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Measuring Of Energy Performance with Energy Use Index in Wireless Sensor Network

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Abstract:- This paper explains the problem of energy with Wireless Sensor Network (WSN) and the unconsidered Quality of Service energy parameters of WSN. In addition this paper aims at bringing out the different energy measures involved with WSN and the accuracy involved with the recording of the energy measure relevant data. Different industry specific methodologies of energy measures like energy model, energy portfolio, energy benchmark, energy use Index are defined specific to Wireless Sensor Network. The energy performances of WSN system for the defined energy portfolio are explained. All Energy Engineering initiatives specific to WSN revolve around these basic factors and ultimately try to improve the energy performance of the WSN

Keywords:- Wireless Sensor Network, Energy Portfolio, Energy Use Index, Energy Benchmark, Energy Performance

I. INTRODUCTION

Wireless Sensor Network (WSN) is formulated by deploying the set of sensor nodes in a distributed fashion which are connected to the coordinator node called sink or hub. The key advantage of the network is to get the environmental factors like humidity, temperature, pressure, movements through the sensor devices and make the decision at the application end. The main distinguishing factor in the whole network is communications are wireless. The application area of WSN are the industry specific operation control, weather forecasting, wild fire detection, asset monitoring, smart homes, intelligent traffic control system, military intruder detection, precision agriculture. As most of the WSN system evolved from the traditional network system, the focus is on the throughput and performance. But, not on the energy or power which is very limited in the WSN nodes. In many cases the nodes are thrown to the remote area and are self-configured. So, it is difficult to charge the node and they survive with their limited battery supply. So, in later years many energy management initiatives have happened in this field. The first step of any energy engineering initiative is to measure the energy and decide the energy performance of the WSN system. The systematic approach to measure the energy is discussed in detail here.

II. DEFINITION OF ENERGY

As we generally know current is the compound component. When it is said, one volt and one amp or one watt what we really mean is to be made clear before explaining energy measures of WSN and discussing the battery capacities of WSN as some of the vendors data sheet explains it in ohms, some in volts and some in Watts.

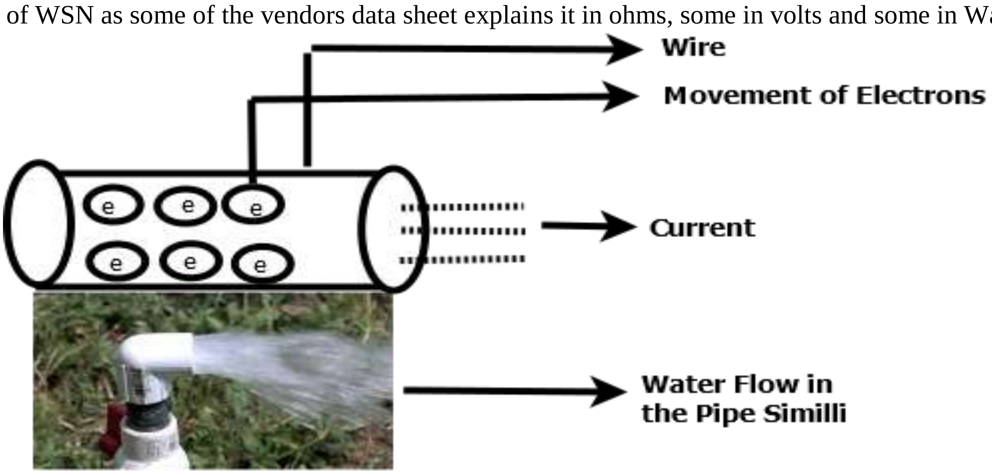

Fig 1: Current with Water Simile

The energy relevant measures can be easily understood with a simile of water in a pipe [1].

2.1 Voltage (Electrical Potential)
Volt can be compared to the "Water Pressure" in the water pipe. The potential difference or the pressure across the electrical conductor is volt which defines how forcibly the conductor is capable of discharging energy to the user.

