide* [18] are shown in Table 1.

The radios used in the simulations using the IEEE 802.15.4 standard with transmission capacity of up to 38.4 Kbps and operating range of 108 meters. The mobility was not considered in the calculation of energy consumption of the protocols analyzed PEQ [19] and LEACH [16], since it makes the protocol complex and with a higher energy cost for the network.

To achieve the results reported an average of 15 simulations with different seeds, that due to the simulation period generating a large volume of data for analysis were performed. The metrics analyzed to prove the efficiency of PBP were energy consumed, the delay of packet delivery and the number of dropped packets.

4.2 PERFORMANCE ANALYSIS OF PBP

The Energy Consumed metric provides information about the energy consumption in sensor nodes during the simulation time. This metric is important to prove the efficiency of the protocol. In this simulation protocol PBP served for 32 weeks using the established policy, where the transmission interval between one message and the other was for sixty minutes, called policy 1. As a result, there was a shift of the observed phenomena, changing the policy of sensor nodes, acting for 16 weeks with a policy at intervals of thirty minutes, called Policy

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2. Finally, there was a transition policy implementation during the last four weeks with intervals of one minute, which was called Politics 3.

Figure 5 shows the simulation results of the metric of energy consumed by different protocols. The resulting curve shows the protocol PBP values with lower and upper limits of the confidence interval and the trend line calculated by linear regression of values.

These curves clearly show that the proposed protocol has the lowest energy consumption over time, even considering the exchange of policies that would be part of more expensive in energy consumption. In Figure 5 there is a transition of policies directed by the administrator during the simulation, if these were stored in the sensor nodes, there would not be much expense as presented. The protocol PBP showed an increase of 16.84% in network lifetime compared to other protocols evaluated.

The protocol used PEQ values of certain limits on the sensor node, behaving as the observed values and transmitting information every thirty minutes if necessary. The protocol LEACH acted creating clusters of sensors between nodes and transmitting information according to the events that occurred and transmited information every thirty minutes.

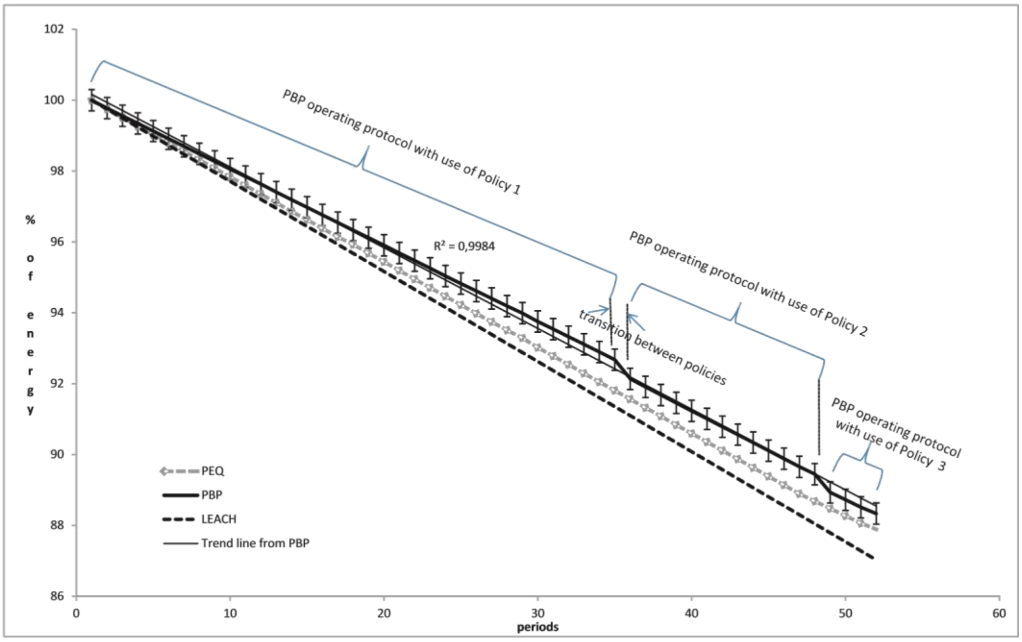

Figure 5. Comparison of the Power Consumption Metrics

Another important metric used to verify the behavior of the protocol during the simulation was read latency of the event until the arrival of the package at sink, called here ”delay end-to-end.” The protocol PBP showed an average of 0.2564 seconds, being within the margin of error mean standard protocol and higher than the PEQ Procolo LEACH, as noted in Figure 6, much lower than the other protocols evaluated.

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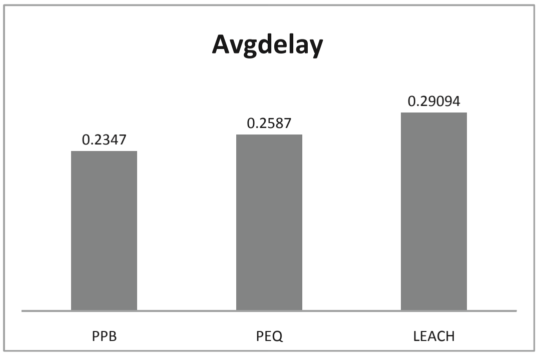

Figure 6. Comparison of the Metrics Average delay end-to-end

The PBP protocol performed better than the average delay end-to-end protocols too (PEQ and LEACH) in this metric.

The protocol PBP also had a low ratio of dropped packets, showing an yield of 12% vs. 10% PEQ of the protocol the sum of dropped packets of tests equivalent to the PEQ within the margin of error pattern and superior to LEACH, as shown Figure 7.

This measure proves the efficiency of the protocols tested, demonstrating the lifetime of sensor networks in a wireless time.

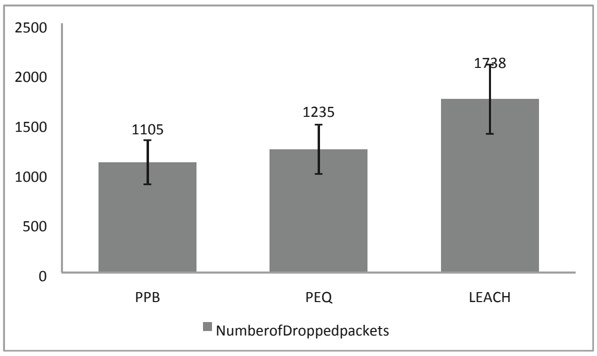

Figure 7. Comparison of the Metric Package Deleted

As noted in the results obtained, the protocol PBP presents a promising result compared to the others evaluated. Featuring better performance in energy consumption metrics and metric delay end-to-end, thereby demonstrating that the use of policies for power management is efficient compared to protocols using reduction techniques traffic, network organization and timing data as the PEQ protocol and protocol LEACH.

5. CONCLUSION

This article describes the protocol as PBP Policy-Based Protocol for wireless sensor networks, proposed for the efficient control of energy in a WSN, thus prolonging its lifetime. The evaluation protocol was performed using a case study where the sensors are reading rainfall values, values that interfere with the moisture level of hillsides, which is one of the factors of landslides by soil saturation. Metrics such as power consumption, latency and packet loss are used in the comparisons between the proposed protocol and other protocols PBP. The PBP showed the best results compared to protocols analyzed. The low latency

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of observed events and delivered to collector also proved that PBP can be used for monitoring critical situations such as the lowest value compared to the others and also making it able to monitor real-time events.

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