# Simulation Of Energy Consumption In Multi Cluster Wireless Sensor Networks

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**ABSTRACT**

Energy conserving protocols in wireless sensor networks (WSNs), such as S-MAC, introduce multi-cluster network. The border nodes in multi cluster WSNs have more active time than the other nodes in the network; hence have more energy depletion rate. Since battery replacement in most networks is considered difficult, one or more nodes running out of energy prematurely will affect the network connectivity and decrease the overall network performance severely. This paper aims to (1) analyze the energy consumption in a multi-cluster sensor network and compare it to the single cluster scenario (2) investigate the merging time in a single cluster network. The result shows that, in average the energy needed to deliver a packet in the multi cluster networks is about 150% more than the energy needed in the single cluster networks. Moreover, the merging time in the single cluster network using schedule offset as the merging criteria in average is slightly smaller than one in the network using schedule ID as the merging criteria.

**Keyword:** *WSNs, Energy Consumption, Multi Cluster, Convergence Time.*

## 1. INTRODUCTION

In Wireless Sensor Networks (WSNs), energy depletion plays a significant role in the network design since in most WSNs energy is a scarce resource. Replacing the battery in the sensor nodes is considered costly and impractical due to several factors, such as the physical location of the nodes and the number of nodes implemented in the networks.

Sensor MAC (S-MAC) [1, 2] proposed a way to prolong nodes' lifetime in WSNs by employing sleeping schedule scheme. Nodes in an S-MAC network turn off their radio modules and enter the sleeping mode, according to a certain schedule, to conserve their energy. Periodically the node 'wake-up' and enter the active mode, in which they can send their data and monitor the network traffic.

Since S-MAC, plethora of other energy conserving protocols is proposed to improve the performance of S-MAC. T-MAC [3] introduced the use of timeout timer called TA to reduce the idle listening during the active mode for more energy saving. DSMAC[4] proposed the use of dynamic active mode duration to reduce the latency caused by the sleeping period. B-MAC [5]and Wise-MAC Wise-MAC [6]proposed ways to even further reduce the energy consumption in the nodes by having the nodes periodically polling the network instead off staying in the active mode for a certain amount of time.

The schedule formation in sleeping schedule based WSNs obeys following procedure. During its initiation stage, a node listens for an announcement of any existing schedule(s) in the neighborhood. If it discovers an existing schedule, it adopts the schedule as its own schedule. At the end of its discovering mode, if there is no schedule announcement is received, it generate its own schedule and announce the schedule to the neighborhood by broadcasting a special packet called SYNC packet.

Although the schedule formation procedure works well in distributed networks such as randomly deployed WSNs, it enables the creation of multi-schedule networks. In such a network, nodes that implement a same schedule form a cluster. Nodes that physically located in the border of two or more clusters need to operate in tactive mode of their own own cluster's and the neighboring cluster(s)'s active period to maintain the network connectivity. This causes the border nodes to have more active time than the other nodes in the network and consequently consumes more energy.

This study focuses on investigating the energy depletion in a multi cluster WSN. First we simulate the formation of multi cluster in a randomly deployed WSN. Then we compare the energy depletion in a single cluster and in a multi cluster network. We then simulate the convergence time, which is the time needed for all the nodes in the network converge from a multi cluster to a single cluster scenario. The rest of the paper is organized as follows. Section 2 describes the architecture of OMNET and CASTALIA which are used as the simulator. Section 3 proposed the scenario of the simuations. Section 4 presents and discussed the results of the simulations and Section 5 summarizes the paper.

## 2. SIMULATION TOOLS

In this study, MATLAB and OMNET++ simulator with Castalia are used to conduct simulation. MATLAB is generally used to plot the nodes to the network according to some distributions, densities and network shapes. In later part of the study, MATLAB is also used to simulate the maximum chain length in the network. OMNET++ and Castalia is used to simulate energy depletion in the network for multiple and global schedule network

OMNET++ [7] is an open source simulation tools that is developed using C++ programing language. OMENT includes several built in network protocol modules and user developed modules that can be used for develop a simulation. Basically each module at least has a NED file (*.ned) and a C++ file (*.cpp, *.h). NED file is written in NED language defining the module parameters and the gates. The gates are used to send and receive data between modules. The algorithm of the protocol in the module is defined in C++ files. Besides NED and C++ files, a configuration file (*.ini) is needed to run a simulation. Configuration file defines the modules that are used in simulation and feeds the values to the parameters in each module.

CASTALIA[8] consists of modules to simulate WSN/BAN protocols in OMNET++ platform. The modules in CASTALIA are grouped into node module, physical process module and wireless module. Fig.2 shows the relation of node composite module with other modules.