2.2 Amperage (Electrical Flow)
In the water in pipe analogy it is the flow that is how continuously the current can pass through the conductor. It determines the electrical current flow rate. It is denoted by **I** as well **Amp**.

2.3 Resistance (Electrical Resistance)
The resistance in the pipe that obstructs the water flow as per the example. It is the measure of how the device or material or conductor opposes the current flow. It is defined in **ohms** and denoted as **R.**

2.4 Wattage (Electrical Usage)
The electrical usage or how much the electrical energy has been consumed is measured here. How many litters of water are decided over here. It is denoted as W or P for Power.

2.5 Formulas Associated
Watts = Volts x Amps
Amps = Volts / Ohms

2.5 AC and DC Current
Current is nothing but the movement of electrons in the conductor like wire. The difference between AC and DC lies in the direction in which the electrons flow. In DC, The electrons flow steadily in a single direction, or "forward." In AC, electrons keep switching directions, sometimes going "forward" and then going "backward."

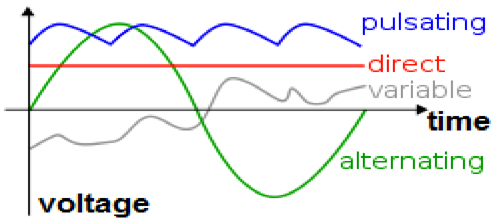

Fig 2: Alternate and Direct Current

Alternating current is the best way to transmit electricity over large distances. In case of AC rotating magnets are kept along the wire whereas in case of DC steady magnetism is kept on the wire.

III. PROBLEM OF ENERGY WITH WSN
Every Node in the Wireless Network basically has 4 units sensing unit, processing unit with internal storage, communication or transmission unit and the power supply unit. The Node structure varies based on the additional features added or functional capability or the sensor type like thermistor or humidity or pressure sensor.

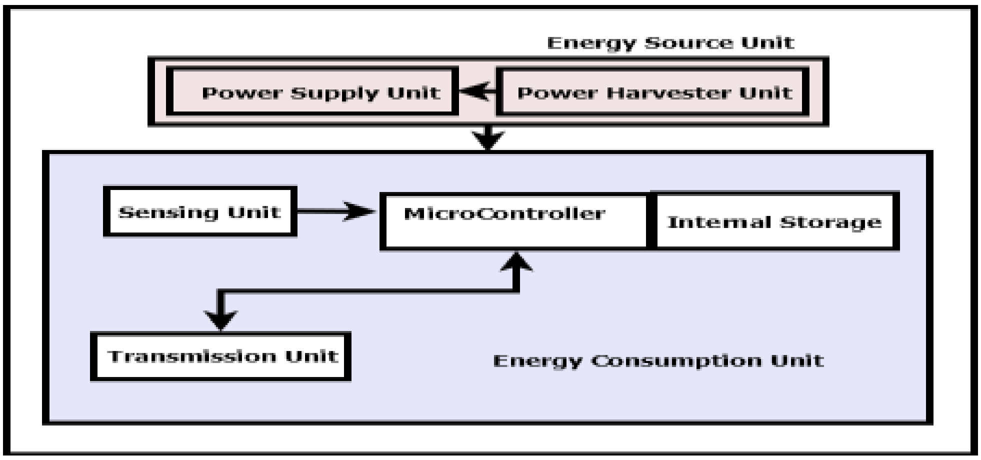

Fig 3: Node Structure of WSN with Energy Units

3.1 Energy Hole in WSN

In WSN, the simple node senses and propagate the data to the nearby special node called Sink which aggregates the data from the nodes in its region and pass on the propagated data to the Agent node which in turn process the aggregated data from various sink and pass the processed data to the manager node which in turn infers and pass on the information to the WSN application. Nodes, Hub and Gateway are the different components in the network. The nodes are differentiated by its functionality as well its location to form the range of coverage. To facilitate the communication and simplest routing there is a logical topology framed. The Cluster Head node is the parent node of the cluster, which manages and checks the status of the links in the cluster and routes the information to the right clusters. Inter cluster data transfer takes place through the cluster gateways [2].

