SEEDS

Solar Energy-based Embedded Distributed Server farm

Round 2 Report

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Executive Summary

Recent advances in information and network technologies make it possible to use a large number of computer systems to help people and to improve the overall productivities. These computer systems such as database, email servers, web servers, usually operate all day long, consume huge amount of energy, and seriously influence the environment of the Earth. For example, a 300-watt personal computer (PC) operating for a whole year produces 1.6 ton[1] carbon dioxide (chemical formula: CO_2), but on the other hand, a tree can merely absorb 18 kilograms of CO_2 per year. Obviously, to widely apply information technologies and PCs to handle daily operations and business in a company poses a monstrous threat on the Earth and the environment.

As one of the global villagers, we do believe that people should pay much more attention on the Earth's environment and consider the long-term development while they are using IT technologies for improving the efficiency and productivity. Therefore, we propose a concept called, SEEDS: **S**olar **E**nergy-based **E**mbedded **D**istributed **S**erver farm, which utilizes peer-to-peer technologies to construct a solar-powered, high-reliable, and high-available server farm for an enterprise. The proposed server farm not only significantly reduces the power consumption of IT servers but also offers high-reliable, and high-available IT services.

Solar energy is an eco-power source without generating CO_2. To use solar energy to operate a computer is not a new idea, but to enable a solar-powered computer operating for 24 hours a day and 365 a year is very challenging since the sun sets everyday and weather also influences the provision of solar power. Therefore, we deploy a number of small-size, solar-powered embedded systems all over the world and the server nodes are connected via Internet and form a SEEDS farm. In that way, we could have at least a portion of embedded system nodes that can receive sunlight, have solar energy and are active in operation. Based on this infrastructure, data and tasks are distributed and replicated among these nodes to ensure the availability and reliability of the SEEDS farm. A special P2P network among server nodes are designed in this project and server node joining/leaving/keep-alive procedures, solar power detection, data migration, data replication between server nodes are also developed. The SEEDS farm is particular useful for international chain stores such as McDonald, Starbucks or company such as Hilton and Microsoft which have offices or stores all over the world. The company can easily deploy such solar-powered embedded nodes in their offices all over the world. Server nodes can connect and form the SEEDS farm which provides high reliability and availability IT services. In this project, email service is used as an example to demonstrate concept of the proposed SEEDS farm.

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[1] 0.6083(Kg CO_2/kW·h) * 0.3(kW·h/hr) *24(hr/day)*365(day/year) = 1599 kg= 1.6 ton. The production of 0.6083 (Kg CO2) per (kW·h) is according to the *Carbon Dioxide Emissions from the Generation of Electric Power in the United States*, *P11*, Department of Energy and Environmental Protection Agency.

Situational Analysis

Problem Analysis

Computer systems are widely used today to improve the efficiency and productivity of daily life and work. A huge number of computers are operated all day long and consume a significant portion of the total energy generated in the world. The cost to power a computer is quite high, not only for the money spending on the electricity but also the amount of carbon dioxide (chemical formula: CO_2) produced in order to generate electricity. Table 1 gives an example. To operate a 500-watt server costs USD 574 per year and generates 2.8 tones CO_2 per year. Obviously, to widely apply information technologies and PCs to handle daily operations poses a monstrous threat on the Earth and the environment. Therefore, we propose a concept called, SEEDS: **S**olar **E**nergy-based **E**mbedded **D**istributed **S**erver farm, which utilizes peer-to-peer technologies to construct a solar-powered, high-reliable, and high-available server cluster for an enterprise.

Table 1. The cost to operate a server

Average amount of CO_2 produced by electricity generation in Taiwan	0.638 Kg CO_2/kilowatt-hour
Power consumption of a server	500 Watts
CO_2 generated in order to operate the server for a year	0.5 * 24 * 365 * 0.638 = 2794 Kg CO_2
Electricity cost per year to operate the server (Assumed NTD 4 per kilowatt-hour electricity)	0.5 * 24 * 365 * 4(NTD) = NTD 17,520 =USD 574

Project Analysis

This project, SEEDS: Solar Energy-based Embedded Distributed Server farm, aims to use solar energy to power the server cluster. Two critical issues need to be solved. First, it is difficult to develop a pure solar-powered and 500-watt server which requires a large solar panel and sufficient equivalent sun hours (ESH). To resolve the first issue, we use a number of small-size, embedded systems such as ebox which only consumes 30W to replace a server. To operate an ebox only needs a 60cm x 60cm solar panel. Second, it is very challenging to operate an embedded server node running 24 hours a day, 365 days a year since that the sun sets everyday and weather also influences the provision of solar power. In order to solve the second issue, we could deploy a number of embedded server nodes over the world so that we could have at least a portion of embedded server nodes having solar power at any given time. Then, the problem becomes how we could deploy the embedded server nodes and how they are working together to form a high-reliable, and high-available server cluster which provides non-stop IT services. The solar power is evaluated by using the equivalent sun hours (ESH). ESH differs from area to area. Figure 1 illustrates the ESH of the North America. Based on our calculation, for an area with ESH=5, a 60cm x 60 cm solar panel can support 30W ebox running for 7 hours. If we could install four ebox in different areas on the Earth, each area could have ESH=5, then, the server cluster with 4 ebox could provide virtually non-stop service from users' point of view.

