

Efficient Placement and Routing in Grid-Based Networks

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ABSTRACT

This paper presents an efficient technique for placement and routing of sensors/actuators and processing units in a grid network. Our system requires an extremely high level of robustness and efficient power optimization techniques. By modeling the faults, we evaluate the probability of having failures in network. Then we study two problems of placement and routing in the sensor networks such that the fault tolerance is maximized while the power consumption is minimized. We develop efficient methodology to address these problems and perform both placement and routing simultaneously. This ensures that the solution is a lower bound for both problems. We evaluate the effectiveness of our proposed techniques on a variety of benchmarks.

Categories and Subject Descriptors

B.8.0 [Performance and Reliability]: Fault-tolerance and power optimization in grid sensor networks.

General Terms

Algorithms, Management, Performance, Design, Reliability.

Keywords

Sensor Networks, Placement, Routing, Fault-Tolerance.

1. INTRODUCTION

The characteristics of the flexible electronics technology and the requirements of the applications enabled by it necessitate radical innovation in system-level design. Electronic components built of flexible materials have characteristics that are very different from that of silicon and PCB-based electronics. Fault tolerance become more eminent in electronic textile due to criticality of the applications running on this architecture. We use pervasive patient monitoring and sensor-driven personalized trans-dermal drug delivery as our driver application. One possibility of

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leveraging electronic textile technology in the context of such an application is to create a flexible garment (i.e., vest) that the patient can wear, which has sensing, computation, communication, and actuation elements embedded in it.

2. RELATED WORK

Placement and routing problems on a grid have been studied extensively in the field of VLSI CAD. There has been considerable research effort to solve these problems. Like most other VLSI layout problems, it is believed that placement and routing cannot be solved optimally in a reasonable amount time [1] [2]. Therefore, heuristic algorithms are used to obtain near-optimal solutions [3] [4]. The main difference between our approach and other existing techniques is that we perform both placement and routing simultaneously. The solution that we find is also a lower bound for both problems. Our technique easily accommodates our requirements in terms of the instance size and the number of sensors, actuators and processing units to be placed and routed.

3. PRELIMINARIES

3.1 Interconnection Topology

The interconnection medium for our proposed system is a mesh of wire segments. The mesh interconnection topology is a wire-frame that has a regular structure, each vertex being connected to exactly four other vertices. The interconnection topology is modeled as a grid graph illustrated in Figure 1.

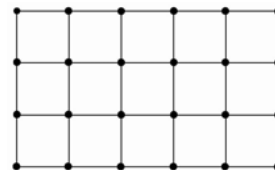


Figure 1: Interconnection Topology

3.2 Power/Fault Lifetime

The mobility of our system requires the use of constrained power sources (i.e. batteries). Therefore, in the design of such system, power optimization is one of the major objectives. The amount of power resources available to the system determines the life time of the system which will be referred to as power lifetime (l_p). In the following equations, E indicates the remaining energy of the

system power source while P_w represents the power consumption rate of each node in the grid and n exhibits the number of active nodes. We define the power lifetime of the system as follows:

$$l_p = \frac{E}{P_w n} = \frac{1}{\lambda_p n} \quad \text{where} \quad \lambda_p = \frac{P_w}{E} \quad (1)$$

Our system is made of fabric which is susceptible to accidental damage via tears and punctures. Such faults may yield loss of a connection and therefore, may result in total system failure. When a fault occurs, assuming the probability of losing a particular edge is given, we can calculate the expected lifetime of our system. The expected fault lifetime is shown below where λ_f and α are the fault occurrence rate and probability of having system failure respectively.

$$\bar{l}_f = \frac{1}{\lambda_f \alpha} \quad (2)$$

4. PROBLEM DEFINITION

To increase the power lifetime, once we perform placement and routing, we seek to minimize the total length of routing. To improve the fault lifetime, we attempt to use the edges which are less susceptible to faults. The overall lifetime of the system is dependent both on power and fault lifetime. Therefore, to maximize the overall lifetime of the system, we shall maximize the minimum of power and fault lifetimes.

$$MAX(MIN(l_p, \bar{l}_f)) \quad (3)$$

However, the objective function in an ILP formulation may not contain both MAX and MIN as shown in (3). Therefore, we redefine the objective functions as illustrated in (4) and (5) and have the solver optimize both objectives individually in two different runs.

$$MAX(l_p) \quad \text{s.t.} \quad l_p < \bar{l}_f \quad (4)$$

$$MAX(l_f) \quad \text{s.t.} \quad \bar{l}_f < l_p \quad (5)$$

5. EXPERIMENTAL ANALYSIS

Various benchmarks are generated for the experimental analysis. The size of benchmarks varies from 5x5 to 11x11. The number of communication pairs is altered as well. The communication pairs are placed across the grid randomly for each instance size. The power consumption of the processing units is assumed to be $P_w = 30 \text{ mW}$ (Berkeley mica2dots - power supply voltage 3V). We also assume that the system is equipped with sixteen 1.5V, 2000mAh AA batteries. Hence, $\lambda_p = 0.000625 \text{ h}^{-1}$. Fault occurrence rate, λ_f picks the values of $1/24 \text{ h}^{-1}$ and $1/36 \text{ h}^{-1}$. $\lambda_f = 1/24 \text{ h}^{-1}$ implies that on average, a random tear occurs in every 24 hours.

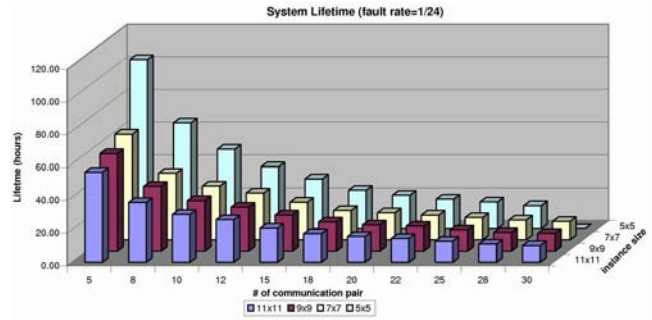


Figure 2. Lifetime Analysis

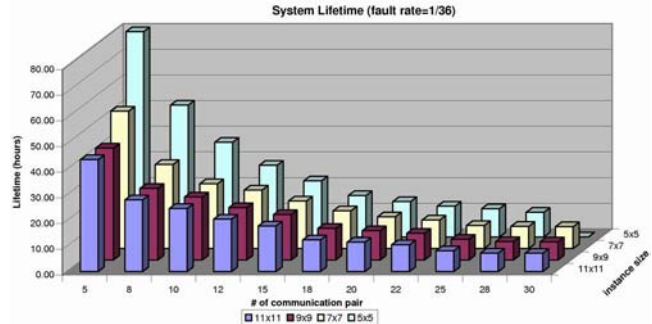


Figure 3. Lifetime Analysis

Figures (2) and (3) present lower bounds for both power and fault lifetime of systems with $\lambda_f = 1/24 \text{ h}^{-1}$ and $1/36 \text{ h}^{-1}$ respectively. As shown, once the fault occurrence rate, λ_f , increases, the overall lifetime of the system decreases and more efforts must be spent on fault tolerant routing.

6. CONCLUSION

We proposed a new technique for placement and routing in sensors networks. Our technique employs ILP and generates a lower bound solution for both placement and routing problems. Our method accomplishes both placement and routing simultaneously and considers both fault tolerance and power optimization objectives. We showed that in order to improve the overall performance and lifetime of a sensor network, it may not be sufficient to focus on only one aspect of optimization and various factors may have to be considered.

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