Poster: Environment-Adaptive Clock Calibration for Wireless Sensor Networks

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ABSTRACT

In this paper, we propose a novel clock calibration approach, which addresses two key challenges for clock calibration in Wireless Sensor Networks: excessive communication overhead and the trade-off between accuracy and cost. To achieve this, our approach leverages the fact that the clock skew is highly correlated to temperature, which can serve as both an assistant for clock skew estimation and a regulatory factor for the duty-cycled design. Our approach is one order of magnitude more power-efficient than communication based approaches since the calibration largely relies on local temperature information. In addition, our approach provides a nice feature of self-adaptive period, which can substantially promote the system flexibility. We present the theory behind our approach, and provide preliminary results of a simulated comparison of our approach and some recent approaches.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

Keywords

Clock Calibration; Environment Adaptive; WSNs

1. INTRODUCTION

Tightly synchronized time cross the network is extremely significant for many WSN (Wireless Sensor Network) applications, since WSNs typically comprise numerous nodes and a common notion of time between the nodes is required to facilitate cooperative transmission, information fusion, localization, etc. Thus, an uncontrolled clock offset will inevitably leads to the high network loss ratio and the failure of data processing, which eternally disrupt the normal operation of the WSNs.

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Clock calibration in WSNs, however, is a very challenging issue. Recent studies[2, 3] show that the low-cost crystal oscillators in wireless sensor networks (WSNs) are prone to be affected by environmental temperature. This property, and the fact that WSNs are mostly deployed over harsh environments, lead to the following two severe challenges in clock calibration approaches: (i) excessive communication overhead; and (ii) trade-off between accuracy and cost.

Excessive communication overhead: The temperature variation may lead to the fluctuation of clock skew (clock drift rate). Due to this uncertainty, no matter how accurately clocks are initially calibrated, they will ultimately tick towards divergency. Thus continuous skew calibration which based on timestamp exchange is required to minimize the negative impact from the dynamic environment. Unfortunately, WSNs today typically composed of hundreds of sensor nodes, and those nodes usually wireless interconnected in a multi-hop manner. As a direct consequence, frequently calibrating clocks prohibitively incurs high overhead and significant energy consumption for coordinating the entire network[1].

Trade-off between accuracy and cost: Existing calibration approaches[1, 2, 3] typically configure the clock skew compensation in a fixed cycle fashion. In spite of microsecond level accuracy achieved, they are fail to provide a trade-off between accuracy and cost. In practice, clock skew exhibits a hybrid change pattern due to the dynamic temperature[3]. Therefore, an auto-adaptive interval adjustment design, which is universal for all the skew changing patterns should be introduced for the best cost performance.

In this paper, we introduce a novel environment-adaptive clock calibration approach that enables nodes to estimate their clock skew by exploiting temperature information. The approach can substantially reduce communication overhead since clock skew estimation is mostly rely on local information. In addition, we further propose an environmental-adaptive interval adjustment scheme for duty-cycled clock calibration, which provides a convenient trad-off between the timing accuracy and the energy efficiency.

2. ENVIRONMENT-ADAPTIVE CLOCK CALIBRATION

In [2, 3], the correlation between the temperature and the clock skew is assumed to be invariable. This assumption is unrealistic and will leads to skew estimation error. Therefore, we introduce an innovative correction factor TSF(t) ("Temperature-Skew" Factor), which express the correlation as a function of time and thus requires periodically update.

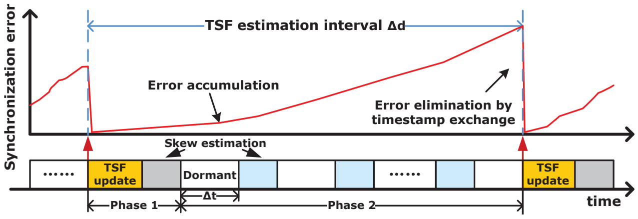

Figure 1: Illustration of two-phase calibration.

By using TSF(t) and the temperature measurement, nodes can estimate the clock skew autonomously.

