Enhancements of WSN Energy Consumption Reduction with Cloud Networks Integration

Abdellatif I. Moustafa, Shahad Y. Alzahrani, Reem M. Ganadily, and Majid M. Alotaibi

Abstract—**Wireless sensor networking is the emerging field of research which is responsible for the next-generation technology called Internet of things (IoT). Wireless sensor networks (WSNs) have many constraints, such as low power resources, limited data storage, and limited areas of access. On the other hand, Cloud Computing (CC) has solved many of these issues by providing data storage in the cloud and streaming that data. Integration of these technologies needs further study to investigate the energy consumption issues. In this paper, we dealt with this integration to improve WSNs with more energy savings and with an efficient subvention scheme through the cloud services. Various WSN configurations integrated with cloud networks through remote connections showed performance improvements in terms of energy consumption and WSN network lifetime.**

Index Terms—**Cloud computing, energy consumption, integration, WSN.**

I. Introduction

Wireless sensor networks (WSNs) have become a major trend in various industrial, environmental, and commercial fields. WSNs contain spatially distributed, self-regulated sensors that together monitor and control environmental and spatial conditions like temperature, sound, vibration, pollution, *etc*. The amount of data in a sensor network is huge, heterogeneous, and multidimensional in nature in which storing processing these data needs big storage area as well as. To store and process these data, high amounts of storage and computation energy are required. A WSN has its own design and resource constraints that are unlike those of traditional networks, which have a limited amount of energy, short communication range, low bandwidth, and the limited processing energy and storage space in each sensor node. Design constraints are application-dependent and are based on the monitored environment [1].

Cloud Computing (CC) permits companies to quickly increase the capacity without the need for new infrastructure investment. Similarly, companies can decrease capacity quickly and efficiently. Recently, IBM stated that the "Cloud is a new consumption and delivery model for many internet technology IT-based services, in which the user sees only the service, and has no need to know anything about the technology or implementation" [2].

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According to the US National Institute of Standards and Technology (NIST) CC is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources [2]. With pools of computing power, network, information, storage resources, the cloud offers the use of a collection of services, applications, information, and infrastructure. CC components can be rapidly orchestrated, provisioned, implemented, decommissioned, and scaled up/down, providing an on-demand utility-like model of allocations and consumption [2]. On-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service are five essential characteristics of CC depicted by NIST [2].

The integration of WSNs and CC can help to uncover the solutions for unsolved problems by allowing WSN nodes to send data remotely to be stored and analyzed for selecting the best use for that data when needed. However, at the same time, we encounter many constraints in WSNs when the integrating with CC is arranged such as storage capacity, limited power and quite small coverage area.

In this study, we focused on the WSNs energy consumption and investigated how the integration with CC could improve the energy savings as reducing the processing time and storage area reductions.

The rest of the paper is organized as follows: Section two presents the literature review. Section three outlines the discussion based on the problem and the tools used in the research. Section four displays and discusses the performance evaluation and numeric results. Finally, section five concludes the paper.

II. Related Work

The study of WSNs is a vast and interesting field of more research. Many scholars have found a tremendous potential for WSNs in fields like as health monitoring, transportation, disaster prevention, and industrial automation, in which, WSNs have the potential to make these fields more efficient.

In the last decade, much research has been done to improve WSN architecture and allow the nodes to be able to work on lower power sources for long periods of time. A. Pasha [3] proposes the notion of micro-tasking and highlights the architecture of a WSN node based on micro-tasking. WSN applications being event-driven in nature can be represented as task flow graphs (TFGs) where a task's execution is triggered by events, be they external or generated by another task.

Chang *et al.* [4] measured the power consumption of different encryption algorithms in Mica2. They created an application that encrypts a message and sends it. The resulting power consumption is obtained by adding the

CPU's power consumption while executing the algorithm and the power consumption due to the message transmission.

Dâmaso *et al.* [5] also investigated the power consumption of WSNs. The authors proposed a Coloured Petri Nets (CPNs) model, consisting of a set of CPN models that represent the power consumption of nesC operators, that are assembled together to model the power consumption of the entire application. Necessary in this strategy is the evolution and implementation of the nesc2cpn translator that is responsible for both generating the CPN models and evaluating their power consumption by cooperating with the CPN tools.

