Achieving Sustained Quality-of-Service in Pervasive Computing with Renewable Energy Source

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The goal of pervasive computing is to seamlessly weave information technology into the fabric of everyday life until it becomes invisible. The key of invisible computing is the ability to provide reliable and sustained quality-of-service (QoS). This requires an intelligent QoS management with the consideration of all available resources. Energy, as one of the system resources, has the most direct impact on the system availability.

OUR VISION The world of pervasive computing consists of large number of remote sensing, actuation, and portable computing and communication devices. The heterogeneity of pervasive computing also reflects on the choice of the energy supply of each device. In addition to traditional energy supply such as rechargeable batteries and super capacitors, current material and device technology enables us to collect renewable energy (such as wind power, solar power, and kinetic power, etc.) from environment to power the electronic systems. The energy in the world of pervasive computing is no longer simple expenditure. Similar as information, it can be generated, stored, consumed, and possibly even be transported.

The participant believes that the QoS management for the future pervasive computing system should consider the regenerative nature in its energy supply. For example, an iPad will be recharged every night. A wearable health monitor may be powered by piezoelectric shoes which generate energy from the user's footsteps. Current technology already enables us to print sensors and photovoltaic (PV) cells on a flexible surface which could be integrated with architecture materials for smart building. Given that the energy is replenishable, it is not necessary to overemphasize on energy saving (which is used to be the focus of existing research in low power electronics). Instead, it is more important to focus on efficient energy utilization. That is, how to utilize the available energy to achieve the maximum QoS continuously and constantly.

The straight forward solution to the above problem is through energy management at node level. At node level, a pervasive computing device with renewable energy source has three major components: an energy generation module (EGM, e.g. a solar panel), an energy storage module (ESM, e.g. a battery or an ultracapacitor) and an energy dissipation module (EDM, e.g. an embedded processor). They are connected by energy conversion units (ECUs, e.g., DC-DC converter). Our goal is to find the balance between energy dissipation and energy generation with the energy storage module acting as a buffer between these two. We identify 3 research topics that mostly relate to the goal.

1. Environment aware prediction of energy generation and dissipation. The pattern and the rate of energy generation are determined by the environment. For example, when and how frequent an iPad is charged depends on the habit of the user and whether it is a weekday or weekend. The energy harvesting rate of the piezoelectric shoes is determined by the pace of the user, which may change based on his/her location. The pattern and the rate of energy dissipation are determined by the sensing, actuation, computation and communication tasks in the system. Because these tasks are triggered by user inputs and external events, they are also closely related to the environment.

With various sensors installed in the system, environment awareness will be one of the features in future pervasive computing. What information is needed, how to utilize the available information to enhance energy prediction, and how to tradeoff between prediction complexity and accuracy are urgent research topics to be investigated. This research may produce new feature selection algorithms and data classification algorithms designed specifically for energy prediction.

2. Accurate modeling of the non-linear behavior of the energy generation, storage and converting modules. The efficiency of the EGM, ESM and ECU are complex functions of many variables. For example, the solar panel delivers the maximum power when the load resistance matches the internal resistance of the PV and the "rate-capacity" property of a battery states that the overhead of battery charging/discharging is an increasing function of its input/output current. Such variable conversion efficiency and battery overhead should be included in the models for the available energy and energy dissipation.
3. Models that reveal the intrinsic relation between the QoS and the power supply system of the device. The model must be able to answer two questions. i) Given the predicted energy generation as well as the capacity and efficiency of the energy storage, what is the maximum achievable QoS? ii) In order to achieve the required QoS, what is the minimum requirement of energy generation and energy storage?

The node level solution is over simplified because it does not consider the networked nature of a pervasive computing system. The energy dissipations on different nodes are not independent random processes. Instead they have high correlations due to information exchange, task migration, and response to the same local events. Similarly, the energy generation process on neighboring nodes may also have dependency on each other. Furthermore, what we are really trying to maintain is the overall QoS of the pervasive computing system, which is a joint function of the QoS of all nodes. In order to maintain the system level QoS, multi-agent negotiation among nodes may be carried out. Each node estimates its achievable QoS using the node level models, and multiple nodes share the QoS requirement based on their maximum capability through negotiation.

IMPACT OF PROPOSED RESEARCH We believe that a very large portion of pervasive computing devices will be powered by renewable energy in the future because it is the only way to achieve energy autonomy and to provide sustained service. The key challenge in pervasive computing using renewable energy is the high fluctuation in the energy harvesting rate. The success of this research will enable us to receive constant QoS from a pervasive computing system powered by energy source with high fluctuation. In contrast to the traditional research in low power electronics, which considers energy as a pure expenditure, the proposed research considers energy as a renewable resource and hence will produce a set of completely new algorithms for energy aware QoS management.

EXPERIENCE OF THE PARTICIPANT The participant has more than 10 years research experiences in dynamic power management of different computing systems. She is the recipient of NSF CAREER award in 2009 for the proposal "Adaptive Power Management for Multiprocessor System-on-chip." Her recent research focuses on machine learning based power management, multi-agent distributed thermal management for multi-core architecture, and adaptive power management for energy harvesting real-time embedded systems.