On Efficient Message Passing in Energy Harvesting Based Distributed System

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Energy Harvesting Based Distributed System

- Thermal Gradient
- Light
- Wireless Transmission
- Motion
- Traditional Node with Power Supply
- Energy Harvesting Node
Previous Works

Wireless radio is one of the highest power consuming components

• **Node-Level: Offline Optimization Policy**
  – Assume energy profile is known and adjust transmission rate based on packet, ambient energy and/or channel state information

• **Network-Level: Harvesting-Aware Routing**
  – Routing Protocols: route selection
  – Clustering: route packets to cluster heads, cluster formation and cluster head selection
Motivation

• Energy waste due to retransmission
  – inadequate and unstable input power
  – frequent power off of energy harvesting device
  – frequent failure of transmission

• Previous works
  – Assume that energy harvesting times and harvested energy amounts are known offline
  – Have not discussed transmission failure due to inadequate energy of the sender or the receiver

• Our method: predict and improve success rate of transmission
Process of Reliable Message Passing

- Loss of message
  - Feedback (similar to TCP)
- Energy waste due to retransmission
  - Predict probability of success first
Prediction of Successful Transmission

- Conditions for successful transmission
- Steps of prediction
- Probability prediction of conditions
- Parameters for prediction strategy
Conditions for Successful Transmission

• Conditions for successful message passing
  – The sender sends message successfully
  – The receiver receives message and sends feedback successfully
  – The sender receives feedback successfully

• Success of message passing is equivalent to satisfaction of all the three conditions

• When one of the device is with stable power supply, the only difference lies in prediction
Steps of Prediction

Steps of prediction of successful message passing

• Calculate the probability \((P_1, P_2 \text{ and } P_3)\) that three conditions are satisfied respectively

• Estimate the weight of every condition \((\alpha_1, \alpha_2 \text{ and } \alpha_3)\)

• Calculate the probability of successful transmission

\[
P = P_1^{\alpha_1} \times P_2^{\alpha_2} \times P_3^{\alpha_3}
\]
Probability Prediction of Conditions

Assumptions

• Communication channel is always perfect
• Work status of node is quasi-periodic
  – Work status: on and off
  – Quasi-periodic: length and duty cycling of the work period is approximately periodic
    • Quasi-periodic input power (motion, vibration)
    • Adaptive control of duty cycling in energy harvesting device, variance of duty cycling less than 20%
Probability Prediction of Conditions

Parameters

- Delay: $d_{12}, d_{21}$ (known)
- Message: $l, l_f$ (known)
- Node state:
  $T_1, T_{1,off}, T_2, T_{2,off}, t_1, t_2$
    - $T_1, T_{1,off}$ (update online from latest N periods, average)
    - $t_1$ (known)
    - $T_2, T_{2,off}, t_2$ (received message)

\[
    t_2 = (t_2 + d_{21} + t_{\text{passed}}) \% T_2
\]

Message is from node 1 to node 2
Probability Prediction of Conditions

Formulation of 3 conditions

The node should stay on when sending or receiving

• Condition 1: node 1 sends
  \[ t_1 \leq T_{1,\text{on}} - l \]

• Condition 2: node 2 receives and sends feedback
  \[ (t_2 + l + d_{12})\% T_2 \leq T_{2,\text{on}} - l - l_f \]

• Condition 3: node 1 receives feedback
  \[ (t_1 + l + d_{12} + l + l_f + d_{21})\% T_1 \leq T_{1,\text{on}} - l_f \]
Probability Prediction of Conditions

Probability calculation of each condition
(take condition 2 as an example)

Condition 2: the receiver receives message and sends feedback successfully

\( (t_2 + l + d_{12})\% T_2 \leq T_{2,\text{on}} - l - l_f \iff t_2 + 2l + l_f + d_{12} \leq T_{2,\text{on}} + nT_2 \)

L.H.S are all fixed values. Average value and variance of T on R.H.S are calculated with latest N periods. We can use certain distribution to estimate distribution of R.H.S and then calculate the probability that RHS is larger than LHS.
Weights of conditions

- Conditions have different weights ($\alpha_1$, $\alpha_2$ and $\alpha_3$) according to which one fits the actual situation better.
- Condition 2 predicts status of other nodes based on last message from receiver, $t_2$, $T_{2,\text{on}}$, $T_2$ may change a lot after long time, the weight $\alpha_2$ should decrease with time.
  - One simple method: linear model

$$\alpha_2 = 1 - \omega \times \frac{t_{\text{passed}}}{t_{\text{ref}}}$$

where $\omega$ and $t_{\text{ref}}$ are user defined parameters.
Parameters for Prediction Strategy

- Probability threshold
  - Decide effect of prediction
  - Based on the quality of prediction
- Interval of prediction (time interval between attempts of prediction)
  - Decide overhead of prediction
  - Based on the period of node cycle
- Number of latest cycles used to calculate $T$
Experimental Results

Experimental setup

• Evaluation of efficient message passing method: success rate and energy consumption with and without prediction (mean duty cycle 15% to 90%, variance up to 50%)
  – Previous works on adaptive control of duty cycling for energy harvesting devices: mean 15% to 40%, variance less than 20%
  – Wide range of power consumption of wireless node

• Analysis for parameters of prediction strategy
  – Probability threshold and interval of prediction
Experiment Results

Evaluation of efficient message passing method

Comparison between Message Passing with and without Prediction (Variance: 10%)
Experiment Results

Evaluation of efficient message passing method

Effect of Duty Cycle Variance on Efficient Message Passing (Duty Cycle: 30%)
Experiment Results

Analysis for parameters of prediction strategy

Parameter Analysis for Prediction Strategy (Duty Cycle: 30%, Variance: 10%)

(a) Change Probability Threshold

(b) Change Interval of Prediction
Question Time

Thanks for Your Attention!