# On Efficient Message Passing in Energy Harvesting Based Distributed System

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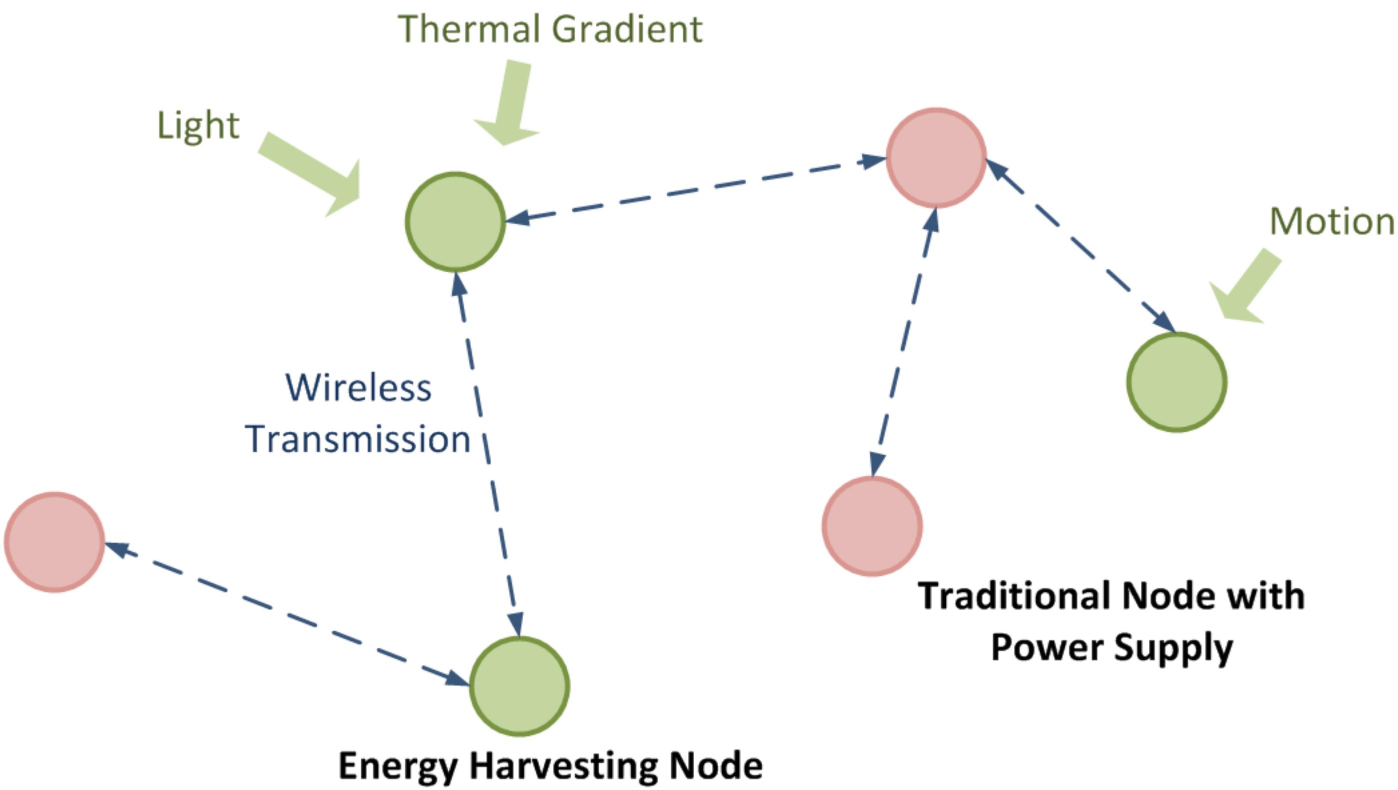
# Energy Harvesting Based Distributed System