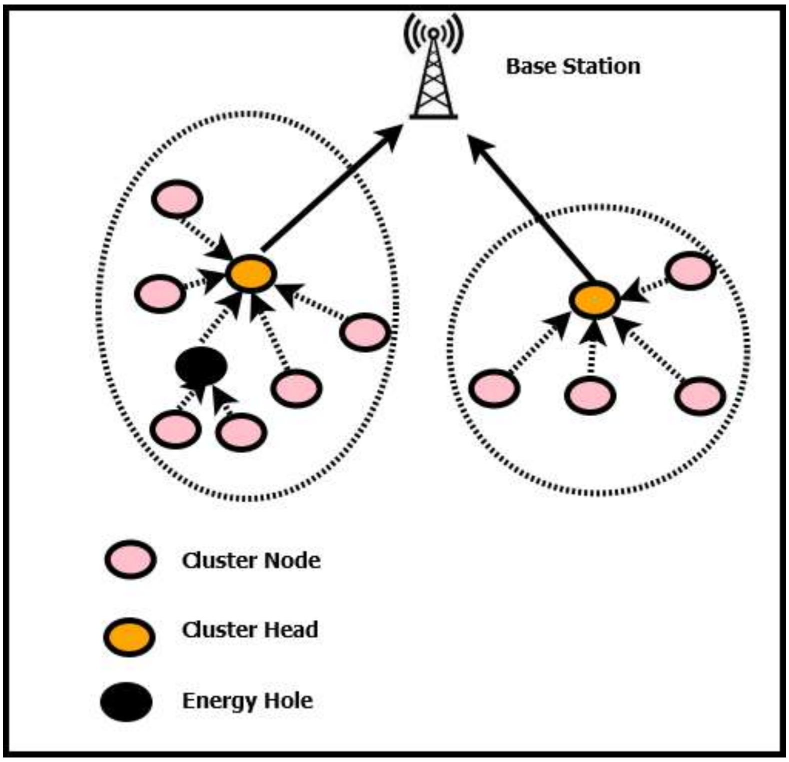

Fig 3: Energy Hole in WSN

During data transfer, the nodes nearby the cluster head are overloaded with the transmission and finding the destinations. So, they deplete energy and become less in energy not able to carry over any operations when most energy node is identified for transmission, this is called as energy Hole [3]. Rotation of cluster head dynamically is the solution usually proposed to avoid the energy hole or high energy depletion at certain node.

3.2 Limited Power Batteries in WSN

Wireless communication means we not only dis connect the data wires but also power supply wires. So, the nodes have to exist with the limited batteries and limited power supply. There are initiatives how to optimally use the energy in the battery or how to harvest the energy from the environment. Overall battery capacity is measured in milli-Amp-hours (mAh) or Amp-hours (Ah). A rating of 3 Ah means the battery can supply 3 A for 1 hour or 1 A for 3 hours. We tend to say that a battery is empty when the potential or voltage drops below a certain level. Typically, for a 1.5 V cell such as a AA-sized cell, we consider the battery empty when the voltage drops to around 0.9 V [4].

So, the initial high energy density is required for the batteries. The other factor is how much external temperature or cold of the environment the battery can withstand. Extremely long battery life, extended temperature range, and reduced battery size and weight are important considerations for deciding the batteries for remote sensing.

3.3 Unconsidered Energy QOS in the Design of WSN

The sensing unit, communication unit and transmission units are the energy consumer units whereas the battery and harvesting or power generator unit or power actuator units if available are the energy source units. The energy consumption is more in transmission unit in most of the cases. The overall transmission energy varies with the coverage area as well. The protocol and the middle ware of the WSN where the transmission and computation happens play the major role in energy consumption [5]. The power to transmit one 1KB is equal to execute 1000s of instructions. Legacy batteries can be eliminated through the use of Energy Harvesting techniques which use an energy conversion transducer tied to an integrated rechargeable power storage device.

