Poster Abstract: Energy Management in Wireless Healthcare Systems

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1. INTRODUCTION

Today's cutting edge mobile healthcare systems have a heterogeneous and tiered architecture consisting of a set of wireless sensors, a wireless local aggregator (LA) for each user and a backend server (BE) as shown in Figure 1. The main mode of operation is to gather the data from the sensors at the local aggregator and transmit it to the backend for further processing. Some great examples are the wireless preventive healthcare projects run at UCSD. These projects focus on encouraging study subjects to increase their physical activity and optimize their energy intake through real time monitoring and feedback to the study subjects via sensors (e.g. accelerometer, GPS, heart rate) and cell phones. During a 16 week clinical trial [2], the group using our system lost an average of 4.4 pounds more than the control group. As much as 96% of subjects were satisfied by the system and would recommend it to others. Clearly the study showed that real-time feedback to users is much more successful than other methods used to date.

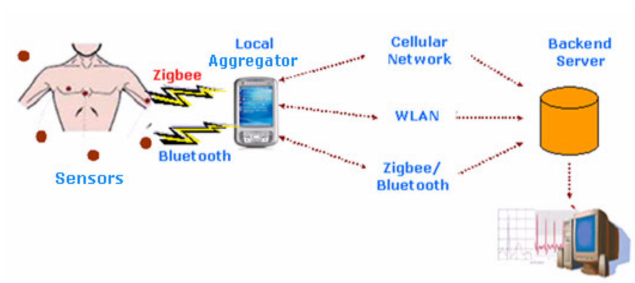

Figure 1: Wireless healthcare system architecture

One of the key challenges encountered during the clinical trials is managing energy consumption of the mobile devices used in the system due to limited battery lifetime. While today's sensor and cell phone processing capabilities have significantly increased, the cost of data transmission in terms of performance and energy required has not significantly decreased. As a result, the paradigm has shifted in favor of doing more processing locally to the user, and transmitting data only when connectivity and battery lifetime are favorable. The challenge in such systems is balancing the desire for immediate feedback from the sensing system against the cost in terms of battery life. Our work aims to address this challenge by implementing a task assignment strategy capable of selecting the level of processing (and thus data transmission) done at each system component (sensor, aggregator and backend) while maximizing the system lifetime and meeting delay and task dependency constraints.

2. TASK ASSIGNMENT PROBLEM

The tasks in a wireless healthcare system are categorized as sensing, processing and communication tasks. They are associated with each other through data producer/consumer relationships. Sensing tasks perform the raw measurements (e.g. ECG samples) and act as sources to various data processing tasks. Data processing tasks receive their inputs from one or more sensing and/or data processing tasks through communication tasks and perform computation to generate the desired output. Sensing tasks are tied to appropriate sensors while processing tasks, depending on their complexity, can be assigned to Sensors, Aggregator and/or a Backend Server. Assignment of the processing tasks to a given node affects its battery lifetime and task latency due to computation and communication costs. Thus, it is unclear which task assignment strategy leads to maximum system lifetime and real-time feedback to the users.

To determine the optimal task assignment we model the mobile healthcare application as a Directed Acyclic Task Graph (DAG): $G = (T, E)$ in which each vertex represents a task $T_i \in T$. Each edge in the graph $E_{ij} \in E$ shows that task T_j is dependent on T_i in order to perform computation. The weights W_{ij} on edge E_{ij} represent the amount of data to be communicated from task T_i to T_j. Based on the DAG we formulate an integer linear program (ILP) as outlined below.

Given: A DAG containing a set T of n tasks, a set R of m (heterogeneous) resources where for each resource, the fraction of energy consumed from the total battery lifetime available Bat_r by a specific task assignment $Assign: T \rightarrow R$ running on resource r is given by E_r / Bat_r.