Lajara *et al.* [6] used the same measuring technique but concentrated on comparing the power consumption of WSNs' operating systems (e.g., TinyOS, Contiki and others). In order to perform the comparison between motes, two motes were used (Tmote Sky and MICAz) with four different applications representing common tasks (e.g., read temperature and send the value).

Hiltunen *et al.* [1] evaluated the performance and power consumption of the POBICOS middleware through measurement in Imote2. In specific, their objective was to show the influence of the middleware on the performance and power consumption of WSNs.

III. Discussion of the Problem and Proposed Approach

As aforementioned, WSNs have limited power resources to govern the use of the nodes for performing tasks and manipulating the energy consumption needs to be very efficient in nature. Our approach in this article is how to save the WSN nodes' energy by moving as much as possible data processing and storage into the cloud instead of WSN nodes, and we focus on the side of sender's node. To better understand this scenario, Fig. 1 illustrates that.

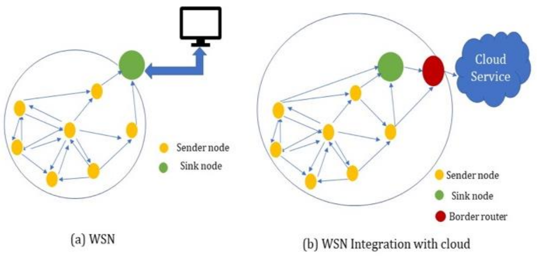

Fig. 1. WSN and WSN-Integrate with cloud.

In order to run the investigate that, simulation of the case studies is achieved in terms of the WSNs power constraints in which Contiki OS had been used with Cooja. Contiki OS, a portable and lightweight operating system designed for constrained environments like typical sensor nodes. Some features of Contiki are adopted to support for TCP/IP and pre-emptive multithreading on a per-process basis. Cooja is Contiki OS application use common programming language include C and Java and comes with an informative (educated) graphical user interface that interfaces the preferable way to interact and analyze the node's behavior which help us to perform our experiments after adoptions we had to add. Several scenarios were simulated for various environments for the WSN nodes to mimic real environments for the sake of performance evaluation. Experiments for different types of sensor nodes available as a real environment such as temperature, sound, and motion detection. Client-server connection with IPv6 is been used connections that counts the bit transfer from client to server and creates a cloud computing environment with the WSN nodes.

IV. Performance Evaluation and Numeric Results

In this section the experimental measurements are presented for many scenarios which includes WSNs of 5 to 100 nodes as senders, with/without CC integration (i.e. the same WSNs without CC are executed and results are obtained and integrated the same network with cloud computing network and re-executed again), for different lengths of time, ranges between 60 min to 150 min.

WSNs were included two different type of nodes: a 1-node with Routing Protocol for Low-Power and Lossy Networks (RPL) node as a sink and multiple-node RPL network nodes as senders. All nodes, senders and sinks, are using User Data Protocol (UDP) for to information exchange as packets in a radio environment (UDGM).

TABLE I: Simulation Parameters

Parameters	Values
Execution time	60 min to 150 min
Numbers of nodes	5 to 100
Number of sinks	1
process of nodes	UDP Sink, UDP sender, and RPL border router
Radio medium	Unit Disk Graph Medium (UDGM): Distance loss
Mote startup delay	1,000 ms
Network router	Routing Protocol for Low-Power and Lossy Networks (RPL)
Transport router	User Data Protocol (UDP)
Mote type	Virtual Sky mote
Network Topology (Deployed)	Random placed node (mesh)
Matrices	Number of nodes, times and power consumption

Table I shows the simulation parameters for testing. Multiple scenarios were performed, with each testing for particular duration and number of motes, which type is sky mote for sensing temperature, humidity and light sensors. The topologies used in the transmission parameters are also listed above for both, WSN and WSN with CC integration.