# Previous Works

Wireless radio is one of the highest power consuming components

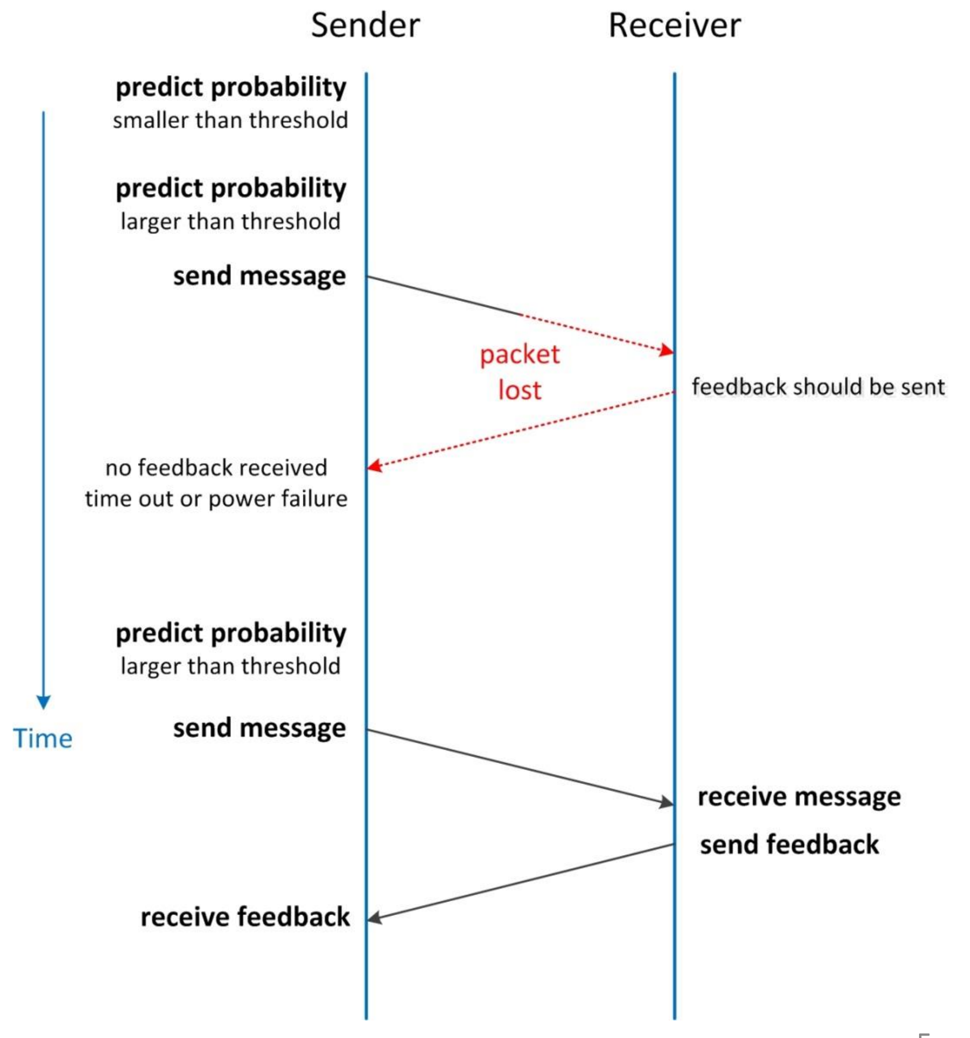
- Node-Level: Offline Optimization Policy
  - Assume energy profile is known and adjust transmission rate based on packet, ambient energy and/or channel state information
- Network-Level: Harvesting-Aware Routing
  - Routing Protocols: route selection
  - Clustering: route packets to cluster heads, cluster 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 retransimission
  - Predict probability of success first



# Prediction of Successful Transmission

- Conditions for successful transmission
- Steps of prediction
- Probablity 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 ($P_1, P_2$ and $P_3$) that three conditions are satisfied respectively
- Estimate the weight of every condition ($\alpha_1$, $\alpha_2$ 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**