The server nodes form a cluster and know each other. In the client side, a client maintains a list of server nodes. The client could connect to one of the server nodes and updates the latest active server nodes in this cluster from any active node. If the data is fully replicated between server nodes and If we could have a least one active server, and then the cluster could offer non-stop IT service. Obviously, to fully replicate the data consume extra resources and storage and may not be a good design, we will describe our design in detail in the next sections. If the area that the SEEDS node deployed does not have enough sunlight, then alternative energy sources such as wind power can be used. Generally speaking, the proposed SEEDS farm is a world-wide distributed embedded server cluster, designed to reduce electricity usage and also maintains the stability and reliability of services.

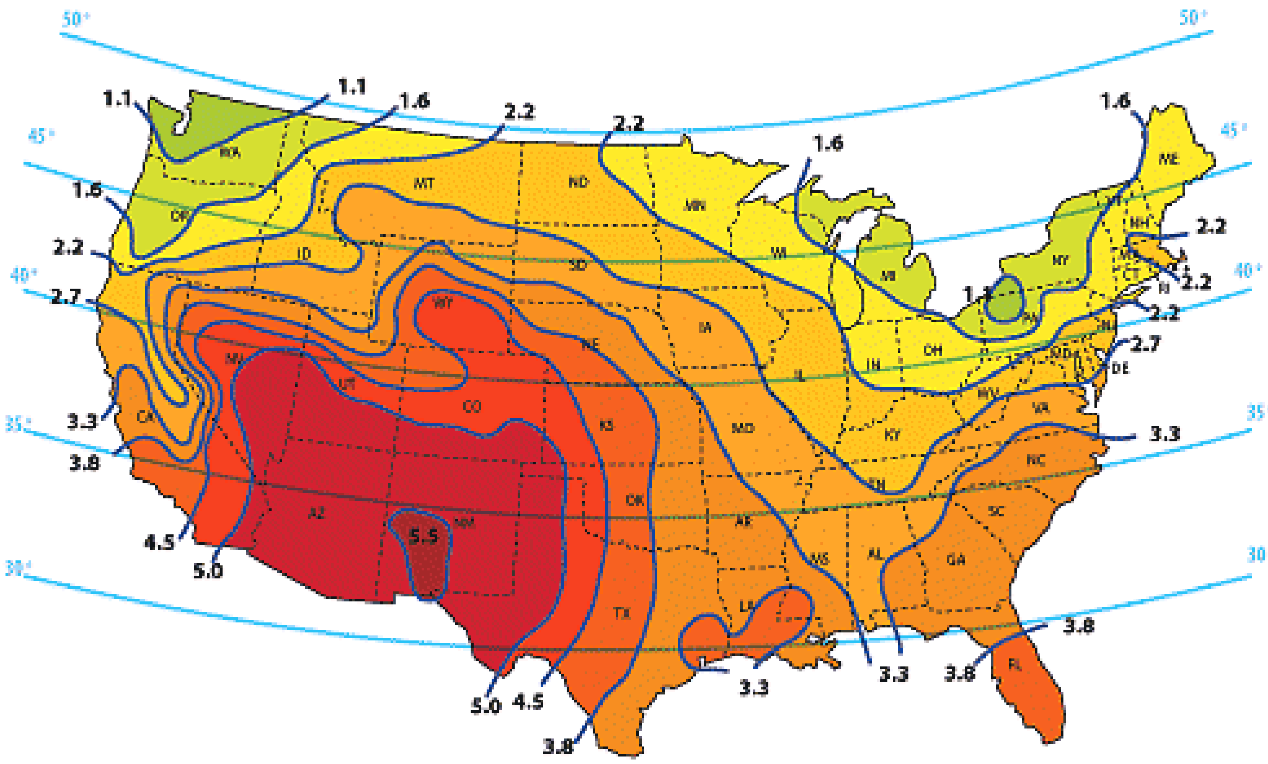


Figure 1. An average ESH graph of North America

User Experience

For end users, there is no much change. Users still see the same website; use the same service like email. Since the services are provided by the server farm which consists of a number of embedded server nodes, special client is required to operate special SEEDS functions such as locating the server, update the server etc. It is also possible that the SEEDS functions for clients are implemented in the operating system layer so that all software remains unchanged. The connection to the server cluster will be redirected to one of the server nodes in the SEED farm. The service delay probably increases since it may require extra time to locate proper SEEDS nodes. Although all SEEDS nodes are spread all over the world, system maintenance can be done by network. In general, the SEEDS farm is designed to be an easy-to-use system.