WSN-integrated are handled in which the network includes the same WSN with adding one node at the border to work as a router for cloud connection. Many runs using the simulation came up with the following observations: the communication between nodes in every network is tracked to analyze their influence on the total and average power consumption of the WSN and WSN-integrated networks.

For the total and average power calculations of the entire network, we used the remain power for every node to calculate the power consumption with the assumption that at the starting of the run each node was charged with battery level. Then according to the following equation, the remaining power in every node:

$$Power_{(id=i)} = P_{(CPU)_i} + P_{(LMP)_i} + P_{(L)_i} + P_{(T)_i} \tag{1}$$

where P_{CPU} is the *CPU* power of nodes, *LMP* is Low Power Mode, *L* is the power of listen, *T* is the sensor power for transmit, *i* is the number of identifications for node and *n* is the number of nodes in network. The network never in mode (LMP) and (CPU) at the same time, but the sum of power of these elements are the total power of the system. So, the power consumptions were obtained, and the total remaining power (P_{t-r}) for whole network is given by

$$P_{t-r} = \sum_{i=1}^{n} power_i \quad (2)$$

The prediction of the total power consumption (P_{t-cons}) for whole network can be obtained from (2) and total basic power ($P_{t-basic}$) for whole nodes in network:

$$P_{t-cons} = P_{t-basic} - P_{t-r} \quad (3)$$

TABLE II: EVALUATION PARAMETERS: NUMBER OF NODES, EXECUTION TIME, TOTAL AND AVERAGE POWER CONSUMPTION

Number of nodes	Execution time	Total power consumption (mW)		Average power consumption (mW)	
		WSN	WSN-Integ.	WSN	WSN-Integ.
5 nodes	60 min	9.339	9.324	1.8678	1.8648
	90 min	9.362	9.357	1.8724	1.8714
	120 min	9.376	9.373	1.8752	1.8746
	150 min	9.384	9.378	1.8768	1.8756
10 nodes	60 min	26.124	26.09	2.6124	2.609
	90 min	26.181	26.146	2.6181	2.6146
	120 min	26.205	26.174	2.6205	2.6174
	150 min	26.234	26.204	2.6234	2.6204
15 nodes	60 min	35.938	35.3	2.395867	2.353333
	90 min	36.028	35.585	2.401867	2.372333
	120 min	36.074	35.71	2.404933	2.380667
	150 min	36.114	35.792	2.4076	2.3861333
20 nodes	60 min	44.114	42.56	2.2057	2.128
	90 min	44.274	43.297	2.2137	2.16485
	120 min	44.374	43.628	2.2187	2.1814
	150 min	44.436	43.836	2.2218	2.1918
30 nodes	60 min	68.235	67.699	2.2745	2.256633
	90 min	68.523	68.257	2.2841	2.275233
	120 min	68.675	68.561	2.289167	2.285367
	150 min	68.762	68.761	2.292067	2.292033
50 nodes	60 min	93.068	61.519	1.86136	1.23038
	90 min	94.03	63.035	1.8806	1.2607
	120 min	94.457	63.718	1.88914	1.27436
	150 min	94.768	73.554	1.89536	1.47108
100 nodes	60 min	163.351	29.905	1.63351	0.29905
	90 min	166.321	38.217	1.66321	0.38217
	120 min	167.967	41.634	1.67967	0.41634
	150 min	168.524	41.724	1.68524	0.41724

The numerical results for evaluating and the total power consumption of all nodes in the WSN compared with WSN-integrated networks is shown in Table II. One can see that, the relationship between the total power consumption as well as the execution time for different number of nodes and how they affect the WSN and WSN-integrated networks.

A. Total Power Consumption

The total power consumption is analyzed with every node in the network. Many scenarios are examined in terms of the number of WSN nodes (ranged from 5 to 100 nodes) under different execution durations (ranged from 60 to 150 min). The numerical results are shown in Fig. 2 and Fig. 3.

For better comparisons, we evaluate each scenario in three-time intervals (60, 90, 120, and 150 min). The results showed that the WSN's power consumption was lowered when the cloud computing networks are integrated. For instance, in Fig. 2, which illustrates 50 nodes, after around the 90 min of execution time, the total power consumption of nodes in the WSN was 94.03 mW, on the hand, the WSN-integrated network after the same duration consumes 63.035 mW, means that the latter network consumes less total power.

