Power-aware Server Selection in Nano Data Center

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***Abstract*—Optimizing the total power consumption within a data center is an NP-hard problem. Project nano data center was started with the promise of reducing power and cooling cost. This paper is focused on reducing the total power consumption within a nano data center by introducing power-aware server selection. We studied effects of several attributes such as power consumption of servers, size of request, and power consumed by routers, in reducing overall power within a nano-data center. Inspired by our study, we introduced two heuristics for the selection of nano servers as well as intermediate routers. Our heuristics are based on selecting the shortest path with respect to number of intermediate routers and using the least recently used server to serve a request. Through GNS-3 based experiments, we confirmed that our proposed heuristics reduce the overall power consumption in a data center while avoiding the time complexity of the optimal solution.**

***Index Terms*—nano data center, power management, green computing, power consumption**

I. Introduction

Electricity usage associated with global servers and data centers grew significantly from 2000 onwards. As of 2014, the electricity usage for servers and data centers attribute to 4.6 % of the worlds total power consumption [1]. This usage has grown more than twice since 2000. If cost of power generation and cooling are included then this amounts to a major consideration of worlds IT resources. Cost of energy consumption of a data center includes the power consumed by the servers and interconnects cooling infrastructure [2]. As the size of a data center increases, the cost of overall energy consumption and the associated requirements for its cooling also increases. This work is motivated from the idea of greening the internet, it is estimated that in a typical data center energy cost doubles every five years [3].

A. Nano data center project

Nano data center [4][5] [6] is a European Union research program as part of the Seventh Framework Program that was started in May 2008. The nano data center project was proposed with an aim to conserve energy. It is inspired by the micro data center project; however, we anticipate that the size of the nano data center is smaller [7] [8]. The architecture of a nano data center consists of network edge devices (also referred as nano servers) and intermediate routers. The nano servers may be set top boxes, home gateways, computers or servers. It is expected that due to their smaller size and simplified networking infrastructure, these nano servers can reduce the power consumption and decrease the cooling cost, while meeting the service requirements associated with a cloud. Nano data centers are coordinated and managed by an Internet Service Provider (ISP). In that, the ISP manages the gateways/servers that act as nano servers and the network that interconnects them. The key idea behind nano data centers is to create a distributed service platform based on tiny managed servers located at the edges of the network.

B. Nano server selection

Nano data centers are used for content delivery services. At an instance of a users request, the ISP has to select one of the available nano servers that can serve the request, efficiently. This requires formation of an efficient scheme which can be used to select the data center according to the criteria of efficiency. One of the foremost criteria for the selection is to reduce power consumption - the ultimate goal which motivates the need for nano data centers. However, reducing the power consumption is not trivial as the total power of a nano data center could depend upon multiple factors, such as processor utilization of the nano server, power of the intermediate router, and size of the request. In a data center, minimizing the total power of the nano data center is known to be an NP-hard problem [9]. This research has been motivated by the above mentioned challenge. It has two major goals:

1) To identify factors which effect the power consumption in a nano data center, and
2) To determine an efficient scheme for reduction of overall power consumption in a nano data center.

In order to provide solutions for these goals, we conducted extensive experiments. Using GNS-3-based simulator [10] and Microsoft Joulemeter [11] , we identified that power utilization in a nano data center is dependent on a number of factors that include the size of the file being served, the number of intermediate routers connecting the nano server, and the number of files being served by the nano server at a time. We also observed that finding an optimal solution such that the selected nano server leads to minimal power utilization, is an NP-hard problem [9].

Motivated by the need to reduce the overall power, we proposed two heuristics based schemes that can be used to select an appropriate nano server. Our first heuristic is based on selecting the nano server that is expected to fulfill a users request in shortest path or least number of intermediate routers and our second heuristic is concentrated on selecting the data center which has least recently been accessed to serve a request.