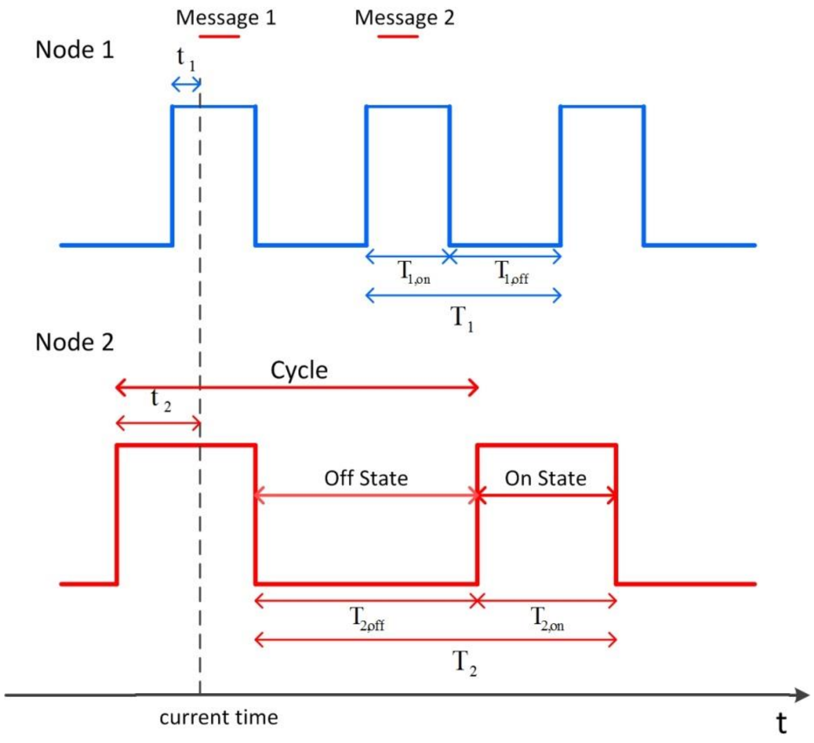
- Communication channel is always perfect
- Work status of node is quasi-periodic
  - Work status: on and off
  - Quasi-periodic: length and duty cycling of the work period is approximately periodic
    - Quasi-periodic input power (motion, vibration)
    - Adaptive control of duty cycling in energy 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: $T_1, T_{1,on}, T_2, T_{2,on}, t_1, t_2$
  - $T_1, T_{1,on}$ (update online from latest N periods, average)
  - $t_1$ (known)
  - $T_2, T_{2,on}, t_2$ (received message)