Goal: Ensure that the rate of depletion of batteries throughout the system is balanced by minimizing the maximum fraction of energy consumed by a specific task binding for each resource subject to constraints listed below. The ILP objective is given in equation 1, while constraints are described below.

$$ILP : \min \left\{ \max \frac{E_r}{Bat_r} \mid r = 1,2,\ldots m-1 \right\} \quad (1)$$

- **Placement constraints:** A fraction of tasks can be executed only on some resources, so there is a subset of feasible assignments. For example, sensing tasks are bound to specific sensors. We call such tasks preallocated tasks.
- **Resource constraints:** If R_h denotes the resource requirement (CPU, memory, input/output) of task t_h and R_d is the total resource capacity of that device to which j tasks have allocated, then the equation below must hold true for each device.

$$\sum_{h=1}^{j} R_h \leq R_d \quad (2)$$

- **Communication constraints:** In certain cases, data must be communicated between tasks. Communication can occur internally on a device, if both its source and destination are assigned to the same device. If tasks are assigned to different resources, a communication network is used.
- **Task precedence constraints:** When execution of a task T_i requires data produced by task T_j, a precedence relation stating that T_i has to finish prior to T_j starting is formulated.
- **Delay constraints:** Tasks should meet their deadlines.

The output of the ILP is a static binding of tasks to resources in the system. In the next sections we evaluate the results of various static task assignments and motivate the extension of our work to dynamic task binding.

3. EXPERIMENTAL EVALUATION

To evaluate static task bindings we first modeled our system with the Qualnet simulator [5]. Sensor nodes (e.g. ECG and accelerometer) are modeled as MicaZ nodes with Zigbee radio. Sensors use small coin cell batteries, so their capacity is 560 mAh. The local Aggregator is modeled as UMTS-UE (User Equipment i.e. Handset) with Zigbee. The handset is connected to the Backend Server via UMTS network. Battery capacity for the UMTS handset is 1300 mAh (based on the HTC Tilt UMTS phone). We used a linear battery model in our experiments.

The results of simulations, shown in Table 1, indicate that processing on sensors rather than communicating raw data to LA and BE improves the lifetime of the system by approximately 250%.

Table 1: Experimental Results

Processing task at	System Lifetime	Node that died first	% of battery left on other nodes
Sensors	~14 days	LA	ECG: 40% Accelerometer: 67%
LA	~ 4 days	Sensors	LA : 70%
BE	~ 4 days	Sensors	LA: 72%

To further analyze this trade-off in real systems we implemented the task binding on a system developed for preventive healthcare research [3]. This system consists of a Bluetooth sensor AliveHeart [4] which measures ECG samples and acceleration. We use the HTC Touch 3G PDA phone as a local server and IIS .Net framework for the backend server. We ran the system under two different configurations. In one configuration, the phone does all the processing which includes heart rate per minute and activity count calculations. In the second test, the server does all the processing of raw data sent from the sensor via the phone. Our measurements show that processing data on the phone rather than communicating the raw data to the server for the same computation improves the battery lifetime of the system by approximately 300%. These results confirm that choosing the right task assignment has a large impact on the overall system battery lifetime.

4. CONCLUSION AND FUTURE WORK

We implemented and analyzed the battery lifetime optimization problem for wireless healthcare systems and showed that task assignment can play a major role in energy management. In the static case, where system parameters are fixed (e.g. processing and communication latency), the assignment of tasks to heterogeneous nodes in the system significantly affects performance and the level of available energy. Since task binding and scheduling problems are NP hard [1], heuristic algorithms are needed for practical solutions. Furthermore, the overall system characteristics are dynamically changing – the availability of the wireless network and its throughput, battery capacity of various nodes in the system, the user's needs, etc. To address the dynamic aspects of the system and the resource constrained nature of the mobile nodes, we will implement a heuristic algorithm to achieve a longer battery lifetime of the system. We plan to evaluate the performance of the heuristic and compare it against the optimal solutions produced by the ILP.

5. REFERENCES

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[5] Qualnet – www.scalable-networks.com