Market Analysis

As far as we know, this project is the first work to design and implement a solar-powered server farm which offers high availability and high reliability IT services without generating CO_2. The server farm is constructed by a number of small embedded server nodes which are deployed all over the world. As environmental issues become more and more critical these days, we believe that SEEDS farm is an ideal solution for this problem. Table 2 shows an SWOT analysis of the SEEDS farm.

Table 2. SWOT analysis of the proposed SEEDS system

	Positive	Negative
Internal factors	Strengths • Low or zero electricity cost • Reduce CO_2 emission • Data redundancies	Weaknesses • Low computing ability, unbalance server loading • Worldwide-spread servers may increase the complexity of management
External factors	Opportunities • Eco-awareness raising, CO_2 reducing is a critical topic • Enterprises wish to reduce the energy cost • Cheaper solution for enterprise ITs	Threats • Transfer from the regular servers to SEEDS farm may take efforts. • Cost for large scale SEEDS farm • Worldwide environmental upheaval

The SEEDS farm first targets on international enterprise which has many branch stores, such as McDonald's, all over the world. Worldwide enterprise with a lot of branch stores is an ideal environment to setup SEEDS farm. It would be easier to deploy the SEEDS server nodes all over the world, so that there would always be some part of the SEEDS network which can receive solar power at anytime, thus assures uptime of the services.

Cost Analysis

In our project, we use ebox as the SEEDS server node. The following data is computed under the assumption that ebox 4300 is used as our main components. To make a reasonable estimation, we assume a company of 1,000 employees. As the example shown in the previous section, we assume 4 SEEDS server node can be seen as a server if they are deployed in four different areas with ESH=5. Table 3 shows that the breakeven time by using the SEEDS farm is about 1.8 years. That means in terms of money spent for constructing and operating the server farm, the SEEDS farm spends less money rather than conventional electricity-powered server if both of them could operate more than 1.8 years. Of course, in terms of CO_2 generated, the SEEDS farm introduces 0 but the conventional server farm produces about 14 tons CO_2 every year.

Table 3. Parameters for cost analysis and comparisons

	SEEDS Server	Conventional Server
Price per machine(USD)	500 (Solar cell included)	1000
Disk space(GB)	40 (CF Card)	40 (SCSI Hard Drive)
Disk space per user(GB)	0.2	0.2
Power supply(Watts)	30	500
Total storage(GB)	200	200
Servers needed	20	5
Electricity consumption (year)	0	21900 KW-H
Total CO_2 emission (year)	0	13972 Kg
Electricity cost(USD/year)	0	2800
Hardware cost(USD)	10000	5000
Years to balance		**1.8**

The cost analysis above has neglected the connection fees and the CO_2 emission during the producing process. We could learn from the above table that the proposed SEEDS farm is not only avoiding the production of CO_2 for generating the electricity, but also reduce the construction and operating cost for the IT server.

Research Description

So far, we have successfully implemented the solar-powered SEEDS node, the construction of the SEEDS farm and the P2P network. The procedures and mechanisms such as solar power detection, data migration, data replication, server joining/leaving/keep alive are all implemented on ebox. An email client program is also developed, and could send and retrieve emails to/from the SEEDS farm. Feasibility study for solar power has been conducted to evaluate the ESH and solar panel size. Cost study and market analysis shown above has been done. Research on design parameters and design issues are also finished and will be described in detail in later sections. In summary, we have demonstrated the proposed SEEDS farm is a practical approach to reduce power consumption of IT servers and has commercial values.

Technical Analysis

Overall Architecture

We have designed and implemented a solar power system for an SEEDS node. We use ebox 4300 as the SEEDS node. In order to demonstrate the SEEDS nodes can form a SEED farm. We use other embedded system boards which are Intel PXA 255-based RISC CPU and are very similar to ebox. The four SEEDS nodes form the server cluster. Our solar power system has three main functions – (1) transform the raw solar voltage input into stable 5V output for the ebox, (2) store the surplus power in the battery for later use, and (3) turn on the ebox when power is sufficient, (4) inform the ebox with the amount of energy left in the battery through RS232 for consideration of whether to shut down or not. Figure 2 demonstrates the circuits and the demo system. As we could see from the photo, ebox is connecting to our design circuits, and then connecting to a 60cm x 60 cm solar panel and a battery. An RS232 which is connecting between solar panel and ebox exchanges the solar power status between panel and ebox. That is very important for the SEEDS node to detect the solar energy and remaining operation time.

