Energy Efficient Phone-to-Phone Communication Based on WiFi Hotspots in PSN

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Outline

- **1. Introduction**
- 2. Model Description
- 3. Communication Strategy
- 4. Evaluation
- 5. Future Work

1. Introduction

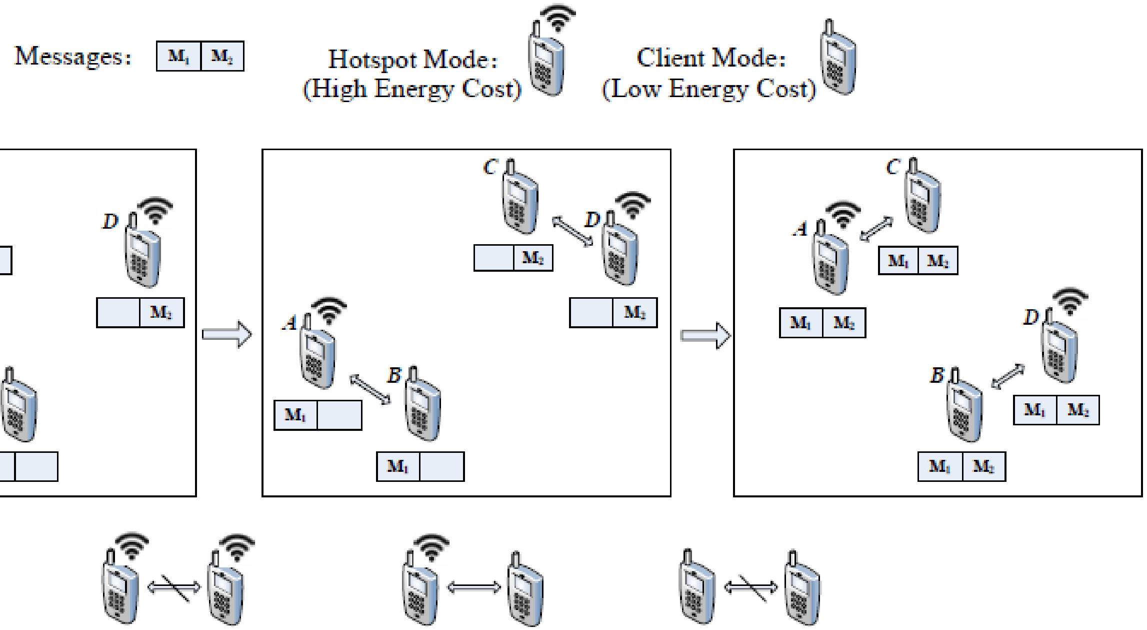
1.1 Motivation

- **Pocket Switched Networks (PSN)**
  - **Both human mobility and occasional connectivity to transfer messages among human-carried mobile devices**
  - **According to International Data Corporation (IDC), the number of smartphones will reach 982 million by 2015**
- **Limitation of WiFi ad hoc mode and WiFi Direct**
- **Phone-to-phone communications in the PSN without WiFi Aps**
  - **Hotspot mode**
  - **Client mode**

1. Introduction

1.2 Problem

- **The phone-to-phone message dissemination process**

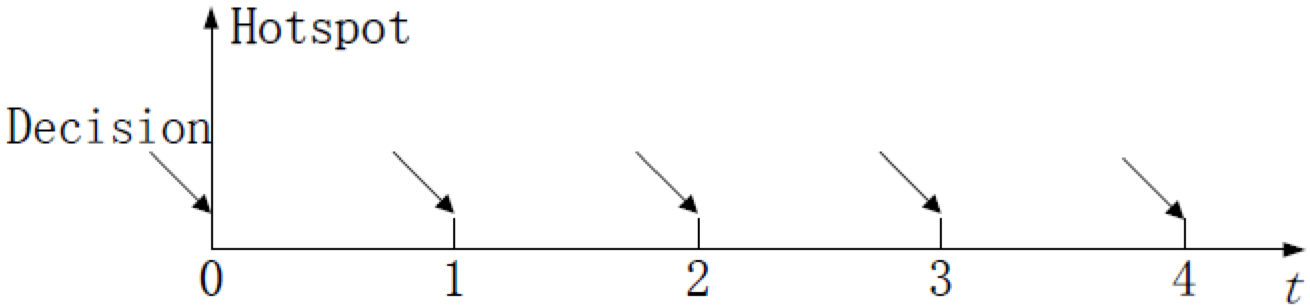


- **How to minimize wasted time and energy due to phones being in incompatible mode?**

