SmartGreen: A Novel Green Computing Architecture for Environmental Data Acquisition in IT/Automation DataCenter

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ABSTRACT
Ongoing concerns about climate change and poor environmental sustainability in today’s world could eventually result in computing processes that impact the environment negatively. The IT/automation industry can significantly impact on the worldwide carbon footprint by adopting a ‘greener’ approach to computing for environmental sustainability. This paper then presents green computing as an efficient strategy to energy optimization in DataCenter computing processes. In this regard, a novel SmartGreen architecture for computing process regulation is proposed leveraging on the functionality of Wireless Sensor Network (WSN) for Temperature, humidity and energy data acquisition while offering recommendations on potential energy cost savings for the IT/automation industry. CC2340 Telosb RF nodes, a remote terminal server and a SmartGreen monitoring application was developed as a testbed for the DAS. The computational benefits associated with green environmental monitoring was discussed.

Keywords: Green Computing, WSN, Data Acquisition, environmental Sustainability, Carbon Footprint

1. INTRODUCTION
Green computing refers to the practice of using computing resources more efficiently while maintaining or increasing overall performance and ensuring environmental sustainability. Sustainable IT/automation services require the integration of green computing practices such as power management, virtualization, improving cooling technology, recycling, electronic waste disposal, and optimization of the IT infrastructure to meet sustainability requirements. Recent studies have shown that costs of power utilized by IT/process control departments can approach 50% of the overall energy costs for an enterprise organization [1]. Green computing includes the dimensions of environmental sustainability, the economics of energy efficiency, and the total cost of ownership, which includes the cost of disposal and recycling [2].

While there is an expectation that green IT should lower costs and the firm’s impact on the environment, there has been far less attention directed at understanding the strategic benefits of sustainable environmental monitoring in terms of the energy waste reduction, efficiency optimization and process regulations using wireless sensor network architecture. This work then proposes a novel SmartGreen architecture that satisfies the above requirements while offering SmartGreen recommendations which will help the enterprise market segment better comply with green sustainability. The rest of this paper is organized as follows, Section II: Literature review, Section III presents the experimental design testbed and data collection. Section IV presents the data analysis. Section V gives the recommendations for environmental sustainability. Section VI presents discussions and Section VII concludes the research work.
2. RELATED WORKS

The authors in [3] developed an integrated wireless SCADA system for monitoring & accessing the performance of remotely situated device parameter such as temperature, pressure, humidity on real time basis. In their approach, a mobile network, which is based on GPRS technique, was used for the monitoring application as shown in Fig 1.

![Integrated wireless SCADA system](image1)

**Figure 1: An Integrated wireless SCADA system [3]**

The authors in [4], proposed Green Computing Observatory (GCO), an energy saving IT systems which addresses the previous issues within the framework of a production infrastructure dedicated to e-science, a unique facility for the Computer Science and Engineering community. GCO collects monitoring data on energy consumption of a large computing center, and publish them through the Grid Observatory [5]. These data include the detailed monitoring of the processors and motherboards, as well as the global site information, such as overall consumption and overall cooling, as optimizing at the global level is a promising way of research [6].

![Monitoring instruments and scale](image2)

**Figure 2: Monitoring instruments and scale [4]**

The work noted that the first barrier to improved energy efficiency is the difficulty of collecting data on the energy consumption of individual components of data centers, and the lack of overall data collection. Also, the second barrier is making the collected data readily usable. Fig 2 shows the monitoring infrastructure of GCO. The authors in [7] proposed a green cloud architecture that can reduce power consumption of clouds as well as the carbon emission while providing a unified solution to enable Green Cloud computing for providers. In figure 3a, for a common cloud usage, green issues are highly evidenced as the cloud datacenters will be averagely dissipating more energy than that of fig 3b which have green monitoring setup. The high level view of the green Cloud architecture is given in Figure 3b. The goal of this architecture is to make Cloud green from both user and provider’s perspective [7].
Consider cloud deployment architecture in fig 4, the issues of energy conservation and environmental sustainability is obviously lacking.

IT as Service cloud architecture must obviously address these issues before enterprise organization considers it for deployment.
The authors in [8] reported a mixed initiative intelligent system that employs multi-modal sensor system, context awareness model, semantics, and service-oriented architecture to provide real-time energy consumption information and recommendations for positive behavior change on households’ energy consumption. The system adopts concept of On-Line Analytical Process (OLAP) to summarize large volume of data generated from energy consumption monitoring sensors into a set of meaningful information for the intelligent system to reason. The system is currently deployed in around 250 households across Europe for evaluation. Fig 5 shows the system architecture. In the next sections, we shall present the energy challenges of datacenters as well as the contextualization on SmartGreen architecture.