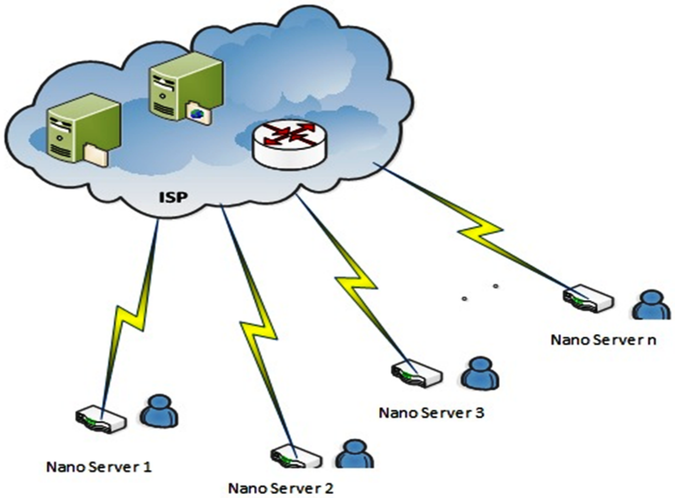

Fig. 1. Nano Data Center Architecture

We observed that our heuristic based approach is effective in reducing the cost of the computation, while achieving an efficient solution for the problem. In summary, our contribution in this paper is as follows:

- We identified relevant factors that affect the power consumption in a nano data center environment.
- We propose heuristic-based approaches for efficient selection of nano data centers.
- We performed extensive evaluation in order to validate our proposed heuristics approaches.

Nano data center is the next step in the field of cloud computing, which is more efficient when it comes to low energy consumption and overall data center cost reduction [12]. This research will be beneficial in managing power, CPU and memory loads amongst nano data centers. It also highlights the efficient use of underutilized devices. Further, our research is beneficial for power-ware server selection schemes in a non-virtualized environment and selection of Content Distribution Network (CDN) [7] [13].

II. Background and Related Work

. Nano data centers have been proposed as a low cost solution that incorporates reduced requirements of cooling devices and localization that reduces distance from the end users and decreases network delays. The architecture of a typical nano data center is illustrated in Fig. 1, where n nano servers are being hosted by an ISP. Based on a users request, the ISP can select a nano server from any of the available servers.

Considering the broad spectrum of power efficiency in data centers, we divide the related work in four broad categories and highlight the novelty of our work.

A. Green IT

As power requirements for hardware and software in data centers grow, intelligent power management techniques are required. Subsequently, analytical modeling of power and energy consumption is becoming more significant. This is a challenge to model power, performance, and management techniques that can give benefits to different power modes, load distributions and power trends of different components [14] [3]. The total electrical energy consumption by servers, computers, monitors, data communications equipment, and cooling systems for data centers is steadily increasing [15]. Our work is significant in the overall context of power reduction.

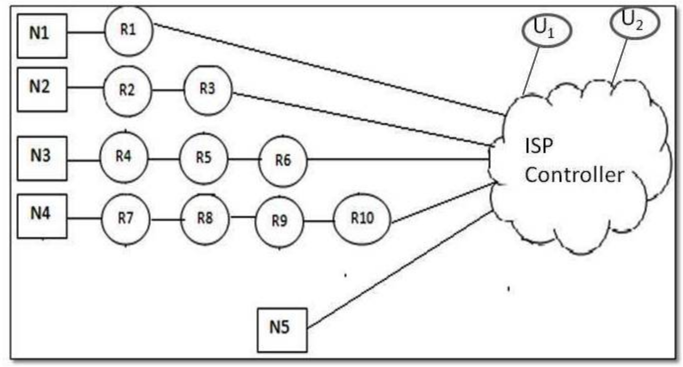

Fig. 2. Experimental Setup

B. Power issues with data centers

Some major limitations of classical data centers are highlighted in prior research projects that are related to over provisioning, high cost of heat dissipation, and high latency from the end users which increases the network infrastructures cost [2] [16]. To shun this increase in data center power consumption, studies have been conducted about the data center architecture. To match the peak demands of users; data centers are over-provisioned. Further, classical data centers are centralized and offer high distance between data centers and the users [4][17]. Both these challenges lead to high cost encountered by data centers. In our research, we are motivated by power efficiency of nano data centers. Our research is focused on improving this efficiency by carefully selecting nano servers.

C. Power aware scheduling algorithms

Duy et al. proposed a scheduling algorithm which integrates neural network based approach which optimizes server power consumption by shutting down underutilized servers [18]. The overhead incurred in doing neural network computation is expensive hence the power optimization comes at the cost of extra computation.

Chen et al. have proposed a holistic workload scheduling which considers green energy availability, cooling power and fine grained scheduling [19]. In this work, the authors have not performed evaluations of the proposed mechanism.

Barrel et al. introduced a machine learning based approach of scheduling to improve the energy consumption in data centers [20]. In this work, the authors have not evaluated the correctness of the proposed machine learning approach to conserve energy. Similarly, Gao and his co-authors optimized the flow in the network to improve the energy efficiency of the data centers [21].

