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Smart Software and Smart Cities: A study on Green Software and Green Technology to develop a smart urbanized world

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Abstract

Due to tremendous increase in population, many people living in villages are now migrating to the cities. It is predicted that very soon most of the human civilization will be concentrated in the cities. This increased population will consume more energy and need more space to live. Finally, they will leave behind a more prominent environmental footprint as the cities grow to metropolises. This has been occurring globally and has led to serious consequences. So, to restrain the burden on traditional cities, a paradigm of a new kind of cities has come up, one called smart city. A smart city uses advanced technology to minimize the effect of human activities on the environment. With the increase in population, more and more people also learn and are taught to use computers/handhelds. This has resulted in having a large number of computers/handhelds in every city. In this paper we propose to develop smart software which is used to from a smart system to use optimal power and hardware resources to produce minimum carbon footprint and to make the city smart and green.

Keywords

Smart cities, green software, green computing, smart system, sustainable technology, urbanization, smart urban system, smart operating system

1. Introduction

Since the industrial revolution, the human civilization has been putting pollutants like carbon dioxide into the atmosphere and that makes the environment unhealthy for the human beings. We can see in Fig 1 that the rise in CO_2 level can cause serious temperature changes that if allowed to continue may prove to be fatal for the human race. The term 'global village' was coined in the 1920s [1] when the radio was invented. In those days one can send message only through radio and it was mainly one way data communication. But today the world is inter-connected through networks which make the entire globe really a global village as data can be sent and received from one place to another place.

Most of electronic and electric instruments have sensors to perceive the world around them. They may not themselves be intelligent but they provide us, in most cases, with data about its surroundings and how energy is being consumed. In most cities, there are many such sensors in everyday life. That is, there is an abundance of data but lack of analysis/interpretation. The world has to move on from being a global village to a smart urban world and to intelligently minimizing our footprint on nature so as to leave behind for the future generation what we have always taken for granted. The concept of the smart city is the realization of this vision and in this paper, we propose means of using green software to make it smarter.

In section II we give a brief introduction to the terms used in the paper topic. We go on to discuss how the smart cities are made smarter with green software in section III. In section IV we present a system that uses green software in a smart city and show how it could benefit the smart cities. In section V we discuss some issues related to the smart system that we proposed in section IV.

2. Concepts

A United Nations report estimates approximately 70 percent of the world's population will live in cities by 2050 [3].Therefore it is evident that the most of the planet's energy consumption and other needs will be generated from the cities. Therefore to minimize the effect of human activities on nature and to understand and learn from human activities itself, we have to envision a world of cities that are smart. Smart cities can be identified along six main axes or dimensions – a smart economy, smart mobility, a smart environment, smart people, smart living, and, smart governance. [4] A smart city uses technology, network systems and infrastructure to improve economic and political efficiency and foster development while minimizing the environmental degradation and promoting environmental regeneration.

A software application whose direct and indirect negative impacts on economy, society, human beings, and environment that result from development, deployment, and usage of the software are minimal and/or which has a positive effect on sustainable development can be termed as sustainable software. [5] In this paper, we use the term 'green software' to emphasize on sustainable software's objective to minimizing the direct and indirect impacts on the environment. The green software communicates with the network in order to minimize the effect on the environment. We will use the terms 'smart software' and 'green software' interchangeably as they have the same goals to realize. We explore the role of green software in making a city smart and we go further to describe a smart system that uses green software and methods to make a city smarter.