3. DATACENTER ENERGY CHALLENGES

The Cloud datacenters are quite different from traditional hosting facilities as depicted in fig 3a, fig 3b, fig 4 as well as in figure fig6a and fig 6b. A cloud datacenter could comprise of many hundreds or thousands of networked computers with their corresponding storage and networking subsystems, power distribution and conditioning equipment, and cooling infrastructures [7]. Due to large number of equipments, datacenters can consume massive energy consumption and emit large amount of carbon. According to 2007 report on computing datacenters by US Environmental Protection Agency (EPA), the datacenters in US consumed about 1.5% of total energy, which costs about $4.5 billion. This high usage also translates to very high carbon emissions which was estimated to be about 80-116 Metric Megatons each year.
Table 1 lists equipments typically used in datacenters with their contribution to energy consumption. It can be clearly observed that servers and storage systems are not the only infrastructure that consumes energy in the datacenter. In reality, the cooling equipments consume equivalent amount of energy as the IT systems themselves. Ranganathan [9] suggests that for every dollar spent on electricity costs in large-scale datacenters, another dollar is spent on cooling.

As Cloud data centers are located in different geographical regions, they have different CO₂ emission rates and energy costs depending on regional constraints. Each datacenter is responsible for updating this information to Carbon Emission Directory for facilitating the energy-efficient scheduling. A green initiative in datacenter designs and other automation processes will facilitate environmental sustainability.

Table 1: Percent of Power Consumption by Each Datacenter Device [7].

<table>
<thead>
<tr>
<th>Datacenter Devices</th>
<th>Percent of Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling devices (Chiller, Computer Room Air Conditioning (CRAC))</td>
<td>33% +9%</td>
</tr>
<tr>
<td>IT Equipment</td>
<td>30%</td>
</tr>
<tr>
<td>Electrical Equipments (UPS, Power Distribution Units (PDUs), lighting)</td>
<td>28%</td>
</tr>
</tbody>
</table>

The swift network DataCenter architecture (DCN) shown in fig 6a and UNN DCN in fig 6b both lacks the functionality of a green design.

The limitations of existing IT/Automation Architectures are that they lack of green initiative in their architectural layout accounting for high energy consumption and also, most of the architectural implementations are highly capital intensive.

3.1 What is SmartGreen Architecture?
SmartGreen architecture is a special type of Supervisory Control and Data Acquisition (SCADA) as well as a process control system that enables a green analyst (site operator) to monitor and observe control processes that are distributed among various remote end devices as shown in fig 7. Since green computing is the study and practice of minimizing the environmental impact of computer system and related resources efficiently and eco-friendly, our proposed SmartGreen Architecture fits into this context.
Some of the major components of green computing include implementation of energy-efficient CPUs, server systems applications and peripherals. Furthermore, if green computing architecture should focus on reducing resource consumption as well as ensuring proper disposal of electronic wastage, green computing in the context of SmartGreen seeks to primarily reduce power usage, heat transmission, cooling needs of hardware devices, in particular processor chips using extensive hardware controls. Our system is configured to monitor temperature, humidity and other electronic waste parameters.

In this regard, a properly designed green system saves time and money by eliminating the need for service personnel to visit each end system for inspection, data collection/logging or make adjustments. The core of the SmartGreen SCADA are High Performance Computers, embedded application, USB Telosb RF devices/controllers, and interfaces that manage the control of automated IT/industrial processes and allow analysis of those systems through data collection. This system can be used in all types of industries, from electrical distribution systems, to food processing, to facility infrastructures to obtain accurate data for green studies. Next section will present our experimental characterization of our proposed SmartGreen architecture.

4. RESEARCH METHODOLOGY

In this work, our approach focused on the component identification and formulations. Afterwards, a testbed for the SmartGreen Architecture was developed.

4.1 Components of the SmartGreen SCADA system

The system is typically made of four components:

i. **SmartGreen Master Unit** - This is the heart of the system architecture and is centrally located under the operator's control. It is the dedicated server machine.

ii. **SmartGreen Remote Unit** - This unit is installed from where the end device process is actually monitored. It gathers required data about the end device process and sends it to the SmartGreen master unit.

iii. **Communication Mode** - This unit transmits signals/data between the SmartGreen master unit and the remote end device unit. Communication mode is basically via wireless media- RF.

iv. **SmartGreen Software** - This is the application interface on the server which sits between the operator and the end device units. It allows the operator to visualize and control the functions of the process and make predictions on the impact of the data state on the environment.