$$t_2 = (t_2 + d_{21} + t_{passed})\%T_2$$



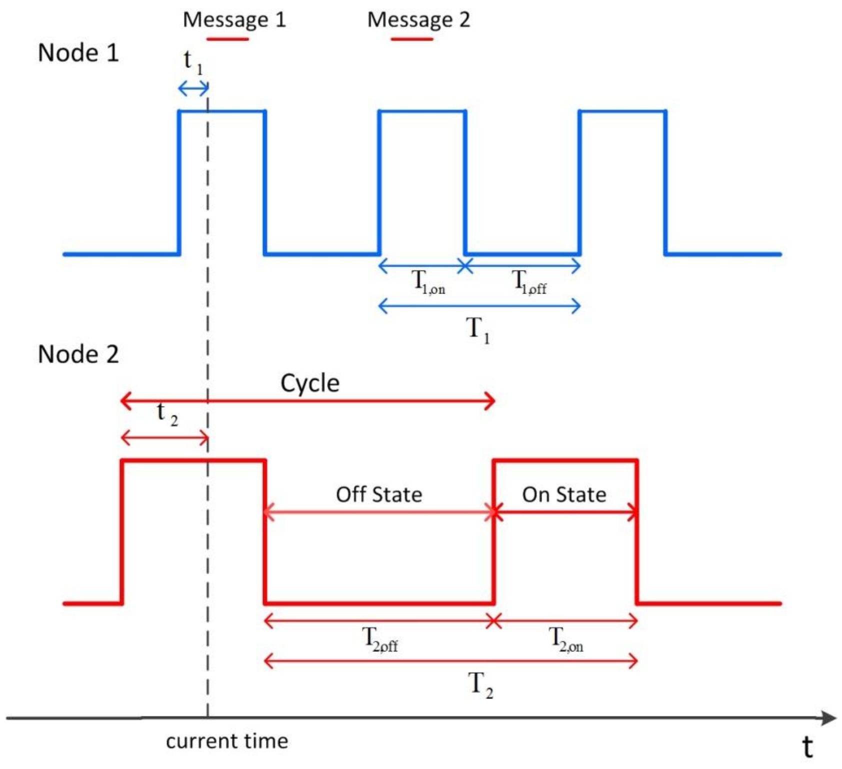

Message is from node 1 to node 2

# Probability Prediction of Conditions

## Formulation of 3 conditions

The node should stay on when sending or receiving

- Condition 1: node 1 sends
  $t_1 \leq T_{1,on} - l$
- Condition 2: node 2 receives and sends feedback
  $(t_2 + l + d_{12})\% \, T_2 \leq T_{2,on} - l - l_f$
- Condition 3: node 1 receives feedback
  $(t_1 + l + d_{12} + l + l_f + d_{21})\%$
  $T_1 \leq T_{1,on} - l_f$



# 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

$$(t_2+l+d_{12})\%\, T_2 \le T_{2,on} - l - l_f \Leftrightarrow t_2 + 2l + l_f + d_{12} \le T_{2,on} + nT_2$$

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.

# Probability Prediction of Conditions

## 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, $t_2$, $T_{2,on}$, $T_2$ may change a lot after long time, the weight $\alpha_2$ should decrease with time
  - One simple method: linear model

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

where $\omega$ and $t_{ref}$ 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 attemps of prediction)
  - Decide overhead of prediction
  - Based on the period of node cycle
- Number of latest cycles used to calculate T

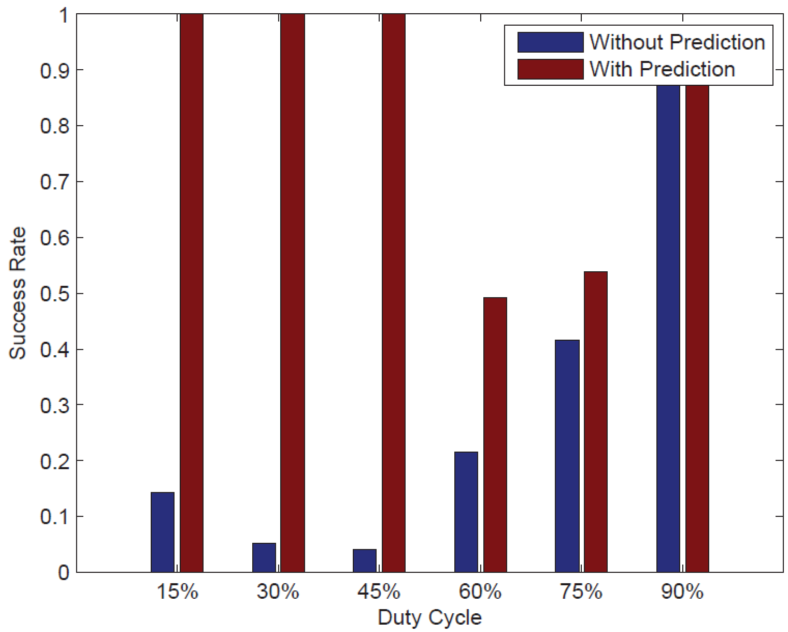
# Experimental Results

## Experimental setup

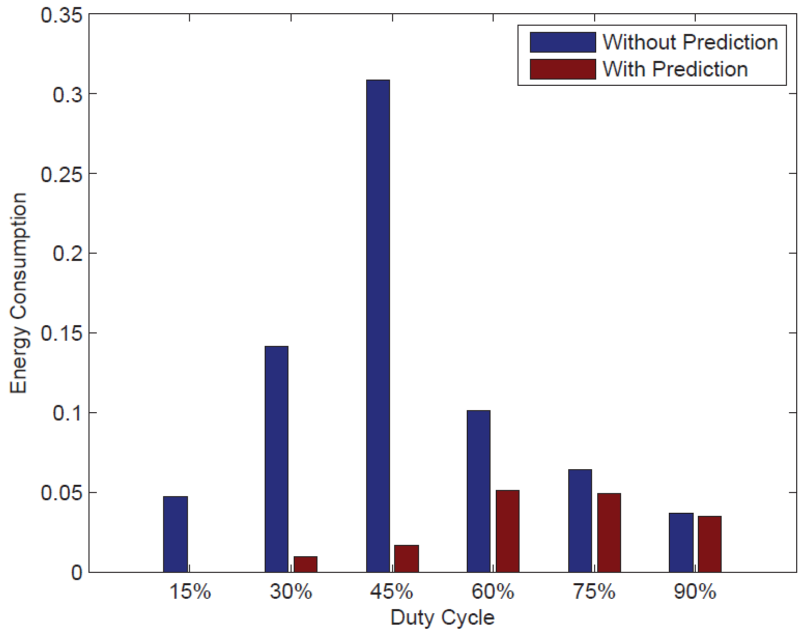
- Evaluation of efficient message passing method: success rate and energy consumption with and without prediction (mean duty cycle 15% to 90%, variance up to 50%)
  - Previous works on adaptive control of duty cycling for energy harvesting devices: mean 15% to 40%, variance less than 20%
  - Wide range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