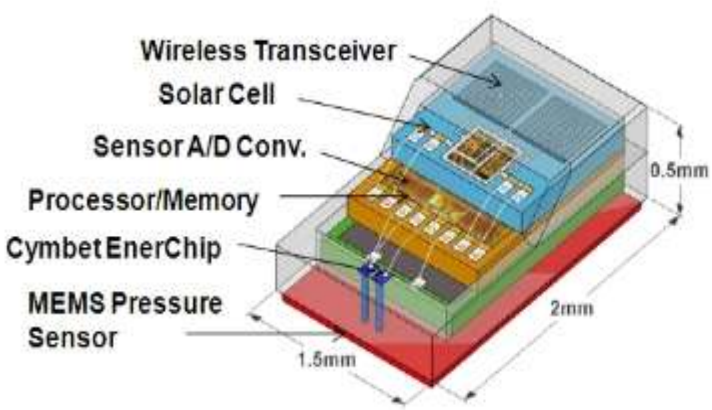

Fig 4: Zero Power WSN Sensors by SYMBET

Energy consumed in sensing depends upon the type of sensing-unit used in a sensor node. Factors affecting the power consumed by the sensing unit include signal sampling, conversion of physical signals to electrical, signal conditioning, and analog-to-digital converter (ADC). Choice of micro-controller unit (MCU) is dictated by required performance level and it also impacts consumed power. The microcontroller usually comes with the scheduler to change the state of the other unit from active to sleep to reduce the energy wastage. The time synchronization to sync the nodes in to the same time stamp, location finding algorithms and routing protocols all consume the network and node energy. Every unit of transmission and every layer of transmission is to design with energy awareness without much compromising the performance is common solution for this. But, most of the operations and transmission unit worry about the throughput rather the energy.

IV. ENERGY MEASURES OF WSN

Every vendor publishes the data sheet where the hardware maximum energy consumptions are listed. Most of the cases it is the actual value realistically getting consumed [6].

Sensor	Producer	Sensing	Power consumption
STCN75	STM	Temperature	0.4 mW
QST108KT6	STM	Touch	7 mW
SG-LINK (1000Ω)	MicroStrain	Strain gauge	9 mW
SG-LINK (350Ω)	MicroStrain	Strain gauge	24 mW
iMEMS	ADI	Accelerometer (three-axis)	30 mW
2200 Series, 2600 Series	GEMS	Pressure	50 mW
T150	GEFRAN	Humidity	90 mW
LUC-M10	PEPPERL+ FUCHS	Level sensor	300 mW
CP18, VL18, GM60, GLV30	VISOLUX	Proximity	350 mW
TDA0161	STM	Proximity	420 mW
FCS-GL1/2A4-AP8X-H1141	TURCK	Flow control	1,250 mW

Table 1: Power Consumption of Popular Sensors

As we discussed it is important to measure the current usage of multiple components of Node. Here are some statistics for a AA battery based Node [7].

Currents	Value(units)
Microprocessor	
Current (full operation)	6mA
Current Sleep	8µA
Radio	
Current in Receive	8mA
Current transmit	12mA
Current sleep	2 µA
Flash Serial Memory	
Write	15mA
Read	4mA
Sleep	2 µA
Sensor Board	
Current (full operation)	5mA

Table 2: Current Consumption by different Components of Sensor Unit

V. ACCURACY IN ENERGY DATA LOGGING IN WSN

There ideal current consumption varies based on the state of the unit. All the units switch to various states. So, the accuracy in the energy data logging of WSN can be calculated based on the state of the unit. Herewith the Mica Unit power consumption data has been short listed [8].