3. How Green Software makes a city Smart

A. Smart operating systems

It is the operating system that binds together all the components of the computer, including the user. A traditional operating system provides an interface between the hardware and the user. Operating systems are also able to interface between the hardware, user, application software and the network. The smart operating system that we propose will be able to interact with the smart network (which is different from the internet or the web) to optimize the functionality of the computer. That is to say, that the smart operating system is always connected to the smart network (which we will come to later), thus conversing with the network of inter-connected computers and all the processing agents and data centers thereby utilizing the collective intelligence and efficiency of the entire system of computers in the smart city. It is to be noted that this is quite different from the cloud computing architecture. In cloud computing, the client is a dumb terminal. It is quite the opposite in this case. In this architecture, the computer is capable of autonomous computation. It only needs to interact with the network to collect information to optimize the working of the computer based on current power/energy level of production and consumption (demand-supply relation and eco-friendly minimization of energy usage) in the grid and/or traffic in the network among other advantages. The magnanimity of this will be understood if we picture a city which during times of shortage in power supply, the computers minimize their functionality to only that which is unavoidable, to reduce power consumption (or switch to battery power). The smart operating system uses real time data from the smart network to change the power modes of the computer and start or terminate software applications depending on the power supply fluctuation with a goal of minimizing the energy consumption. Thus, the gross power consumed by computers could be reduced manifold. The effect of energy consumed by a computer is not immediately apparent as an individual computer does not consume much power. But the effect is cumulative, in the sense that there are so many computers today that even a slight improve in their power consumption would save a considerable amount of energy. Research shows that in some of the developed countries, 50% of PCs are left on overnight, resulting in an estimated annual energy waste of 28.8 billion KWH, and a cost of $2.8 billion to the economy [6]. A smart city is an interconnected system that can sense the energy needs and minimize wastage of energy. A smart operating system would make the smart city much better connected as computers can themselves behave as sensors making the entire system more aware. The smart operating system would connect to data centers of the smart city (which can further be connected to form the global urban virtual network of smart cities) to fetch and upload data about the energy consumption and current power supply scenario. In view of this, we present an architecture of a smart operating system as shown in Fig 2.

B. Information sharing (inter-software interaction)

Software applications running on the same system are often in isolation from each other. This can be viewed as data privacy. But all the software applications *have* to interact with the operating system. This interaction can be used for software applications to interact with each other to satisfy common needs. Suppose a software application on a computer/handheld requires information X, say regarding the latest weather update for example. If the same computer/handheld also runs another software application that needs the same information, it should take the information from the other application rather than fetching it from the network again. This would reduce the energy consumption and the processing time (more processing time leads to more energy being wasted). To make this inter-software communication possible, design of the operating system must be such that the operating system has a better understanding of what each application that runs on it does. That is to say that the operating system will be intelligent and aware of the applications it runs as well as be able to understand the type of information downloaded from the network. Since all access to the network and data fetching is done through the operating system, if the operating system is aware of the kind of information needed, it can recycle the information wherever applicable. This is another aspect of what a smart operating system should be able to do. That is, the smart operating system should be able to better bridge the gap between the application and the network by using intelligent content awareness and overall understanding of what an application does.

C. Use of smart power grids

A smart grid is a network that links power companies to an array of intelligent devices that keep tabs on electricity usage within homes and businesses [7]. The smart grid maintains energy fluctuation levels depending on current energy consumption levels. Using this information, the green software applications can optimize its behavior accordingly. Thereby, optimizing its energy consumption based on availability of energy and hence minimizing energy wastage. If smart cities use power from smart power grids [8], then the entire power consumption of the city can be adjusted to the power supply so that unprecedented power failures will not occur. As we see in section IV, green software applications respond to the data from the smart power grid by choosing a power mode that will optimize the energy consumption.

D. Feedback data

Consumer-based green software should also produce feedback data for the smart city to function better. The feedback data can be in the form of the amount of power the computer requires to function at that instant. With the statistics of the power consumptions of thousands of computers, the smart city analysis centers (discussed later) can make informed choices like instructing the computers to run on power-saver mode or on battery power when there is a power shortage. Again, the operating system must play a very important role here as this feedback signal cannot be sent by individual application software. So we see that at the centre of green software is a smart operating system. The feedback could also take into account other factors like average download and upload speed to understand the current state of the network. In that case this feedback will go to the network processing centre of the smart city (see section IV).

E. Specialized green software

There can be specialized green software for the smart city. Some are explored below:

- An intelligent traffic system that could also connect to the cars (which would have processors to act on the information sent) for real time information streaming – that is, if there is a traffic disturbance in a particular locality, it is to be avoided by taking a detour. This would save time and thus save energy. The smart city's traffic system should also be able to guide the car driver to drive at an optimum speed (depending on the car) that would minimize gaseous emission. In effect, the intelligent traffic system could also connect to the smart network (as described in section IV) and thus be a part of the entire smart system.
- Smart street lighting: A system that would switch off the street lights in smaller streets when there is no one on the road. For major streets this may not be possible but for the interior streets it would be possible to have a surveillance (computer night vision) that would switch on the lights automatically when there is someone in the vicinity, otherwise it would be switched off. While doing so, it would also be connected to the smart system which would disperse the surplus energy to energy deficient locations.
- Smart transport: Using green software systems, a city can have a smart transport application that runs on computers/handhelds to give the current location of a public transport, distance to the location of the user, whether there are seats available. This system would help save time by giving the user the expected time of arrival at the user's stop, save energy by promoting public transport and also act on the patterns of passengers – for example, the transport frequency can be reduced in number at night.