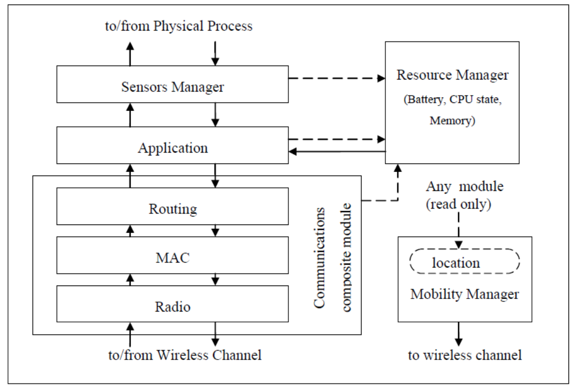


Figure 1 Structure of Nodes Modules in CASTALIA[8]

Physical process module defines the physical process to be sampled by the nodes. It generates a set of values that represents temperature, acceleration, etc. When the sensing device (Sensor Manager Module) of a node 'samples' the environment, the physical process calculate the value and return it to the node. Wireless module mostly deals with wireless channel in the simulation such as path loss and interference. Communications composite module consist of 3 sub-modules namely Radio, MAC and Routing which handle the communication between nodes for transmitting and receiving data packet.

## 3. SIMULATION METHOD

### 3.1. Number of Cluster in a Randomly Deployed Network

The simulation obeys the following procedure.

(1) Network Deployment
We randomly deployed the network by plotting the nodes randomly in the network area for different sizes and shapes using MATLAB. In each deployed nodes, we randomly generate a wake-up timer to determine the time the node come to live for the first time. The nodes' positions in the Cartesian plane (X,Y) and the wake-up timer are then recorded to a text file to be feeded to CASTALIA simulator.

(2) Schedule Discovery and Generation Stage
Based on the nodes position and the wake up timer, CASTALIA running the schedule discovery stage in each node according to S-MAC protocol. Each time a node fails to discover an existing schedule it creates a new schedule and start the formation of a new cluster.

(3) Border nodes
We then investigate the number of schedule a node needs to implement according to its position in the network to maintain the network connectivity.

### 3.2. Energy Depletion Simulation

Using the network configuration and simulation result in 3.1. we simulate the average energy used in a multi cluster network (where some nodes implement more than one schedules) and single cluster network, where once a multi cluster network converge to a single cluster network.

### 3.3. Network Convergence Time Simulation

In this simulation, the nodes in the network are place in certain positions to create multi-cluster network. We then run a simulation to investigate the time needed for the network became fully functional. In a multi-cluster network, it means that the time needed for the network to be fully connected. In the single cluster network, it means the time for all nodes implementing a single schedule.

## 4. RESULT AND DISCUSSION

### 4.1. Simulation 1: Multi Cluster Formation

The main aim of this simulation is to investigate the number of schedules employed in the network and the numbers of border nodes that implement more than one schedule.

We consider a square 20 x 20 network where we randomly deploy 20 nodes. We run the simulation multiple times to validate the result. The detailed configuration follows scenario 1 as shown in TABLE 1

TABLE 1 Scenario 1 Configuration

| | |
|---|---|
| Network Size | Square of 20x20 |
| Transmission Range (R) | 8.254042 |
| Protocol | S-MAC |
| Number of Nodes | 20 |
| Simulation Time | 200 500 1000 2000s |
| Sample | 100 simulation |

The result is shown in Figure 2. Based on the result there are four schedules implemented in the network which consequently divided the network into four virtual clusters. Moreover, around 40% of the nodes in the network implement more than one schedule and around 20% of the nodes implement more than 2 schedules. The consequence of the nodes implementing more than one schedule is they have longer active time (in the simulation up to four times a normal node) and, as a result, consume more energy than the nodes implementing a single schedule.

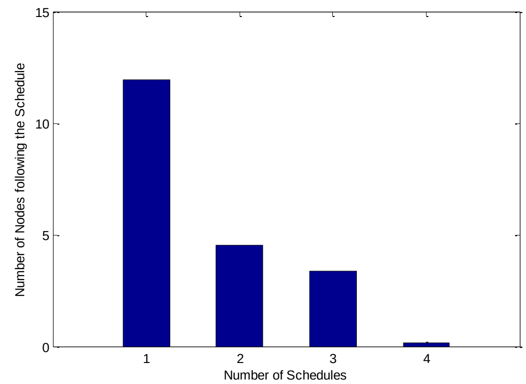


Figure 2 Number of Schedules in the Network

### 4.2. Simulation 2: Energy Depletion in Multi Schedule Network

Based on the fact of some nodes in a multi-cluster network implement consume more energy due to longer active time, this simulation aims compare the energy depletion of a single and a multi-cluster network.