Mode	Current	Mode	Current
CPU		Radio	
Active	8.0 mA	Rx	7.0 mA
Idle	3.2 mA	Tx (-20 dBm)	3.7 mA
ADC Noise Reduce	1.0 mA	Tx (-19 dBm)	5.2 mA
Power-down	103 µA	Tx (-15 dBm)	5.4 mA
Power-save	110 µA	Tx (-dBm)	6.5 mA
Standby	216 µA	Tx (-dBm)	7.1 mA
Extended Standby	223 µA	Tx (dBm)	8.5 mA
Internal Oscillator	0.93 mA	Tx (+dBm)	11.6 mA
LEDs	2.2 mA	Tx (+dBm)	13.8 mA
Sensor board	0.7 mA	Tx (+dBm)	17.4 mA
EEPROM access		Tx (+10 dBm)	21.5 mA
Read	6.2 mA		
Read Time	565 µs		
Write	18.4 mA		
Write Time	12.9 ms		

Table 3: Current Consumption by different units by different states of Mica Mote

Most of the research is based on the residual energy of the node but ignoring the energy consumption at different nodes. The residual energy rapidly decreases when the radius of the coverage increases.

VI. ENERGY MONITORING AND REPORTING

It is usually application specific, it could vary based on the purpose and decides at what level and what energy the monitoring system wants to monitor and report. Herewith the typical energy auditing system for WSN has been mocked up.

