MobiCom Poster Abstract: An Energy-Efficient Fault-Tolerant Monitoring System for Sensor Networks [*]

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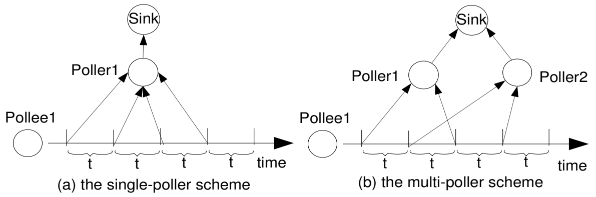
I. Introduction

Because sensors are often deployed in harsh and/or adversarial environments, the sensors or the communication links may fail and hence endanger the mission of the sensor network. Although using more redundant sensors can tolerate some sensor failures, in most cases, only limited sensors are awake to extend the network life time. Therefore, sensor status (such as liveness, density estimation, residue energy, etc.) has to be closely monitored and made known to the sink, which can promptly react to the sensor status changes.

In this paper, we revisit the widely used poller-pollee structure in IP networks [1], where each poller monitors its pollees either actively (i.e., by sending a "ping" message and wait for the reply) or passively (i.e., by waiting for the pollees to proactively send a message). Based on this poller-pollee structure, we let sensors self-organize themselves into two tiers, with pollees in the lower tier and pollers in the upper tier. The pollees send status reports to the pollers, which, in turn, generate aggregated status reports and forward them towards the sink. Different from existing work on poller-pollee structure, we consider two important issues: *fault-tolerance* and *energy efficiency*, when building the sensor network monitoring system.

II. The round robin based multi-poller scheme

To provide fault tolerance, we let each pollee be monitored by multiple pollers. While sending reports to multi-pollers simultaneously can reduce the false alarms, it will increase the bandwidth consumption. To address this issue, we propose a round robin based multi-poller scheme, where the monitored sensor sends the status report to different poller in a round robin manner. Through analysis, we show that the round robin based multi-poller solution can significantly reduce the false alarm rate while consuming similar amount of energy compared to the single poller scheme.



(a) the single-poller scheme (b) the multi-poller scheme

Figure 1: Asynchronous operation at poller and pollee, with the arrow denoting the status reporting

Let t denote the polling time interval at the pollee, and let ω denote the number of pollers for each pollee. Suppose the sink needs time T_d, referred to as the detection time, to detect a pollee failure. The single-poller and multi-poller scheme can be stated as:

- *Single-poller scheme*: each pollee sends a report to the same poller every t; each poller collects reports from its pollees every t and forwards the compressed report to the sink every t; the sink evaluates the failure condition every T_d. It is required that $t \leq T_d$.
- *Multi-poller scheme*: each pollee schedules a report to the different poller every t; each poller collects reports from each of its pollees every ωt and forwards the compressed report to the sink every ωt; the sink evaluates the failure condition every T_d. It is required that $\omega t \leq T_d$.

Fig. 1 illustrates the single poller scheme and multi-poller scheme using an example. In Fig. 1(a), pollee 1 sends reports to poller 1 every t; in Fig. 1(b), pollee 1 sends to poller 1 or poller 2 every $2t$ in a round robin manner. Then the sink can collect two reports every $2t$ and choose detection time $T_d \geq 2t$. With single poller, if the communication link between pollee 1 and the sink has some problem, the sink will have a false alarm on the status of pollee 1. However, there will not be any false alarm in the multi-poller scheme. In general, with the same detection time delay and the same amount of traffic, the multi-poller scheme will have a much smaller false alarm rate.

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[*] This work was supported in part by the National Science Foundation under grant CNS-0519460.