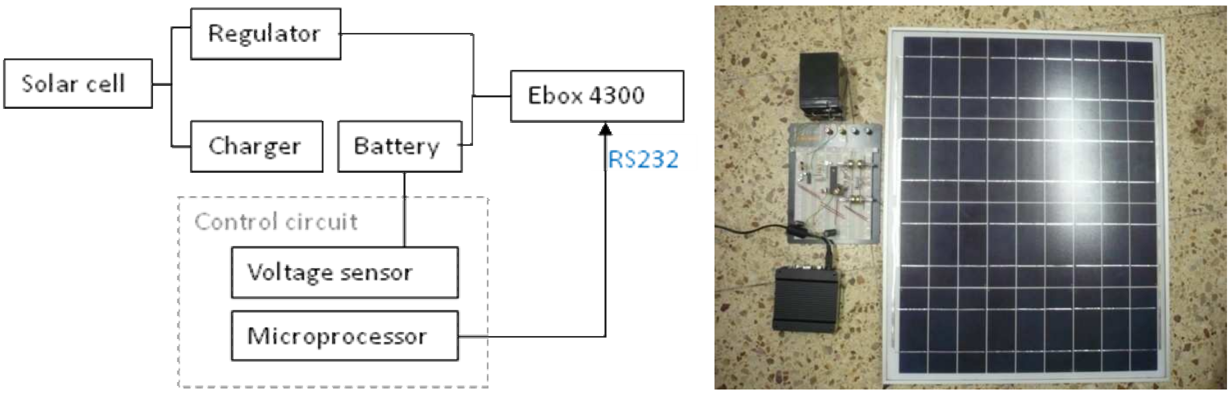


Figure 2. Demonstration of the proposed solar panel/battery circuit for ebox

The SEEDS nodes connect together via network and form a cluster. As we could see from Figure 3, ebox 4300 and other 3 embedded boards are connected and form the SEEDS farm. Our demonstration system is based on this configuration.