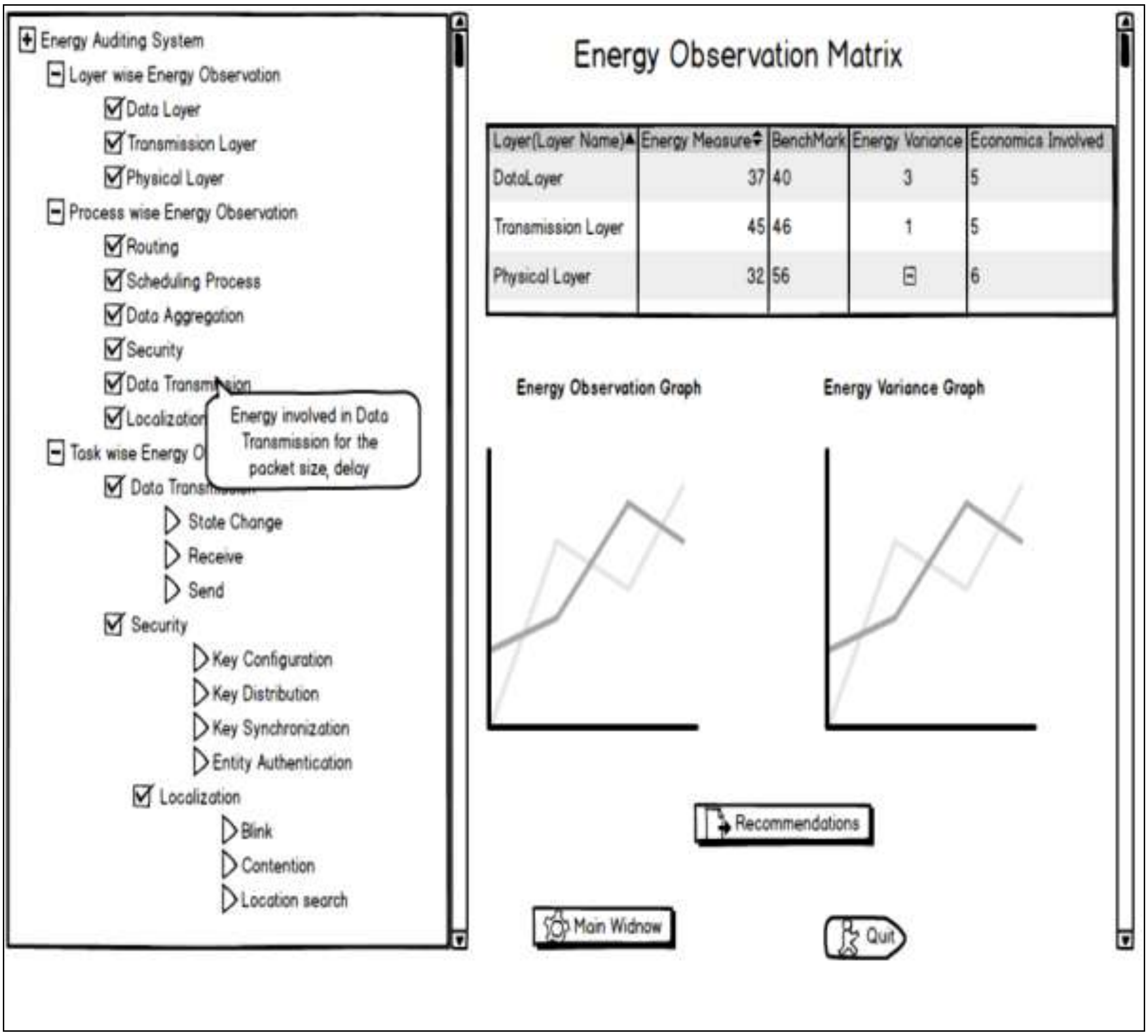

Fig 5: Typical Energy Monitoring and Reporting System in WSN

VII. ENERGY PORTFOLIO WITH ENERGY MODEL FOR WSN

It is as simple as that of forming a mathematical model to determine the **Energy Use Index** (EUI) which measures the overall energy consumption. Energy Use Index can be calculated with the summation of energy at different activity level as well energy consumption at different unit level. This index is calculated for the purpose of validating whether the energy reduction techniques don't alter the final result of the index will be same after different energy consumption scheme changes [9].

EUI_{com} = Energy consumed by Micro Controller + Energy Consumed by Internal Memory + Energy consumed by Sensing Unit + Energy Consumed by Sensing Unit - Energy Depletion
EUI_{Act} = Energy for sensing + Energy for Localization + Energy for Encryption + Energy for Data Processing + Energy for Communication (Transmission, Receiving) - Energy Depletion.