![SmartGreen System Model](image)

**Figure 7: SmartGreen System Model**
4.2 Description of the SmartGreen Configuration Environment

In this section, this work presents its study on the measured CC2420 radio model on end devices as well as its behaviour in the testbed sensing background. The measurement testbed is deployed in a Lab room of Process Control and Network Communication department (Kswitche Labs) which provides an indoor wireless environment for WSN infrastructure. To enable high-fidelity, fine-grained measurement of SmartGreen protocol behaviour in a large-lab setting, the testbed was designed as a two-tier architecture shown in figure 3.1. Each of the nodes is placed 20m apart from the end device. During the active state of the end devices, parameter data are collected by the server whose role is to compare the environmental impact with the required green thresholds. This deployment could consist of distributed servers designed for the purpose of complex data processing and powerful computing, and up to 500 sensor nodes placed on a 9x17 rectangular grid wooden benches with around 2 feet spacing.

Both the server and sensor nodes are the sub-controlled elements of testbed environment. TelosB mote used in this work is an open source platform designed to enable the application deployment for experimentation. The motes run TinyOS 2.1 integration which implements the networking stack and communication with sensors, and provides the programming environment for the platform. The SmartGreen application monitors and captures the required dataset used in this study. Figure 3.1 shows the system architecture for the measurement testbed. \( N_0 \) is the sink while \( N_1, \ldots, N_n \) are the basic sensor nodes attached to the end devices. When the threshold values of the end devices are exceeded, the SmartGreen protocol disengages such terminal to avoid further energy lost while ensuring excellent cost savings and environmental sustainability.

4.3 Data Collection Strategy

From the system model shown in fig 7 and the testbed architecture shown in fig 8, for the end devices which were configured as the sources and the server sink, the Received Signal Strength Indicator (RSSI) in dBm, the Average environmental humidity (RH), Average environmental Temperature (°C), Data rate, and Link Quality Indication (LQI) values were all measured against the end device distances in meters. Although the range of the TelosB node from their datasheet is 75-100m outdoor, at 70m the signal is no longer strong owing to The usage of wireless sensor network technology is ideal for this monitoring task as there are many advantages such as low cost, nonintrusive, can provide wide coverage and can be easily repurposed for other assignments.

Since Signal Strength is affected by weather, different weather conditions were considered such as windy days, bright sunny days and rainy days. In order to extract useful information from the raw measurement data, data processing is necessary which was resolved with different mathematical models.

5. DISCUSSIONS

5.1 Usage Of Wireless Sensor Network For Datacenter Process Regulations

Environmental control systems such as Ventilation Air Conditioning (VACs), IT/automation equipment (such as servers, networking devices), and PLC based systems, all consume electricity with no cost savings as well as leaving traces on the carbon footprint. The ratio of the total facility power consumption over the power used by the IT equipment is defined as the data center Power Usage Effectiveness (PUE). Because of the lack of visibility in the datacenter operating conditions, the PUE can be high.

Since, IT equipments need excessive cooling to operate reliably, therefore air condition systems in many DataCenter use very high fan speed to reduce the heat generated. Now, the datacenter’s complex air flow and thermodynamics, dense and real-time environmental monitoring systems are necessary to improve their energy efficiency. This can be helpful for its operators as it allows for intelligent troubleshooting decisions on rack layout and server deployments on facility management. Also dynamic server provisioning strategies play a major role in power consumption of datacenters for end device monitoring and control. That means it can turn on or shut down, if a sensing threshold is exceed or if a load fluctuation occurs. The usage of wireless sensor network technology is ideal for this monitoring task as there are many advantages such as low cost, nonintrusive, can provide wide coverage and can be easily repurposed for other assignments.
Wireless sensors do not require any additional network and facility infrastructure in an already complicated data center IT/automation environment. Compared to the sensors on motherboard, the external sensors are less sensitive to CPU or disk activities; therefore the collected data is less noisy and is easier to understand. The SmartGreen architecture and captured dataset leveraged on the potentiality of wireless sensor terminals for high fidelity data center environment monitoring.

5.2 Roadmap to Sustainable Green Computing
In this research, we strongly agree with the authors of [10] on the steps to green computing as discussed below:

- Develop a sustainable green computing plan: In any IT/automation industry, a good green computing framework should be factored into IT/automation design plan taking cognizance of the organizational policies and recycling checklists. We recommend the purchase of green compliant equipment which will address optimal power usage, and reduction of paper consumption

- Adopting a Systemic Recycling and Overhaul: At the interval of every 4 years, there should be complete discard of unusable and unwanted electronic equipment in a convenient and environmentally responsible manner. Computers have toxin metals and pollutants that can emit harmful emissions into the environment. This recycling should be carried out via manufacturer programs such as HP's Planet Partners recycling service or donate still-working computers to a non-profit organizations.