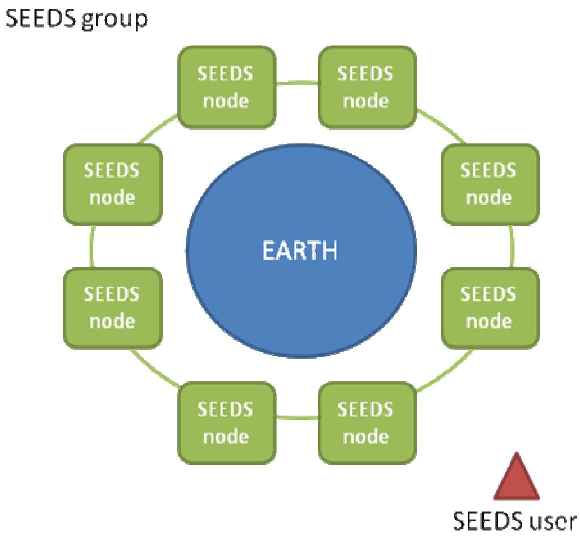


Figure 3. Demonstration of the SEEDS farm operated by the solar panel

Software Overview

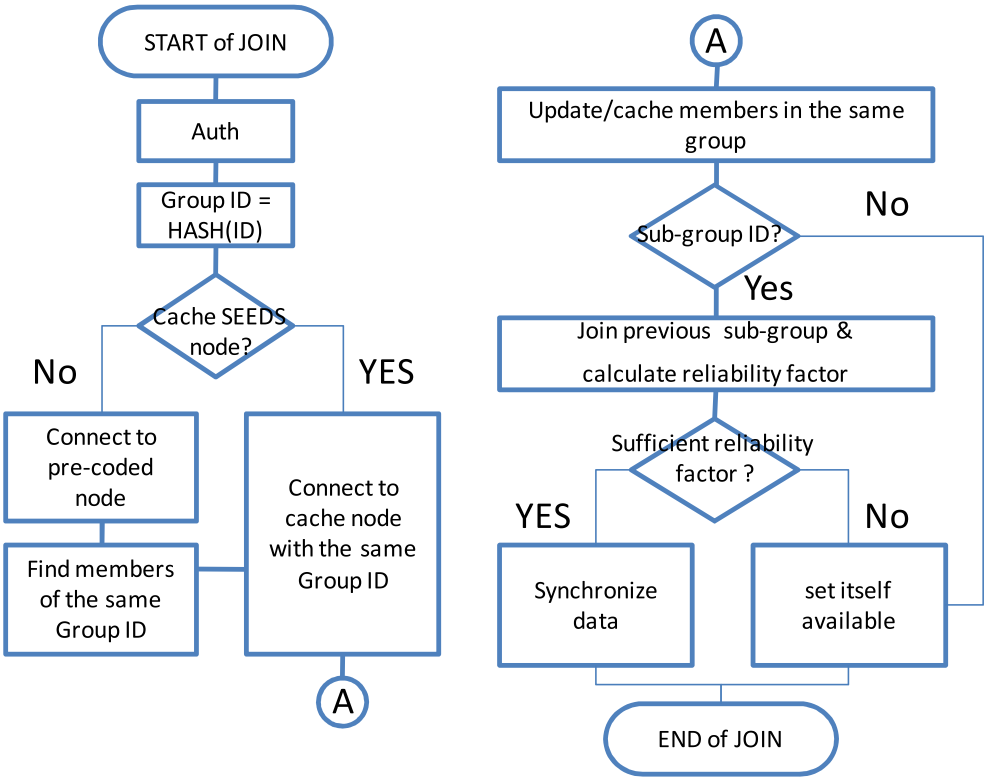


Figure 4. Flow chart of SEEDS server node JOIN

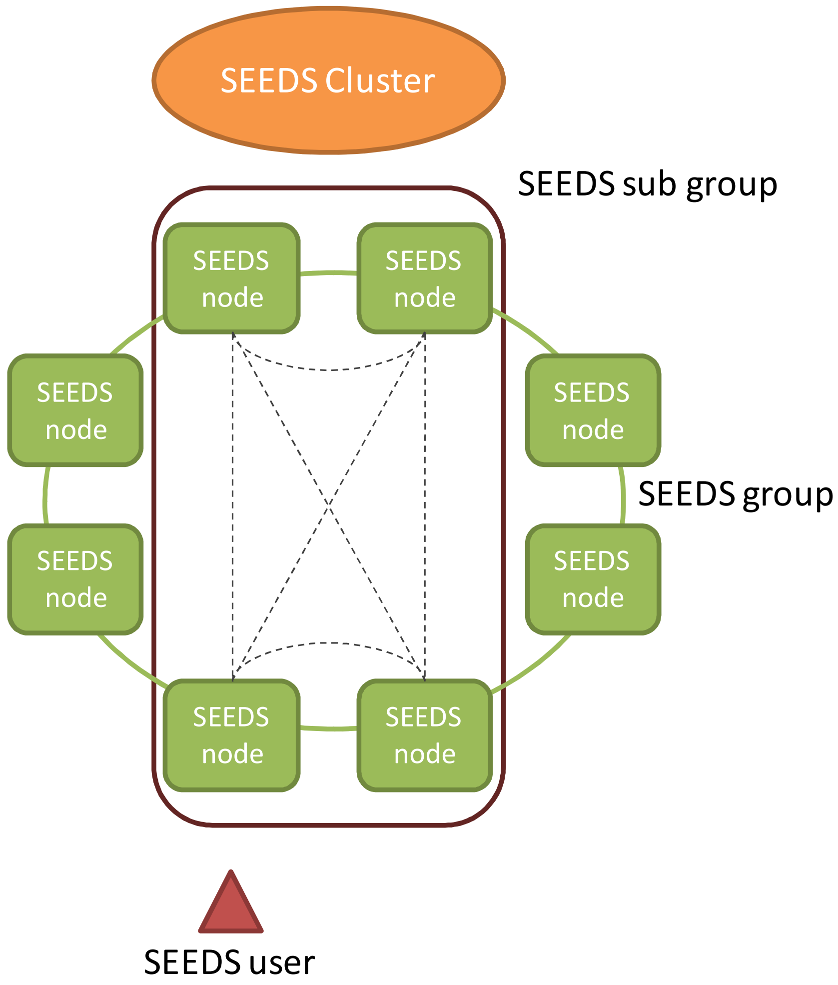


Figure 5. SEEDS subgroup and group

Authentication of the SEEDS server node

While any SEEDS server node joins the SEEDS farm, it has to perform authentication. After the new SEEDS server node passes the authentication, the node could join the SEEDS farm. RADIUS protocol is used in this system. The AAA records of all SEEDS server nodes could be stored in a separated server. The server could be operated by electricity power so that we could assume it is always available. On the other hand, we could assume the AAA records are stored on another SEEDS farm or the same SEEDS farm. After the SEEDS server node completes the authentication process, it could join the SEEDS network.

Join SEEDS network

Every SEEDS node has configured with a unique identifier, called SEEDS ID. After the SEEDS server node passes the authentication, it uses a hash function to hash its ID and obtain a group ID. In the current implementation, the hash function is a simple modulo function. The new SEEDS server node tries to connect to any of the existing SEEDS server nodes. If the new SEEDS server node is first time to connect to the SEED network, it tries to connect to one of the pre-coded (or well known) SEEDS server nodes. Otherwise, the SEEDS server nodes could connect to any of the SEEDS server nodes in its cache. The well-known SEEDS server nodes could be powered by electricity so that they are always available. These server nodes could be also powered by solar power. Then, we might have to configure more well-known nodes to avoid unavailability if these well-known server nodes are solar powered. After a SEEDS server node connects to any of the existing SEEDS server node, it locates its previous sub-group members via other members in the same group. Different from group ID which is hashed, the sub-group ID of a SEEDS server node is assigned by other SEEDS nodes. If the new SEEDS server node does not have sub-group ID, it sets itself as available and waits for other SEEDS server node requests for help. If the SEEDS server node has sub-group ID, it joins the sub group. To join sub group means the SEEDS server node connects to all members in the sub group. In our design, the members, i.e. SEEDS server nodes, in the same sub group are all connected. A sub-group is the basic entity to handle the user data.