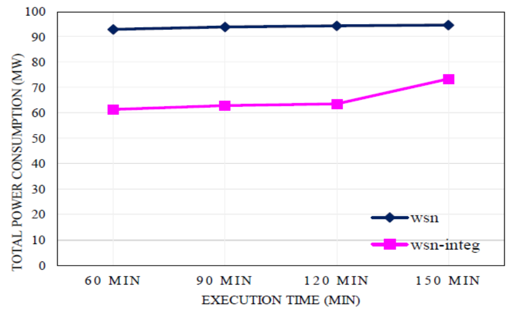

Fig. 2. WSN and WSN-integration total power consumption for 50 nodes after different times.

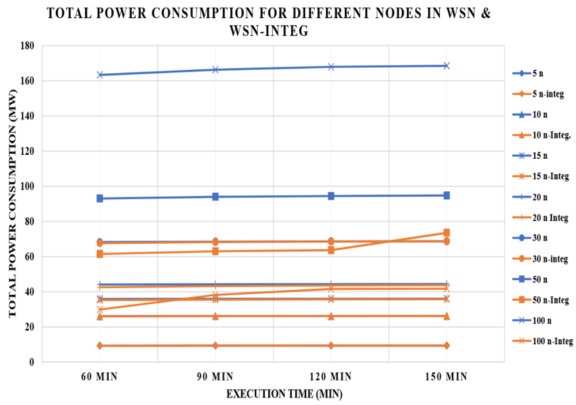

Fig. 3. Total power consumption in WSN and WSN-integration for different number of nodes.

In Fig. 3, the graph represents the total power consumption for nodes ranged from 5 to100 nodes over execution durations ranged from 60 min to 150 min for both of the WSN and WSN-integrated networks. When we increased the number of nodes, it is observed that the WSN-integrated network consumes less power than the WSN within most of time durations. It makes an evident of great achievements on reduction of the total power consumption. Therefore, integration of WSN with the CC reduces the nodes' power consumption as the whole networks' lifetime enhancement.

B. Average Power Consumption

Table II also contains the comparison of the numerical results of the average power consumption evaluation (P_{a-cons}) for both, all nodes in the WSN and also for WSN-integrated networks. It can be obtained using the following equation:

$$P_{a-cons} = P_{t-cons}/n \quad (4)$$

The column which has the number of nodes shows the different scenarios that been examined. It is ranged from 5 nodes and increased to 100 nodes with associated execution time in which the nodes are exchanging information packets. One can see that a lot of power has been saved with the cloud computing integration.

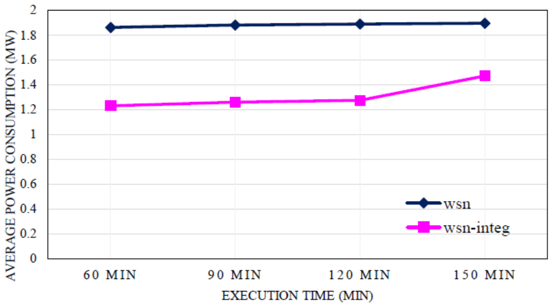

Fig. 4. WSN and WSN-integration average power consumption for 50 nodes after different times.

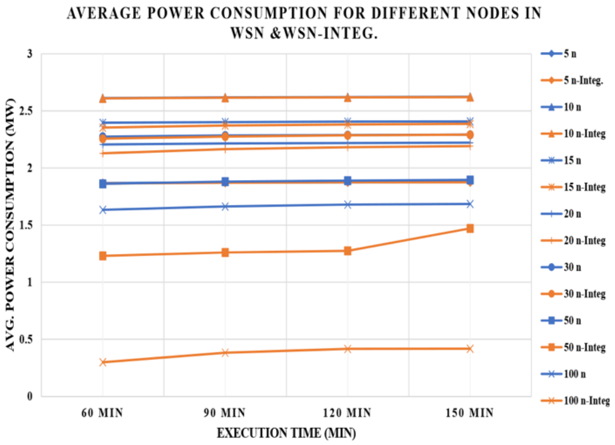

Fig. 5. Average power consumption in WSN and WSN-integration. for different number of nodes.