(a) Comparison of Success Rate

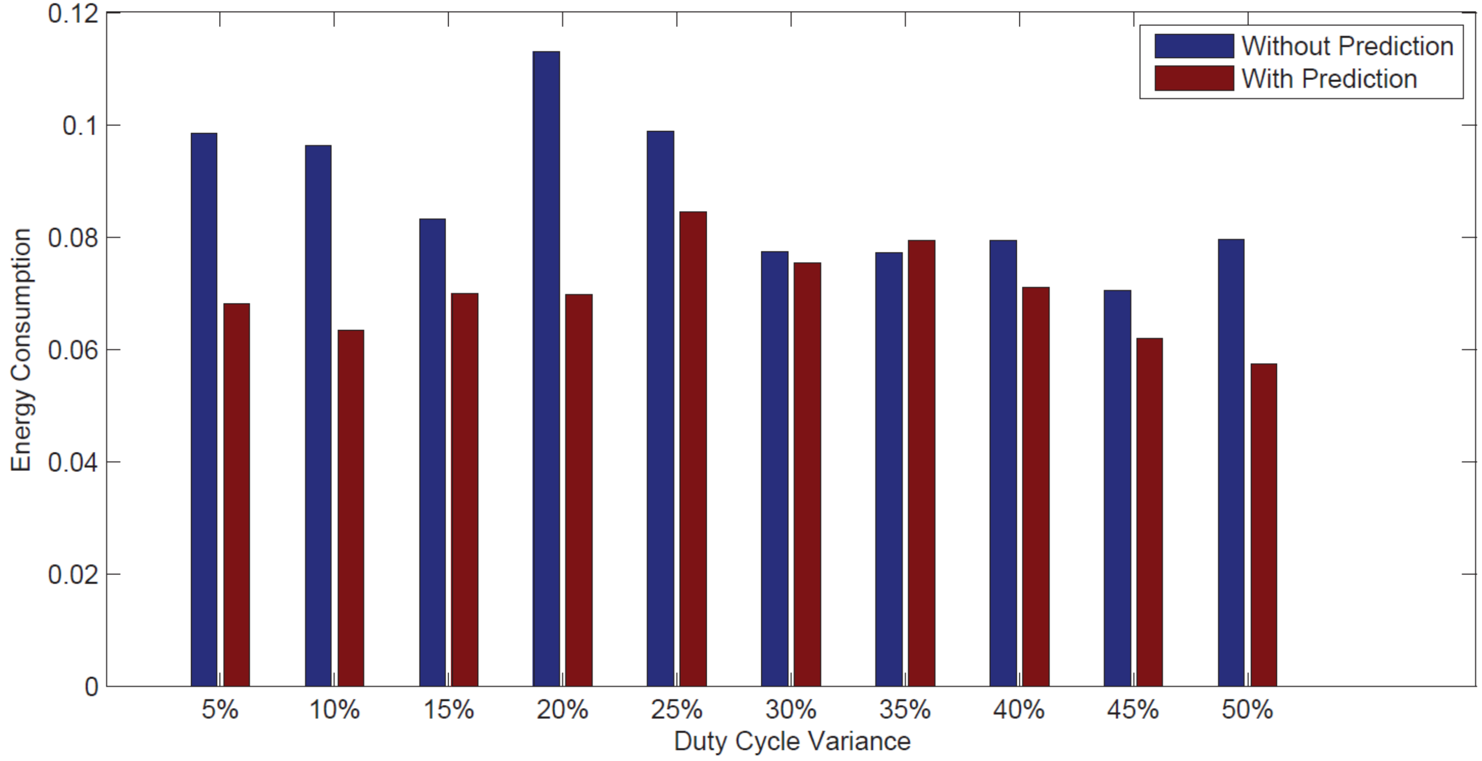



(b) Comparison of Energy Consumption

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

# Experiment Results

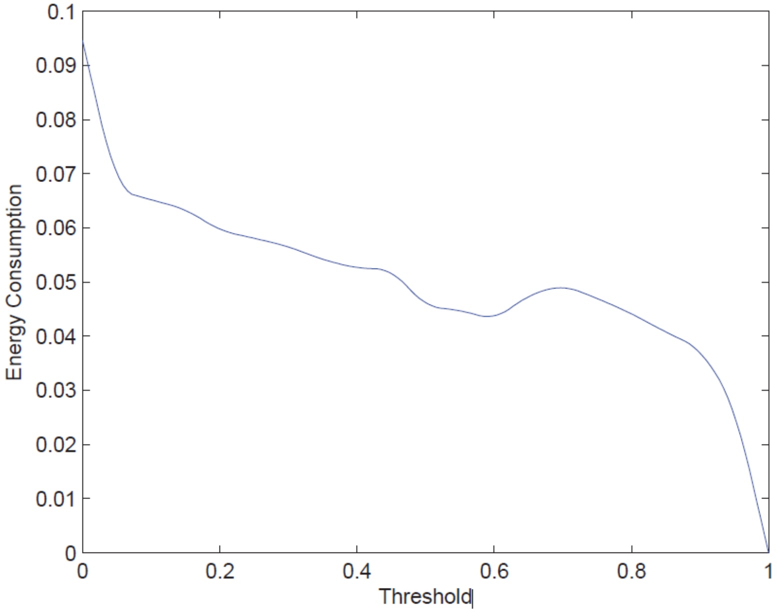
## Evaluation of efficient message passing method



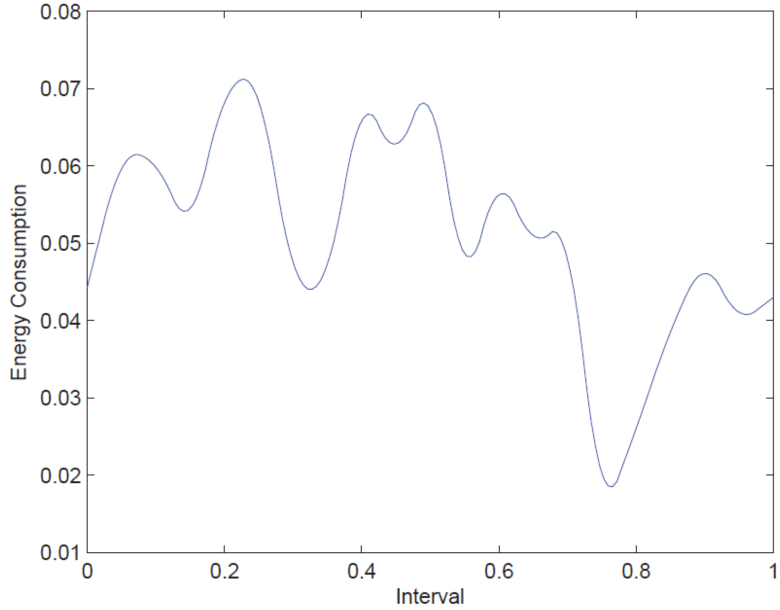

Effect of Duty Cycle Variance on Efficient Message Passing (Duty Cycle: 30%)

# Experiment Results

## Analysis for parameters of prediction strategy




(a) Change Probability Threshold




(b) Change Interval of Prediction

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

# Question Time

Thanks for Your Attention!