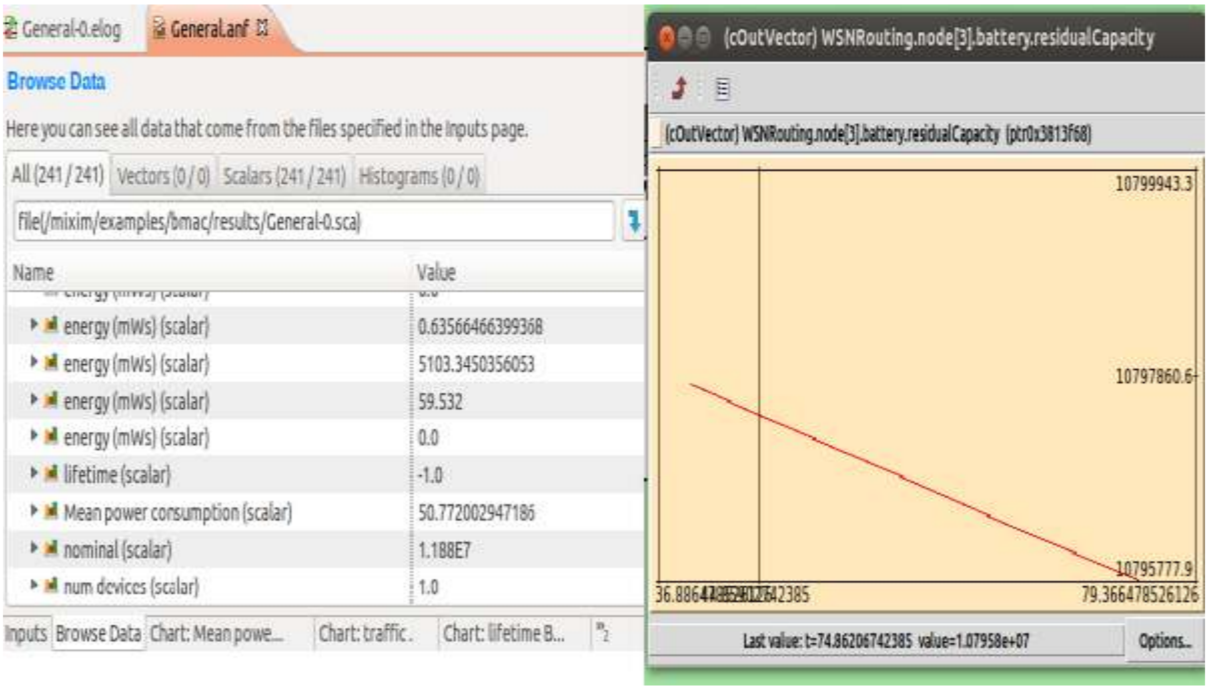

Fig 6: Residual Energy Display in WSN simulation using OMNETPP Simulator

Both the component based and activity based energy consumption indices are calculated before and after energy improvement because to verify the overall energy consumption has been improved. Here the concept of **Energy Economics** becomes popular which shows the reduced energy directly reduces how much of energy cost. A detailed index can be calculated by considering different states of the units. For eg. The different states for CPU could be Idle, ADC noise reduce, Power-down, Power-save, Standby, Extended standby, Internal oscillator. **Energy Model** defines various factors that is considered in a system to measure the energy whereas the **Energy Portfolio** is the complete solution on energy for the destined WSN system to meet the energy target decided. Energy Portfolio includes the energy infrastructure, energy aware communication protocols, energy efficient data collection and transmission techniques, energy potential architecture, monitoring system. Energy Peak Index talks about for a given period of time what is the maximum energy the unit has consumed. Basically it is calculated to choose the battery voltage. It is all based on the WSN profile that has been chosen.

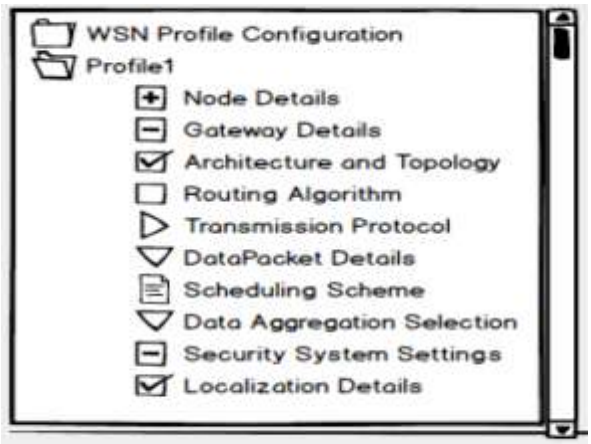

Fig 7: A formal WSN Profile Configuration

VIII. ENERGY BENCHMARKS

The relative reference of data matrices on throughput, delivery rate, energy, stability, scalability memory that basically constitute the performance of the WSN system is called the Benchmark. The energy benchmark focuses on energy matrices alone and in turn define the energy performance of the system. For a defined WSN profile, for the given scenario the energy benchmarks are defined to the Database for comparison.

On the given infrastructure or architecture or protocol the energy readings are compared with the benchmark for finding the energy variance [10].

IX. ENERGY MANAGEMENT

There are lot of energy engineering initiatives are taken by various industry vendors and academic research area. All the initiatives can be classified into three categories 1) Energy auditing and monitoring to measure the energy consumption and compare it with the benchmarks and find the energy variance – this is mainly to find the opportunity to optimize energy 2) Energy optimization by energy aware transmission and routing protocol design, Energy efficient data collection and processing techniques , Power aware hardware as well algorithmic design 3) Energy harvesting unit for to generate power to prolong the life time of the WSN system.

Energy Management strategy should include the business objectives, service management, network and network element management, fault tolerance, performance , security all with the energy awareness and energy minimization.

X. CONCLUSION AND FUTURE DIRECTION

This paper gives the glimpse of energy crises associated with the Wireless sensor network with the definition of energy and energy consumption operations in WSN. The first phase of energy engineering to set the energy portfolio with the energy model is defined here. A systematic approach of setting the energy benchmark for the WSN profile set and comparing the variance and economics are discussed here.
With this conceptual understanding a test bed of sensors is being setup to study the energy at various activities with set of WSN profiles and energy models using electrical sensors to measure the energy consumed on each activity of microcontroller, transmission unit and sensor on various state changes. Data logging for benchmark comparison is decided on the DB server and the energy graph and energy variance graph with the economics details will be brought out.

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