In summary, most of the previous work done in this area emphasizes on the optimization of energy in the data centers by proposing scheduling algorithms. The algorithms also adopt techniques and methods from machine learning to improve the energy consumption of the data centers. None of the work have considered Nano data center as an option to reduce power consumption in a data center.

D. Power aware computing

Elastic tree [22] is an approach that manages data center powered by monitoring data center traffic. It powers down the unused network components and active devices are selected on the basis of various models that are defined in their research e.g.: formal model, greedy bin-packer, topology-aware heuristic, and prediction methods. Based on the network topology, traffic matrix, a power model for each switches and fault tolerance properties; the set of active components is evaluated, so that the unused components can be powered off. Greencloud [23] is another power saving model, the idea enables live monitoring, virtual machine migration and VM placement scheme. It saves around 30% energy than normal virtual machine migration. Live monitoring is conducted on all the physical machines, and based on the physical machines parameters the virtual machines are migrated. Energy aware routing model [9] was also proposed that claims to saves 20-80% energy. Data furnace is closely related to the idea of nano data center architecture [24]. Its micro data center approach use the home broadband network to connect to the cloud. These micro data centers are integrated in the home heating system. Thus data furnace reduces the cost per server in comparison to conventional data centers by leveraging the homes existing infrastructure [2]. In our research, we are inspired by the significance of power-aware computing. Specifically, our focus is to propose effective server selection scheme for servers in a nano data center. However, our work can also be applied on other frameworks, such as Content Distribution Networks (CDN), which utilizes server selection for effective operations.

III. Power-aware server selection

We now explain the problem of minimizing the overall power consumption in a nano data center.

A. Problem Statement

In a nano data center, there is an ISP controller which directs a users request to appropriate nano server through the intermediate routers. Fig. 2 illustrates a scenario where five nano servers and 10 routers are shown. The figure shows two users send their requests to an ISP. It is desired that the ISP selects the server which minimizes the overall power of the data center. Since the ISP controls the intermediate routers within the data center, it can select intermediate routers and nano servers that can minimize the overall power consumed in a data center.

Files are considered as requests to the ISP for any application on the nano data center. For a given request r, the power of the nano data center can be described as follows:

$$P_{request} = P_n + P_D \tag{1}$$

where P_n = Power of the nano server and P_D denotes power of the path used.

For the minimum power problem, the goal is to minimize $P_{request}$ for all the requests being served by an ISP.

B. Related attributes for power consumption

We conducted some initial experiments to determine attributes that are related to power consumption. Our goal was to determine related attributes which contribute to Pn and PD . For this purpose, ten virtual machines were dedicated as intermediate routers and five virtual machines were used as nano servers, to conduct the experiments. Using Graphical Network Simulator-GNS3 [10], routers were configured and connected to the nano servers. Microsoft Joulemeter[11] was used to monitor power at each node as well as at intermediate routers. A script was used to monitor the processor utilization value at each node.

We initially selected following parameters in order to determine relevance for power consumption:

1) Processor utilization percentage of the nano server
2) Size of the request.
3) Power consumed by an intermediate router P_R.
4) Power consumed by the nano server P_n). This include components for static (power in the idle state) as well as dynamic (power under load) power.

For relevance, we directed a number of user requests, to one of the available five nano servers and computed their relationship in determining power consumption.

We observed that for a given request with size i, with size S_i, the power consumed in the three parameters i.e., C_n, P_n, and P_R are all related to power consumption to serve the request. We also observed that while processor utilization is not related to file size, it contributes to the total power consumed to serve the request such that servers with high process utilization are expected to take longer to serve a request and are also anticipated to consume more power. While the results of our initial experiments are explained in section V - the evaluation section, the results conclude that all the four parameters are important and related to power consumption.

C. Optimal Nano Server Selection Scheme

For a given set of n nano servers and m total routers in a data center, the total power of a data center is equivalent to the sum of power consumption of all nano servers and power of all the intermediate routers. The problem of minimum power consumption in a nano data center is equivalent to finding minimum power consumption through all the available nano servers and their relevant paths.

1) **If** there are multiple nano servers, and there are routers with no load then
select any of the available routers such that they accumulate to shortest path for the request

2) **else** compute and select shortest path with minimum number of routers.
If multiple nano servers are found with multiple shortest paths of intermediate routers; select the router with based on the number of requests served by the adjacent router(s) of the corresponding nano servers.