As shown by Fig. 1, our approach features a two-phase process: i) it first estimates and updates the TSF(t) based on the timestamp exchange with the reference and then ii) it estimates the clock skew autonomously based on the temperature and TSF(t) during the TSF estimation interval. The red line between two TSF estimation represents the error accumulation caused by the fluctuation of TSF(t) during the interval, and this error can be eliminated by the timestamp exchange in the following TSF estimation phase. It is to note that, during the TSF estimation phase, clock skew is calibrated based on timestamp exchange.

2.1 Clock calibration

TSF estimation: To estimate the TSF, the temperature variation and the corresponding change in clock skew is during this phase required. Temperature information can be obtained by the temperature sensor and the clock skew is obtained based on timestamp exchange [1]. Thus, the TSF at the i-th TSF estimation period can be updated as:

$$TSF[i] = \frac{g(\Delta\alpha[i])}{f(\Delta T[i], T_0)}$$

$g(\Delta\alpha[i])$ and $f(\Delta T[i], T_0)$ express the temperature variation and the clock skew variation during the i-th TSF estimation phase. T_0 is the reference temperature (25°C). Assuming that the TSF doesn't change during the TSF estimation interval, the node can subsequently switch into the clock compensation phase.

Clock compensation: During compensation, the nodes regularly measure their environmental temperature $T(t)$. After every measurement, the current clock skew estimate $\alpha(t)$ is updated based on $T(t)$ and TSF[i] as:

$$\alpha(t) = TSF[i] \cdot (T(t) - T_0)^2$$

It is to note that every time the node changes its clock skew estimate after a temperature measurement, it has to update its current clock offset estimate as discussed in [2].

2.2 Interval adjustment scheme

To improve the energy efficiency of our clock calibration design, we further propose to configure the TSF estimation interval (or timestamp exchange interval) Δd in a dynamic manner. The challenge in the dynamic interval design is that the achieved performance might be compromised by trading for the energy saving. In our design, we predict the TSF estimation interval based on the observed error accumulation and temperature variation during the previous interval. Thus the nodes can automatically adjust the interval length to control the synchronization error, and meanwhile accommodate to the changing environment.

$$\Delta d[i+1] = min(d \cdot \frac{\mu}{e[i]}, d \cdot \frac{\lambda}{DT[i]})$$

μ and λ are the error and the temperature controlling factor. $\Delta d[i+1]$ is the next interval and d is the standard interval length. e and DT describe the error accumulation and the temperature variation during the previous interval.

3. RESULTS

We report the simulation study in this section for evaluation of our approach. The generated temperature trace is in a hybrid change pattern with both stable period and changing period, which imitates the dynamic environment.

Fig.2 shows the CDF curve of calibration errors for EACS[3] and our approach. For our approach, the skew estimation error is less than 0.6ppm for most of the time. However, for EACS, more than 20% of the skew estimation errors exceed 2.5ppm. It is obvious that our approach is effective in mitigating the skew estimation error.

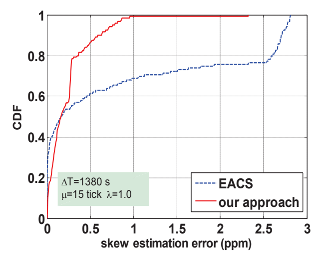

Figure 2: CDF of skew estimation error

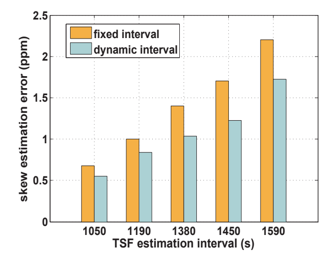

Figure 3: skew estimation error v.s. TSF estimation interval

Fig.3 reveals the effectiveness of the Interval adjustment scheme. We choose five different standard intervals (d) to be 1500s, 1800s, 2000s, 2300s and 2500s. When the simulation terminates, we calculate the average length of the intervals to be 1050s, 1190s, 1380s, 1450s and 1950s. We find that the fixed interval policy generally incurs a larger error than the dynamic one when they have the same average interval. Another important observation is that the timestamp exchange interval can be prolonged to more than 1000s, while that for communication based approaches[1] is less than 150s.

4. ACKNOWLEDGMENTS

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