After the SEEDS server node joins the sub-group, it reports it available service time (based on GMT (Greenwich Mean Time)) based on statistical data to all members in the sub group. The available service time is the time that the SEEDS server node can receive the sunlight and can operate correctly. The SEEDS server node reports the service available time to other SEEDS server nodes in the same sub group. Then, every server node in the sub group has to calculate if the reliability factor meets the requirement. The reliability factor is derived from how many data copies that the user can access at any time. The reliability factor is a MIS-configured factor and implies how reliability of the service that MIS wants to configure. A higher reliability factor means the data stores on the sub group is more reliable. Also, a higher reliability factor implies more replication is required. Figure 6 shows the concept. Sub group K has 5 SEEDS server nodes. The five servers locate on different locations of the Earth. Their times are all translated to GMT. Server #1 could operate from 7AM/GMT to 14PM/GMT, Server #2 could operate from 4AM/GMT to 10AM/GMT, Server #3 could operate from 21PM/GMT to 4AM/GMT, Server #4 could cooperate from 13PM/GMT to 23PM/GMT and finally Server #5 could operate from 21PM/GMT to 2AM/GMT. As we could see from the figure, the current reliability factor is 1 which means at any time there is at least one server has the data. Figure 4 illustrates the flowchart of SEEDS node join and Figure 5 shows the operational architecture and the concept of group and subgroup.

Sub group K

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
SEEDS server #1								*	*	*	*	*	*	*	*									
SEEDS server #2					*	*	*	*	*	*	*													
SEEDS server #3	*	*	*	*	*																	*	*	*
SEEDS server #4														*	*	*	*	*	*	*	*	*	*	*
SEEDS server #5	*	*	*																			*	*	*

Figure 6. Concept of reliability factor

After the SEEDS server node joins the network, finds its sub group members, it joins the sub group, and reports its available services time. If the current reliability factor is enough, the SEEDS server node does not need to join the sub group and could set itself as available. Otherwise, it joins the sub group and synchronizes the data in other server nodes. To avoid frequent change of sub group members, we define a threshold. Without exceeding the threshold, the SEEDS server node still joins its previous sub group even the reliability factor is achieved. Finally, the SEEDS server node completes the join process.

Leave SEEDS network – normal

If a SEEDS server node wants to leave the SEEDS sub group, it has to check if the reliability factor is satisfied or not. If the reliability factor is still satisfied after the SEEDS server node departures, the SEEDS server is permitted to leave. Otherwise, the SEEDS server node has to ask other available SEEDS server node as its replacement. The SEEDS server node at that situation will find other SEEDS server nodes which set themselves as available to help. Migrating data to the new SEEDS server node and assign the sub group ID to the new SEEDS server node. Finally, the old SEEDS node completes the leave process.

Leave SEEDS network – abnormal

SEEDS server nodes maintain connections to each other. Also, they send heartbeat packets to each other in order to keep alive. Once any SEEDS server detects the SEEDS node failure such as no solar power, it activates the abnormal SEEDS server leaving procedures. The procedure is similar to the previous normal case. In case the replacement node is required, the SEEDS node find an SEEDS server node which is available and replicate data to the new SEEDS node.

Data replication

Data replication is the procedure that SEEDS node replicates data to other SEEDS node in order to fulfill the requirement of reliability factor. The procedure is activated while the reliability factor is not satisfied and new SEEDS node joins.

Authentication of the SEEDS client

A user, called a SEEDS client, has to pass the authentication before using SEEDS farm service. Similar to authentication of the SEEDS server node, the SEEDS client uses RADIUS protocols to communicate with the AAA server to gain the access right. The AAA server could be either electricity-powered server or solar-powered server such as another SEEDS farm.

Retrieve SEEDS farm services – sending email

The data, i.e. emails, are stored in a specific sub group. A SEEDS client can sends its email to any server node in the group. The SEEDS server node will forward the email to the subgroup that maintains your email account. It is important to note that the nodes in the same sub group have the same data. So after the client sends a new email to a SEEDS server node, it has to synchronize with other nodes if they are available.

Retrieve SEEDS farm services – receiving email

The data, i.e. emails, are stored in a specific sub group. A SEEDS client must connect to any member in the group and see which sub group handles its email. If a SEEDS client even joins the SEEDS network, it may cache its previous connected server nodes. Then, the connection speed is fast. Otherwise, the client must locate SEEDS server node first, finds its sub group and then get the data. It is important to note that the nodes in the same sub group have the same data. So after the client sends a new email to a SEEDS server node, it has to synchronize with other nodes if they are available.