Fig. 5illustrates the average power consumption for different nodes over different execution periods of times. It is clear that the WSN-integrated outperforms the regular wireless sensor networks in terms of power consumption and execution time which have a great effect on the whole networks' lifetimes. For instance, Fig. 4 with 50 nodes the regular WSN at 60 min consumed 1.86136 mW but the WSN-integrated network consumed 1.23038 mW. This means the power consumption of the WSN-integrated network was 34% lower than the power consumption of the WSN after that time.

Modifying the WSN with cloud integration has a great impact on the nodes' average power consumption. When increasing the number of nodes, one can see more of a decrease in the average power consumption with WSN-integrated networks than with a regular WSN. This shows that integrating with the cloud is a more efficient way to use WSNs for long periods of time.

As a wide view of comparison, we analyzed the total power consumption calculated for the WSN and WSN-integrated networks for different numbers of nodes and observed it over many execution periods of times. We summarized the results as shown in Table II. It is emphasizing that the total power consumption of WSN-integrated networks is lower than regular WSNs with 5 to 100 nodes for different periods of time from 60 min to150 min. Fig. 6, shows the difference between regular WSNs and WSN-integrated networks in power consumption for different numbers of nodes and different times. In regular WSNs the power consumption per node is high; this means the sensor nodes consume more power than the WSN-integrated network per sensor node. Furthermore, the power consumption of the sensor node presented in this work can be compared with the WSN-integrated network to display power savings, as shown in the chart in Fig. 7.

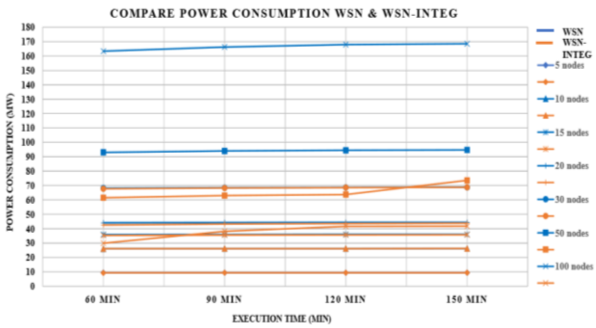

Fig. 6. The differences between WSN and WSN-integration in the total power consumption.

Fig. 7. Amount of saved power.

TABLE III: AMOUNT OF SAVED POWER

Exec. time	5 nodes	10 nodes	15 nodes	20 nodes	30 nodes	50 nodes	100 nodes
60 min	0.015	0.034	0.638	1.554	0.536	31.549	133.446
90 min	0.005	0.035	0.443	0.977	0.266	30.995	128.104
120 min	0.003	0.031	0.364	0.746	0.114	30.739	126.333
150 min	0.006	0.03	0.322	0.6	0.001	21.214	126.8

This means the power consumption of a WSN can be reduced significantly with cloud integration. This again would increase the lifetime of the WSN, which is useful for assessing the performance of the WSN.

Table III summarize the amount of power we can save in networks using cloud integration in comparison to a regular WSN. This results from lower power consumption through the transmission of data between nodes over different execution period of times.

V. Conclusion

Wireless sensor networks (WSNs) have many constraints, such as low power resources, limited data storage, and limited areas of access. On the other hand, Cloud Computing (CC) has solved many of these issues by providing data storage in the cloud and streaming that data. Integration of these technologies had been studied for investigating the energy consumption as an important performance metrics. We have analyzed and evaluated many scenarios, from which we can conclude that power consumption can be saved when WSNs are integrated with cloud computing. We also observed that a greater number of nodes means greater power savings, leading to more efficient use of WSN sensors.

Future studies could consider more environments for node power consumption and make use of longer time frames. Also evaluate the delay, throughput and many traffic issues that could be affected with such integration.

We believe that cloud integration of WSNs could be a good solution for many WSN short comes if it is applied perfectly.

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