4. The Smart Urban System

At the back of the smart city there is a system comprising green software and automated machine interaction that collects data from the entire city, analyses it and puts in use for efficient running of the city. We call this system the smart urban system (SUS). The smart urban system runs all the time with its goal to efficiency and environment friendliness. Analysis of the current scenario of the city by the smart urban system, estimated and evaluated based on the factors (like real time power demand and supply, network congestion and load-distribution) will be called the current *state* of the city. The different components of the SUS (see Fig 3) are named and discussed below.

A. The smart network

It is a city-wide network that stores the current state of the city and also the power optimization plan that is most appropriate for different classes of clients (like computers, handhelds) using which the devices can regulate their power usage depending on the analysis done by the data centers of the SUS. The smart network can be called the face of the SUS as it reflects the changes in the system and the stores the recommended actions. The knowledge-base of all analysis of data received from around the smart city is used to effectively produce the optimum power consumption levels. After series of real time analyses of different parameters, the final state of the city is evaluated by the data centers and uploaded to this network with recommendations on what is to be done in the current state in terms of power consumption and the running of the devices.

The current state of the city is monitored at regular intervals by the smart network. This is done after analysis of the data gathered from the sensors which are present around the city (see Section IV (D)). Smart devices like phones and computers maintain a steady (but light) connection with the smart network. This enables the devices to modify their behavior based on the real-time state of the city. Since blackouts and power shortages develop over a relatively short period of time that all the devices have to stay synchronized with the changing state of the city.

The smart network is also connected to the web. This way, the devices connected to the smart network are in fact, also connected to the web. That is, every device attempting to connect to the web goes through the smart network which will choose the fastest route to the web server as well as it would provide statistical data for analysis of the network traffic for better network routing in the future. In other words, the web would become smarter with the SUS.

B. The smart operating system and the smart device

As mentioned previously, the smart operating system will help the functionality of the smart devices with reduced energy consumption. The smart operating system estimates the power requirements of the computer and generates a power index (as discussed later in the section) based on which the network formulates the optimum power settings for the device. The smart operating system acts on the recommendations of the smart network as far as practicable.

The smart operating system provides the feedback to the smart network based on its perspective. For example, when the average download speed of the network is unusually slow, the feedback helps the data analysis centers to evaluate the network routes and diagnose problems in the network. The user interacts with the application software to perform his/her job. The application software connects to the smart network through the smart operating system. Therefore, the smart operating system is always aware of how the applications are interacting with the network. This facilitates information sharing (as mentioned in the previous section) and better feedback to the system. See Fig 2.To enable existing operating systems to use the SUS, a smart shell can be used which can provide an interface between the smart network, the operating system and the applications (see Fig. 4). An operating system shell is a software component that presents a user interface to various operating system functions and services [9]. The smart shell will be installed on the existing operating system. The shell will fetch the information regarding to resource usage from the operating system and calculates the power consumption details and sends it to the smart network for evaluation. The response from the smart network is also received by the smart shell and based on this recommendation the smart shell instructs the operating system to alter its functionality. The smart shell relays all other interaction with the computer to the operating system, which is all other functionality of the computer, is unaltered.

The operating system calculates a power index depending on the applications currently running and their resource usage. The power index is provided to the smart network. Based on this power index, the smart network estimates the resource usage and energy requirements of the device. The power index is a four digit string (which can be extended further) where each digit is an indicator to the specific power requirements of a class of applications. The power index is generated as given in (1).

$$\textbf{Power index} = 10^3 * C_{OS} + 10^2 * C_{P1} + 10^1 * C_{P2} + 10^0 * C_{P3} \quad (1)$$

Where,

C_{OS} = Power requirements of the fundamental functional and associated units of the system (like the processor cooling hardware) estimated by the operating system. It is the power consumption of the operating system itself. It has highest priority because without it the computer will not function.

C_{P1} = Power requirement (P_i) of the applications having highest priority at that instant.

C_{P2} = Power requirement (P_i) of the applications having medium priority at that instant.

C_{P3} = Power requirement (P_i) of the applications having lowest priority at that instant.

P_i = Power requirement of an application-**i** is calculated based factors like average CPU usage, memory usage, disk accesses, network activity, application state (whether it is running in the background or foreground), power state (whether run on battery or electricity).