The simulation parameters follows the configuration in Scenario 1 as shown in TABLE 1. At the end of each simulation we compute the total amount of energy spent in the nodes in the network and the packet successfully delivered in the network. We then define the energy depletion parameter as the energy used to send a packet in the network as shown in eq.1, where $e_{network}$ is the energy spent in the network and $n$ is the number of packet delivered in the network.

$$e_{packet} = \frac{e_{network}}{n} \qquad \text{eq. 1}$$

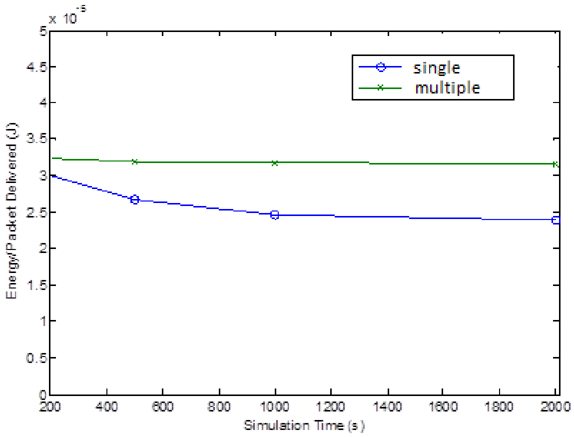


Figure 3 Energy Depletion in WSN

We run the simulation for 200s, 500s, 1000s and 2000s. As shown in the result in Figure 3, a single cluster network spends less energy per packet delivered than a multi cluster network does. It also needs to be noted that as the time goes the single cluster network spends less energy per packet while the energy consumption in a multi-cluster network remains. The rationale behind this is in the early stage of the network (t=200s) , the nodes in single cluster network are still in converging stage so some nodes are still implementing more than one schedule. As the time goes more clusters merge and less nodes need to have more active time. After some time (around t=1000), most node already operate in one cluster so that the energy consumption stabilize in a certain value.

### 4.3. Network Convergence Time

As shown in previous simulation having a single network converse the network energy. In this part of simulation we investigate the time needed for the nodes in the network to merge into one cluster.
We consider two types of merging criteria. The first criteria is Schedule ID, in which when a node discover other cluster(s) with different schedule(s), it decides to adopt the schedule with smallest schedule ID. The second criteria is schedule offset in which in discovering a new schedule, a border node follows the new schedule if the active period in the new schedule precedes the active period of its own schedule.

In the simulation we consider the scenario as shown in TABLE 2. Three nodes are positioned in such a way to ensure there will be two clusters in the network.We use path loss of 55 and transmission range of 8.234. We then run the simulation to get the convergence time.

TABLE 2 Scenario 2 Configuration

| | Node 1 | Node 2(sink) | Node 3. |
|---|---|---|---|
| Position (x,y) | (5,5) | (10,10) | (15,15) |
| Node StartUp | 0 + rand(0.5) | 3 + rand(0.5) | 0+ rand(0.5) |
| Application StartUp | 100 | 100 | 100 |
| Simulation time | 250 | 250 | 250 |

In the single cluster scenario, convergence time is defined as the time all the node merge to one cluster, i.e. implement a single schedule. In a multi cluster scenario, the convergence time is defined as the time that the network is fully connected. In the single cluster scenario, we run the simulation for the schedule offset criterion and for global schedule criterion. To validate the simulation data we run the simulation for at least 100 times and take the average value.
The simulation result is shown in TABLE 3. The data shows the time each node implement its last schedule. The result shows that in average a multi cluster network is fully connected after t= 7.8 s. The single cluster network in fully merged after t=4.6s (offset based merging) and t=6.1s (ID based merging)

TABLE 3 Convergence Time

| | Node 0 | Node 1 | Node 2 |
|---|---|---|---|
| Multi-cluster* | 3.993 | 7.8331 | 3.6871 |
| Single-cluster, offset | 4.5889 | 3.472 | 3.7581 |
| Single-Cluter, ID | 2.147 | 5.5365 | 6.147 |

## 5. SUMMARY

In this paper we have analysed the energy consumption in both single and muti-cluster wireless sensor network. The simulation shows that, in a long run, the multi-cluster network spend approximately 150% more energy per delivered packet than the single cluster network does. Furthermore we have also investigated the convergence time for Schedule ID and Schedule Offset merging criteria for a single cluster network. The result shows that the schedule offset based networks have a slightly smaller merging time than the schedule ID based networks.

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