Deployment Analysis

Power is a crucial factor in our project due to limited sunlight. So we divide all the SEEDS nodes into subgroups, in which the data of each node should be identical. Once the SEEDS replication is invoked when some nodes join, the synchronization is done by replicating only the difference, without copying all the data every time. Compared with PC, embedded system has moderate calculation ability and memory size. Thus, reducing times for I/O between SEEDS nodes is in our consideration. We achieve this by grouping and sub-grouping to make the interaction more efficient.

Performance Analysis

The proposed ideas are implemented on ebox and Intel PXA 255 embedded boards. The SEEDS email server could be accessed from PC using a modified email client. The system has been prototyped. In order to understand the performance, we measure the performance results based on the prototype system.

Data migration speed

Since the average size of an email message 18,500 bytes[2], we test the data migration speed of ebox4300 by sending and retrieving a bunch of 18KB files. And additionally with a relative large 60MB file. The following table shows the testing result.

Storage	256MB CF card	built-in memory
uploading 18KB file segments	27 K/sec	29 K/sec
downloading 18KB file segments	144 K/sec	144 K/sec
uploading large file	478 K/sec	8.5 M/sec

[2] *Internet - Summary*, UC Berkeley

downloading large file	1.47M/sec	8.5 M/sec

Power Measurement

Since the power consumption is a considerable factor in our project, we measure the power consumption of ebox4300 when busy and idle.

	Busy	Idle
current(A) / voltage(V)	1.5A at 5V	1.0A at 5V
power consumption	7.5W	5W

Testing procedures

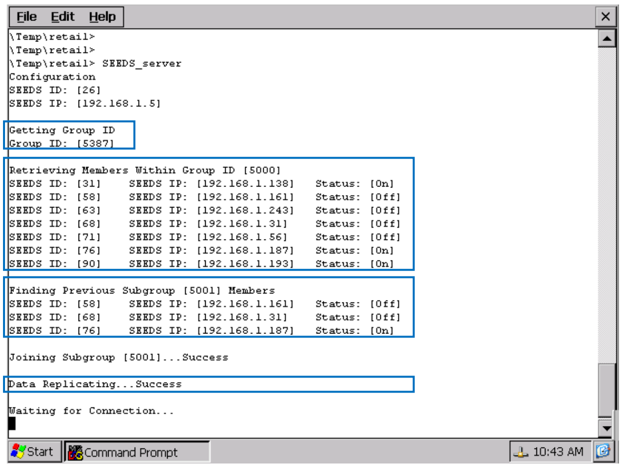
The following are the configuration of how we test the SEEDS cluster.

Ebox with solar power runs well under the sun

ebox works with 3 PCM-7230

Figure 7. Live demonstration of a SEEDS cluster

The message from the SEEDS server running on ebox indicating the following steps: (1)join the SEEDS farm (2)get the group ID (3)retrieve the group members (4)request to get mail (5)request to send mail (6)leave the SEEDS farm normally.



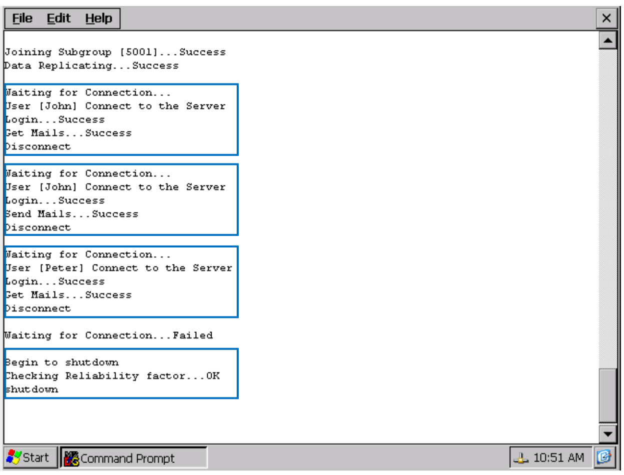


Figure 8. Screen snapshot of ebox which is joining/leaving SEEDS server farm

How users Peter and John send and receive Emails:

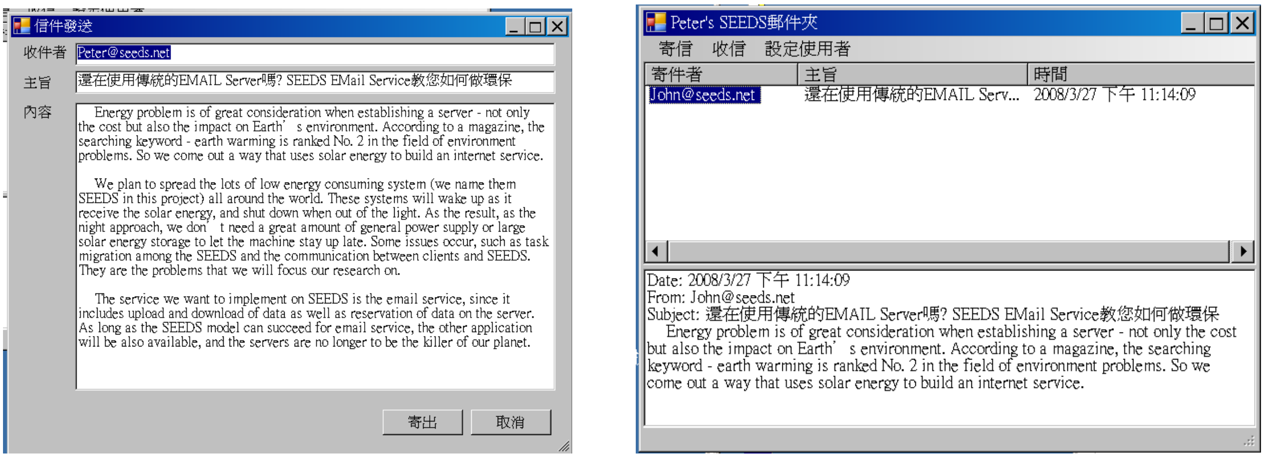


Figure 9. Screen snapshot of users to access email from SEEDS server farm

5. Embedded Analysis

Embedded Image

Before the ebox had arrived, we intended to construct the SEEDS cluster by using the emulator. However, NK.bin, the OS image built according to “Jump Start Guide”, should be loaded on the ebox, not the emulator. Later, we try to make a new project for ARM emulator and build it with SDK. Then we can run several OS on emulators at the same time to form a SEEDS cluster.

Embedded Software Design

Power is a crucial factor in our project due to limited solar power. So we divide all the SEEDS nodes into subgroups, in which the data of each node should be identical. Once the SEEDS replication is invoked when some nodes join, the synchronization is done by replicating only the difference, without copying all the data every time.

Compared with PC, embedded system has moderate calculation ability and memory size. Thus, reducing times for I/O between SEEDS nodes is in our consideration. We achieve this by grouping and sub-grouping to make the interaction more efficient.

Embedded Component

Obviously, the power consumption of a PC is relatively too large for solar cell to operate. (e.g. A 300W PC may require a solar cell whose area is at least 2.6M^2 to operate) Moreover, our goal is to separate the risks on several small embedded device. If a single server has too big storage, it is a burden to migrate the data when a system fails. In contrast a fast recovery can be done on small embedded device. Therefore, this project is not suitable for PC.

Project Status

The project is initiated from this Jan. The team members have weekly review meeting to check everyone's progress. Besides the weekly review meeting, the team members also talk to mentor every Thursday to discuss the system design. We have completed the basic requirement of the system, from software to electronic circuit. We are now at the stage to improve the design and implementation. We expected to finish this project before the competition in June.

Mr. Kuan-Ting Yu (Leader): (1) Manage the progress of the project, (2) Design the system and evaluate the technical solutions, (3) Integrate and test the system, (4) Write the system specification, high level design document and proposal.

Mr. Hao-Yun Liu (Member): (1) Solar cell and battery work environment research, (2) Solar UPS structure design, (3) Solar power supply circuit, battery charger, and control circuit implement. (4) design the communication model and protocol between ebox and solar power control microprocessor. (5) Contact with device manufacturer.

Mr. Ting-Fu Liao (Member): (1) Documentation, (2) Feasibility analysis of the system, (3) Software Implementation, (4) System testing, (5) tuning and building OS image.

Mr. Cheng-Hsien Sun (Member): (1) Cost survey, calculations, and compare between different solutions, (2) SWOT analysis of our project, (3) Report writing and translation

Prof. Shiao-Li Tsao (Mentor): (1) Guide the project, (2) Provide comments and suggest technical solutions, (3) Review the proposal, system design and project plan

Conclusions

In this project, we proposed a concept called, SEEDS: **S**olar **E**nergy-based **E**mbedded **D**istributed **S**erver farm, which utilizes peer-to-peer technologies to construct a solar-powered, high-reliable, and high-available server farm for an enterprise. The proposed server farm not only significantly reduces the power consumption of IT servers but also offers high-reliable, and high-available IT services. We have prototyped the system and proved the concept could be realized based on commercial off-the-shelf equipment. The cost analysis, performance evaluations based on the prototype system also demonstrate that the system is practical and has commercial value. The system is not yet fully complete. Advanced functions such as security, power low detection are not yet implemented. More research and performance evaluation should be conducted to make the whole system more complete. We expect to complete the work before the end of June.