C. Sensors

A smart city has sensors all around the city measuring different parameters to make an estimation of its surroundings. The aim is to create a distributed network of intelligent sensor nodes which can measure many parameters for a more efficient management of the city [10]. Therefore there would be a huge number of sensors all around the city. All data from the sensors could be sent as it is in its unaltered form to the main data analysis centers or the sensory data can be analyzed at different levels and using abstraction, the amount of data sent by sensors could be minimized to save bandwidth and energy. The smart devices (phones, computers, tablets etc.) also act as sensors through the feedbacks they send.

D. Data analysis

This is by far the most important section of the SUS because the entire functioning of the smart city and this system depends on how the huge amount of data from sensors are interpreted to generate guidelines on how the devices should run based on a perception of the city which is analyzed here. It is up to this the analyses to transform a data set into a vision of how the city is currently functioning which we call the current state of the city and depending on the state, analysis is also made on optimizing the way the devices function.

The data analysis center has four major subdivisions (can be expanded to more as the city expands):

- Power/energy analysis: Data from the smart power grid (supply) and the power usage are studied to be able to provide the recommended power usage guidelines. With the smart grids working alongside, power management in the smart city is optimized as far as practicable. This section of the analysis centre also maximizes meeting energy consumption needs using renewable sources of energy and minimizes that using non renewable sources of energy.
- Network analysis: This section monitors the smart network and its functions. Based on the feedback data from the devices and sensors in the network, estimation can be made about the overall functioning of the smart network. It is important to note that if the smart network fails, the devices will not have any idea about the state of the city and therefore much of the purpose of this system would be defeated. Therefore network analysis is a crucial section in the SUS.
- City-wide broad analysis: This section analyses data from sensors such as the weather conditions, road and air traffic, pollution in the air, analysis of waste disposal etc. Each of these is analyzed to estimate the state of the city. For example, heavy rainfall would increase the probability of the occurrence of accidents so the optimum speed limit for cars would be less than the normal value. This recommendation is fetched by smart cars from the smart network and drivers are then advised to slow down by the cars every time they exceed this speed thereby reducing the chances of accidents.
- Statistical analysis: All analysis done by the three above-mentioned sections are stored in form of statistics and experience. The SUS learns more and more as it operates, from its previous experiences. Statistical data can often be extrapolated to reach a possible solution to an otherwise complicated problem. This section uses machine learning, adapting, heuristics and statistical analysis of data to solve newer problems better from past experiences. Storage of data is maintained using data mining and big data techniques.

5. Some major issues while changing a city to smart city

A. Privacy Issues

In the proposed smart urban system, although the smart network has access to the power consumption needs of the computer (which is application-specific), the smart network does not get access to the application data. This is done through the operating system as the smart network does not have access to the applications and user data directly. The smart network communicates with the operating system which shields the sensitive information and only gives access to power consumption details.

B. Compatibility Issues

There is a huge number of computer/handheld devices are currently running operating systems not compatible with the SUS. As we proposed in section IV, we can use the smart shell (see Fig 4) to make the current operating system compliant with the SUS. Thus the SUS can optimize the power consumption of existing systems as well. It is also to be noted that the problems posed by the great diversity in the currently running systems is taken care of by the smart shell.

C. Educated and energy-conscious society

Even after all the technological advancements in the field of energy conservation and green software in an envisioned urbanized world of smart cities, the success of the entire smart system paradigm is based on whether the people are ready to adopt it and accept that an urbanized world of smart cities is the only answer to the climate crisis. It is finally in the hands of the peoples of the world if the smart cities will serve their purpose because unless there is awareness and consciousness, there can be no change. As the citizens are the primary reason for the existence of city policy, engagement can support cities to define and achieve their goals. This is particularly relevant in a world where citizens have become 'prosumers' (producers and consumers) rather than passive consumers of services [11]. That is to say that without smart peoples, a world of smart cities cannot be built.

D. Green policies

National policies should be made both for the software companies and the consumers to promote the green software products compared to their non-green counterparts. This would influence the market to shift to a green system entirely. It is important to do so because people will not change to the new green system proposed above unless it will directly benefit them economically especially in developing countries. It is because the common man often does not see beyond economy, green practices have till date been taking a back seat.

E. Economy

The importance of the role of economy can be understood from the fact that populations are driven from rural areas in search of economic opportunities causing immense pressure on existing cities and demanding creation of new urban centers[12]. Thus, one of the reasons that the concept of smart cities is gaining importance in the foreseeable future is because of the economic division between the urban and the rural populations. As already discussed, the smart system that we proposed optimizes energy consumption and thus reduces the money spent on energy. But the smart system also has other sections that take of data collection, processing, network maintenance, among others. This increases the cost of living in the smart city. It should also be taken into account that the increase in cost is occurring city-wide, that is to say that the government can plan to make a budget to incorporate the cost because it is not an unprecedented cost, but a cost that will come with the smart city. It also can provide income for the city while at the same time cutting down the cost on non-renewable sources of energy.