Fig. 3. Heuristic Approach for Minimum Expected Time

Given m no of routers, total paths would be given as 2^m We define our objective function for the minimum total power consumption of the data center. For j number of intermediate routers in a specific path, power in a nano data center is equivalent to

$$P_{ND} = min[(k \sum_{i=1}^{j} P_R) + P_n] \tag{2}$$

where $i = 1, 2, ..j$ and $k \leq 2^m$ for a given nano server P_n and P_R is used to consider power consumed by all the intermediate routers. In our case, the time complexity will be $O(2^m)$ which is a NP-hard problem. Yunfei et al. have proved this to be an NP-hard problem and our goal is to derive a heuristic based efficient solution [9].

IV. Heuristics based nano server selection

Since the selection of the nano server with minimal power has proven to be an NP-hard problem, heuristics are needed to propose an efficient solution. Motivated by our initial experiments (described in Section III), we outlined following important parameters:

1) Power consumption of nano data centers, while serving a request.
2) Network power consumption, evaluated from the power consumed by the intermediate routers.
3) Estimated time to complete any users request.

While the effect of the first two attributes is obvious in computing the total power consumed in a nano data center, the third attribute, the time to serve a request, impacts the total power indirectly. We propose two heuristics, which are aimed to reduce total power while incorporating the above mentioned considerations. For the proposed heuristics, we make following assumptions:

1) Each router in idle state, i.e., when a router is not serving any request, will contribute to cost = 0.
2) Each router in use will contribute to cost = 1.
3) We are using shortest path algorithm to support our method.

We now explain the two heuristics in detail:

1) **If** there is a path with no file being transferring through it then select it.
if multiple nano servers are found with no load routers, select the one shortest path to the user.
if multiple nano servers are found with free shortest path, select any nano server

2) **else if** the paths to all nano servers are in use, i.e. already serving a request, select nano server which evaluates maximum time since the start of the last request being served.
if multiple nano servers are found that gives maximum time since the previous request start, select nano server with shortest path to the user.
if multiple nano servers are found minimum time to complete downloading request and with shortest path; select any nano data center.

Fig. 4. Heuristic Based Approach for least recently used

1) Shortest Path or least number of routers: Our first heuristic is motivated to select the nano server which can fulfill the request in the minimum expected time. ISP is receiving a set of requests; the controller admission tends to direct the request to the nano server that is expected to fulfill the request in the minimum expected time. The minimum expected time heuristic design will follow the steps outlined in fig. 3

2) Maximum Time Since last allocated request: The second heuristic is based on finding the nano server that has served the request least recently. The rationale is that nano server which are not serving any request are likely to be lightly loaded. As time to serve a request contributes to the total power consumption, which is eventually dependent on the load of the nano server. For this purpose, the controller tends to select the nano server which has least recently been used as earlier jobs are expected to be completed sooner. Fig 4 explains the algorithm.

In the next section, we describe the comparison of our schemes with the optimal scheme. While the complexity of the optimal solution is NP-hard, the complexity of the two proposed heuristics is equivalent to the complexity of the single source all pairs shortest path algorithm. For m intermediate nodes and e edges this is equivalent to $O(e + mlogm)$ [25].

V. Evaluation

Extensive experiments were conducted to derive relationships amongst the observed parameters. Our first goal was to determine related attributes for power consumption.

A. Results for determining attributes related to power consumption

While we have explained the summary of finding related attributes in section III, we describe these experiments in this section. A user requests a file from the ISP. At the ISPs end some parameters of every nano server are monitored continuously. These parameters include processor utilization,