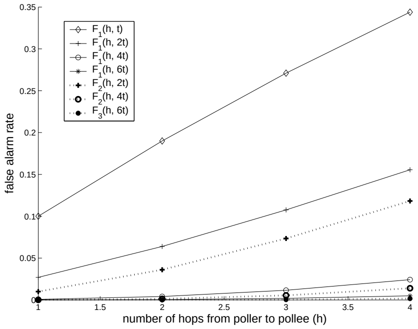

Figure 2: false alarm rate ($f_l = 0.1$)

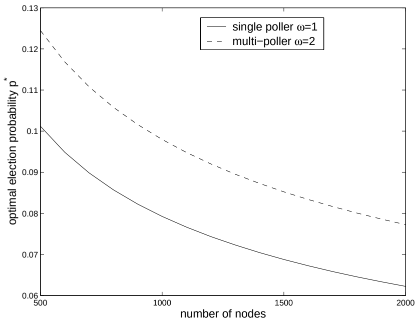

Figure 3: optimal p^* VS. n

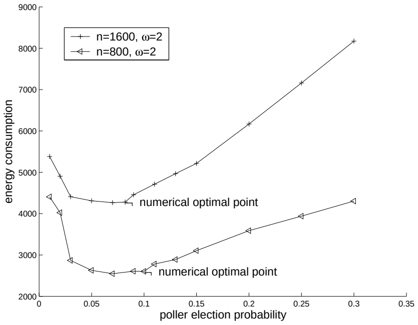

Figure 4: Energy VS. p

We model the link failure as a continuous-time markov chain with average failure rate f_l. We further use $F_1(h, T_d)$ and $F_w(h, T_d)$ to denote the false alarm rate for the single poller scheme and the multi-poller scheme, where h is the number of hops from poller to pollee, T_d and w are defined as before.

Fig. 2 shows some numerical result. As can be seen, the false alarm rate increases as h increases, since longer path is more vulnerable to failure. As T_d increases, the false alarm rate decreases. For example, even for the single poller scheme, when $h = 1$, $F_1(h, t) = 0.1$, but $F_1(h, 2t) = 0.025$; that is, doubling the detection time can reduce the false alarm rate by as much as 75%. We can also see that the multi-poller scheme consistently outperforms the single poller scheme in terms of false alarm rate. For example, with $h = 1$, $F_1(h, 2t) = 0.025$, but $F_2(h, 2t) = 0.01$, which represents a 60% false alarm reduction.

III. An Energy Efficient Randomized Algorithm

A simple randomized algorithm is proposed to select the statistically optimal number of pollers to minimize the average energy consumption. Each node first elects itself as a poller with probability p. The selected pollers then announce their poller status within k hops. Sensor nodes that did not elect themselves as pollers will be pollees, and each pollee selects ω monitoring pollers based on the received announcements. The value of k is carefully chosen to ensure that most pollees can locate their primary and second pollers with a high probability.

Our objective is to find p^*, the optimal fraction of nodes that are pollers, such that the average energy consumption per polling interval can be minimized if each pollee is monitored by ω pollers. Suppose n sensors are uniformly deployed in a square area. Based on the spatial point theory [2], the spatial location of the sensors can be approximated by a homogeneous two-dimension Poisson process. Based on some geometric result [3, 4], we derive the relationship between p^* and the number of sensors n, as shown in Fig. 3.

Fig. 3 shows that as more sensors are deployed, p^* becomes smaller. For example, when $\omega = 2, n = 800$, p^* is about 0.1, but becomes around 0.08 when $n = 1600$. It can also be observed that p^* for the multi-poller ($\omega = 2$) scheme is larger than that of the single poller ($\omega = 1$) scheme.

Fig. 4 shows some simulation result about the effect of p on the total energy consumption. In the experiment, n sensors are randomly deployed in a 20×20 square area. The transmission of one packet over one hop is assumed to consume one unit of energy. We set the aggregation ratio $s = \lfloor \frac{29}{4} \rfloor = 7$. This is because in Mica2 sensor motes, each packet has a 29-byte payload, and we assume the status information such as the residue energy can be represented by 4 bytes. It can be seen that as p increases, the energy consumption first decreases then increases. On each curve, the real optimal p^* corresponds to the point of minimum energy, which matches the numerical result very well.

References

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