6. Conclusion

Having given our views we are led to conclude that as the world is moving towards being an urbanized world of smart cities, the smart system we presented is the next step. It is because the smart city takes data from external sensors, previous experiences and other sources to make informed choices about running the city. It should also take all software systems into the smart system as they have a huge impact cumulatively and can provide large amount of data needed for analysis. It adapts existing software engineering methodologies to have minimal impact on the environment and thus creates software systems or individual software applications which reduce the environmental impact of other entities. Moreover, the smart system comprising green software can be readily integrated into the existing internet backbone without any additional hardware component on the client side. Hence this work recommends the smart urban system of green software for the urbanized world of smart cities as its conclusion.

7. Figures

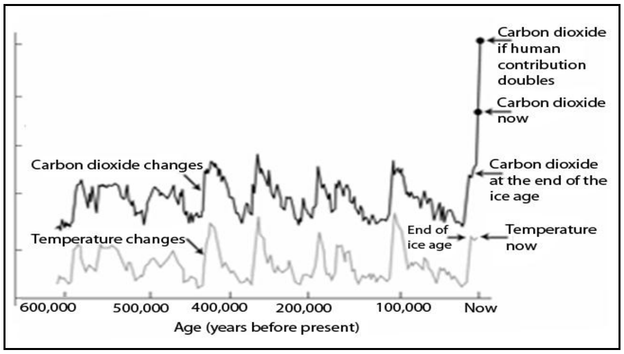

Figure 1: A graph showing the change in temperature with the change in CO2 level in the atmosphere due to pollution and other human activities. Proposed by [2].

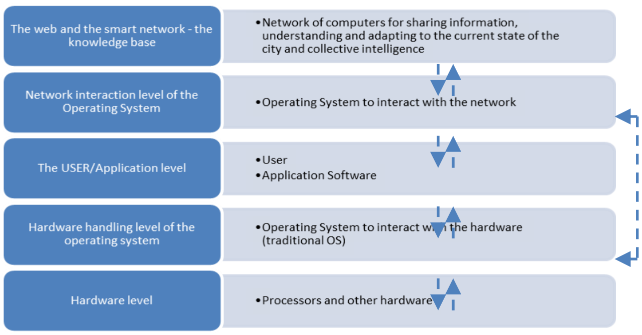

Figure 2: The proposed architecture of the smart operating system

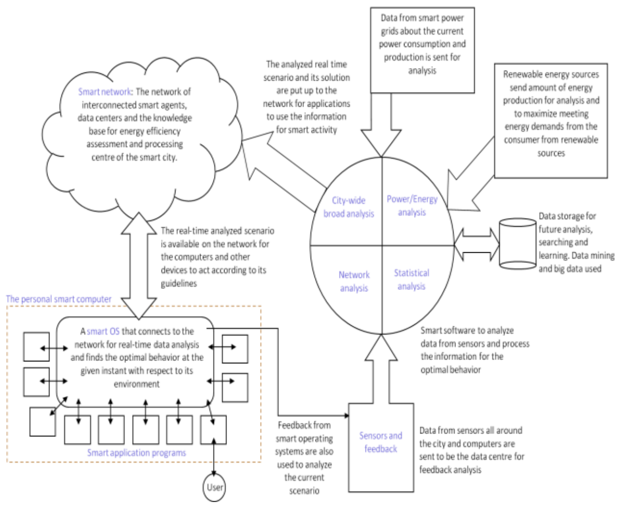

Figure 3: The proposed architecture of the smart operating system

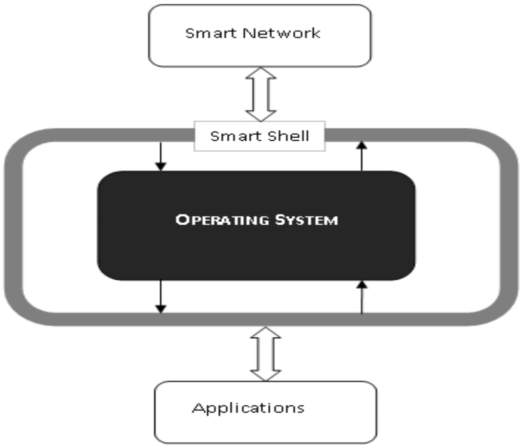

Figure 4: Integration of the smart network with existing operating systems

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