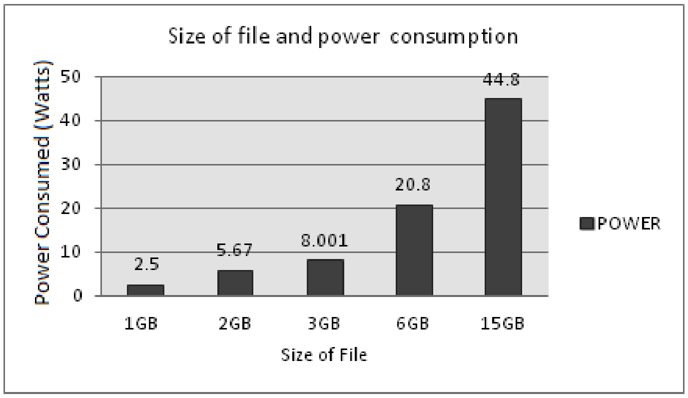

Fig. 5. Effect of size of request served and total power consumption

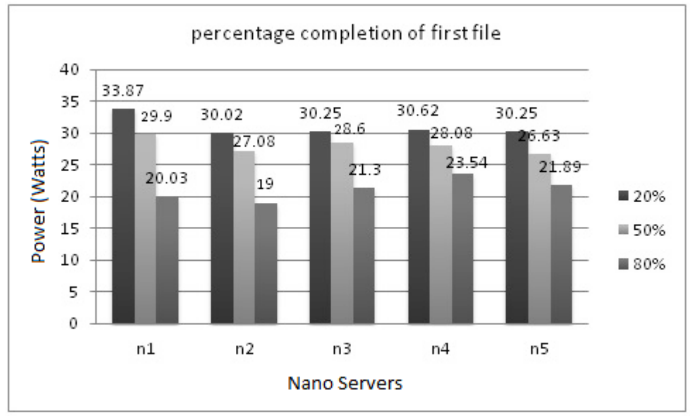

Fig. 6. Power consumption during a request transfer, while the nano data center is already serving another request

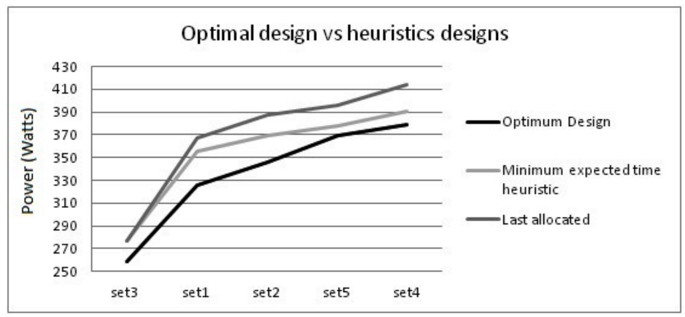

Fig. 7. comparing the power aware selection heuristics with optimal design power consumption comparison

power consumption, time to complete a file transfer, and size of file to be transferred. Depending on the percentage completion of first file the new request is directed to any data center.

1) Effect of file size on Power Consumption: As discussed earlier, we observed during our experiments that processor utilization is independent of file size. As a first step, our goal was to determine relationship between file size and power consumption. Fig. 5, shows that increasing file size results in increased in the total power consumption by the nano server. This device is serving the users requests of transferring files, of sizes ranging from 1 GB to 15 GB. It is observed that when the size of file increases the total power consumed by the nano server also increases.

2) Effect of serving multiple files: For the second experiment, we considered a set of five nano servers and two files (A & B) each of size 1GB. Next, file A was started to transfer to each device. We monitor total power consumption at devices when file B is also forwarded to the nano servers at different percentage completion of file A. It is observed that power consumption vary when file B has begun transferring at 20% completion of file A, as compared to when 80% completion of file A has been achieved. Fig. 6 shows the power consumption in watts during the transfer of 1 GB file. From our experiments, it was concluded that the total power consumption of host nano data center is dependent on the following parameters:

1) Size of request served
2) Time to transfer that request to the user.
3) Number of requests (CPU utilization) being shared at a time.

For above observations, it is evident that the power consumed is related to the number of bytes needed to be transferred. We also observed that CPU usage is not related to the size of file being transferred. These observations motivated us to design heuristic-based approached for power-aware selection.

We verified our observations by the proposed heuristic-based approach for power-aware server selection.

B. Comparison of Optimal and heuristic approaches

To evaluate the optimal and heuristics designs, a setup is configured with ten personal computers, and some virtual machines running on them. The nano data center architecture is designed on Graphical Network Simulator GNS3, where intermediate routers are connected to various virtual machines, power is observed and logged by Microsoft project Joulemeter, and CPU utilizations are also observed for all the systems. Experiments were conducted to achieve optimal power consumed by the nano data center for the topology defined in 2 and using the two heuristics introduced in the previous section. Some sets of requests of different sizes are designed, and theses requests are then directed to the configured topology. Table I elaborates on the different sets of requests used in this set of experiments. Each set has five different requests for files with varying sizes. The table also shows the time interval between the arrivals of these requests.