- Make environmentally sound purchase decisions: This will help institutional purchasers evaluate, compare and select desktop computers, notebooks and monitors, etc based on environmental attributes

- Reduce Paper Consumption: This could be achieved via: e-mail, electronic archiving, use of cloud services like Google docs feature in electronic documents, rather than paper based editing.

- Reduce Power Consumption: Conserve energy by turning off an IT/automation equipment when out of use for an extended period of time. In this regard, turn on power management features during shorter periods of inactivity. This Power management allows monitors and computers to enter low-power states when sitting idle. Power management tactics can save energy and help protect the environment. Corporate social and environmental performance, manufacturers must offer safe end-of-life management and recycling options when products become unusable.

Here the some of the techniques to power saving. By using Power Option in your Control Panel, power E can be saved. By turning off monitor this mode allows for turning off of the monitor, if the system is idle for more minutes. The use of LED, LCD monitors instead of CRTs it will reduce a lot of power, as such is recommended. By turning off the monitor, half of the energy used by the system could be saved. It is recommended to turn off the monitor when download in progress or when it is in idle for some minutes.

- Turn off hard disks: This mode allows you to turn off hard disks if it is idle. You can automate this and what we recommend is to set the turn off time to 30 minutes or to some other value depending upon your usage.

- System Standby / Sleep and Hibernation contribute to energy savings for green computing.

5.3 Benefits Of Green Computing IT/Automation
In this research, we have established that heightened focus on environmental concerns should prompt any IT/automation organizations to consider the benefits of adopting green technology which include [11]

- Cost
- Efficiency & Improved Performance
- Environmental Sustainability throughout the entire IT/automation lifecycle

6. RESULTS
The developed architecture enabled the generation of dataset for green investigations in fig 9, fig 10, fig 11, and fig 12. Figure 9 shows the SmartGreen Sink Captures for the sink datacenter. Here, all the threshold conditions are compared with the environmental realities. Shutdown routines are initiated in end devices as soon as the limits are exceeded. Figure 10 shows the SmartGreen Temperature Impact on the environment, while Fig 11 depicts the SmartGreen Humidity Impacts on the environment. In both plots, at the maximum thresholds of 34.5°C and 63.5 RH, respectively, the feedback shutdown processes is initiated in the SmartGreen DataCenter while ensuring stable energy consumption index. From fig 12, the battery capacity of a WSN determines to some extent how long a the device can function without depletion. To truly determine how long a WSN can go, one must have a model for typical sensor activity and a hardware profile for a specific device. In other words, it must be known at what rate power will be consumed. It is not well known how the battery capacity of WSN will evolve in the future as depletion is quiet insignificant with node distances and time. Advances in WSN battery technology are much slower than in other hardware components.
Therefore, WSN manufacturers are much more likely to design more power efficient nodes before incorporating a battery with a longer life. It is interesting to note, however, that, as shown in Figure 12, the battery capacity of WSN is as predictable as components in silicon technology. At about 2.82v (max) for a 3.3v device, our green conditions engages some feedback processes to ensure sustainability. At this thresholds, control regulations becomes proportional with increase in the device distances.

Figure 9: SmartGreen Sink Captures

Figure 10: SmartGreen Temperature Impact

Figure 11: SmartGreen Humidity Impacts

Figure 12: SmartGreen Energy Dissipation thresholds
7. CONCLUSION

In this paper, SmartGreen master-slave architecture for real-time data acquisition and logging is implemented for green process regulations in a test case DataCenter. Multiple embedded wireless sensor nodes were used for measuring various parameters. In industrial automation, such parameters can be used to monitor and control industrial process. Acquired data which display at each node are sent to master processor of the datacenter sink that compiles the acquired information and initiate a feedback routine control. The data acquisition process then displays the log into spreadsheet for the variations in quantity under measurement. In addition, the master processor of the datacenter processes this information and generates control signals based on predefined cases or can receive the controlling action from remote controller (WSN) to control the industrial application or end device computational processes. This work makes a novel contribution to green approach for data acquisition, continuous monitoring of process parameters, ease of implementation with reliable strategy to measuring, controlling and data logging demands of IT/automation industry. The effect of this monitoring is to save cost in energy consumption and ensure environmental sustainability.

REFERENCES