1) Power Consumption: To evaluate power aware nano server selection scheme the optimal design values of power consumption is compared with both heuristics presented. These power consumption values are monitored on every nano data center and all intermediate routers. Table II gives the comparison for the total power consumption of overall nano data center as compared to the total power consumed if the request is filled through the two heuristics. As shown in fig. 7,

TABLE I
DATASETS FOR REQUESTS OF DIFFERENT FILE SIZES

Dataset	File Size (MB)					Interval for requests (sec)
Set 1	700	1000	800	900	1500	10
Set 2	700	1000	800	900	1500	15
Set 3	700	1000	800	900	1500	5
Set 4	700	1000	800	900	1500	3
Set 5	700	1000	800	900	1500	7

TABLE II
POWER CONSUMED BY NANO DATA CENTER APPLYING OPTIMAL AND HEURISTICS SCHEMES

Set of Requests	Total optimal power (W)	Total power using heuristic 1 (W)	Total power using heuristic 2 (W)
Set 1	325.58	355.68	376.03
Set 2	345.7	387	369.13
Set 3	259.09	387	276.61
Set 4	378.67	413.75	391.2
Set 5	369.3	396.46	377.77

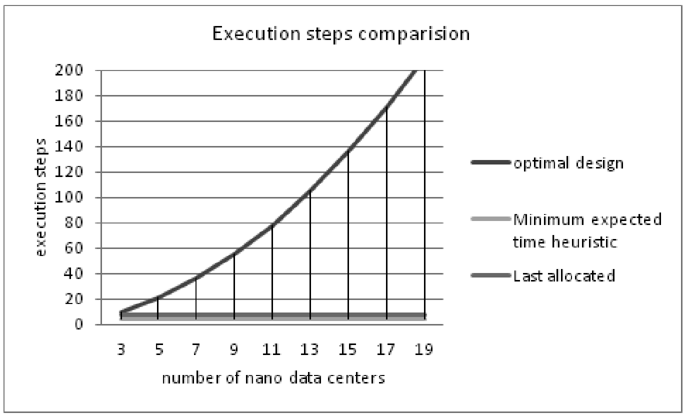

Fig. 8. Effect of size of request served and total power consumption

the power consumption values are compared for both the heuristic approaches and for the optimal design as well. They are plotted with respect to the request sets defined earlier, i.e. five requests were directed to three nano servers. By the above stated results, it is observed that the nano data center consumes near optimal power by minimum expected time heuristic. The selection scheme is based on the minimum expected time to complete the request. Last allocated heuristic design gives various trends of power consumption, since it considers the starting time of the request that is being currently served. However, it is seen that percentage completion of a request in the evaluated time varies as the size of request varies.

2) Cost: We compared the cost of power aware heuristic algorithms with the optimal model with respect to the execution steps to evaluate the favorable power consumption value. The experiments are conducted for three nano servers with distinct number of routers and a consistent set of five requests. For both optimal and power aware scheme, we have considered paths having up to three intermediate routers. Hence, the network power is also measured in both schemes. For the given set of nano servers with the given set of files on the said topology; it can be seen from the fig. 8 that as the number of nano servers and number of requests increase, execution steps to evaluate optimal power consumption value also increases exponentially; where as there is only one execution step to evaluate the near to optimal value of power consumption value of the nano data center configuration. The computation cost is hence reduced in power aware design; that leads to rapid computation. Our experiments confirm that the two heuristics effectively reduce the cost of computation while reducing the total power consumption. Over all our heuristic based approach contributed to only 5-10% more power than the power consumption by the optimal scheme. On the basis of time, our approach was much faster to be computed as the time to compute the solution was 20 times less than the time to compute the optimal solution.

VI. CONCLUSIONS AND FUTURE WORK

The requirements of data center power reduction solutions are immensely increasing with the drastic changes and upgradation in technologies. Nano data center project is one of the most promising projects that efficiently manage power requirements. Our study on power-aware nano data center selection is a novel scheme to select an efficient nano server that can serves users requests. This scheme does not only reduce total nano data center power but also make use of underutilized nano servers. Moreover, the work on network power has made this scheme unique from other research in the field of power management. Further, our proposed heuristics are also beneficial for power-aware server selection in a non-virtualized environment. For future, this work can be extended to incorporate shared hops or interlink paths. We also plan to evaluate replication scheme for the application files that are on nano data centers such that all files may not be available at all the nano servers. More research is required towards profound and cost effective monitoring schemes [26] so that ISPs can monitor their nano data centers. Online applications such as social networking and live financial applications can also be hosted on nano data centers architecture.

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