1. Introduction

1.2 Problem

- **Hotspot Switch Decision**



- **Multiple messages：For each second，each node has the probability of *α(t)* to be in hotspot，and *1- α(t)* to be in client**

- **Single message：For each second，each node with a message has the probability of *α(t)* to be in hotspot mode，and each node without a message has the probability of *β(t)***

1. Introduction

1.2 Problem

A big picture

Y-Y: 1-1, 1-0, 0-1, 0-0
Y-N: 1-1, 1-0, 0-1, 0-0
N-N: 1-1, 1-0, 0-1, 0-0

maximize and minimize

Y: With Message, N: Without Message
1: Hotspot, 0: Client

1. Introduction

1.3 Contributions

- **The proposed EPCWH is intended to improve message dissemination, while minimizing total energy consumption**
  - **For multiple messages, the uniform policy is used for nodes with and without messages.**
  - **For a single message, non-uniform policies are used.**
- **Extensive simulations on the synthetic random-waypoint mobility**
  - **EPCWH achieves the best performance in terms of message dissemination and energy consumption.**

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2. Model Description

- **Two phones within each other's communication range can establish a connection iff one of them is in hotspot mode and the other in client mode.**

- **Intermeeting times tail off exponentially under many popular mobility patterns, including random walk, random waypoint, and random direction.**

$$f(x) = \lambda e^{-\lambda x} \quad (x \geq 0)$$

- **Analysis on pairwise encounters, as opposed to optimizing communications within the clusters of more than two phones.**

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3. Communication Strategy

3.1 Notations (multiple messages)

Notation	Meaning
N	The total number of phones in PSN
T	Initial time-to-live (TTL) for messages
$\alpha(t)$	The frequency of switching to hotspot for each phone at time t
$P(t)$	Probability of establishing a connection at time t
C	Energy consumption rate of hotspot mode (without loss of generality, $C = 1J/s$)
Ω	Maximum energy constraint to each phone

3. Communication Strategy

3.2 Phone-to-phone Communication of Multiple Messages

- **When multiple messages coexist in PSN, we adopt a uniform switching strategy:**
  - ***$\alpha(t)$* as the frequency of switching to the hotspot mode**

- **The probability of establishing a connection between two nodes within each other's communication range:**

$$P(t) = 2\alpha(t)(1 - \alpha(t))$$

3. Communication Strategy

3.2 Phone-to-phone Communication of Multiple Messages

- **The problem changes to solve the following optimal equation**

$$Maximize \int_0^T 2\alpha(t)(1-\alpha(t))\mathrm{d}t$$
$$s.t. \quad \int_0^T \alpha(t)\mathrm{d}t \leq \Omega$$

- **The maximum value of** ***2α(t)(1- α(t))*** **is obtained iff** ***α(t)=1/2.*** **Hence, an optimal situation is shown as follows:**

$$\begin{cases} \alpha(t) = 1/2, & \Omega \geq T/2 \\ \alpha(t) = \Omega/T, & \Omega < T/2 \end{cases}$$

3. Communication Strategy

3.3 Additional Notations (single message)

Notation	Meaning
$\beta(t)$	The frequency of switching to hotspot for the phone without the message at time t
$m(t)$	Number of the phones holding the message at time t
$n(t)$	Number of the phones without the message at time t, $(n(t) = N - m(t))$
$E(I)$	Mathematical expectation of intermeeting times
λ	Parameter in the exponential distribution of intermeeting times $(\lambda = 1/E(I))$

3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- **Two cases that lead to the increase of *m(t)*, the number of nodes with the message**

  A phone holding the message in hotspot (client) mode encounters another phone without the message in client (hotspot) mode

- **Therefore, the derivative of *m(t)* is expressed as**

$$\frac{\mathrm{d}m(t)}{\mathrm{d}t} = \lambda[m(t)\alpha(t)n(t)(1-\beta(t)) + m(t)(1-\alpha(t))n(t)\beta(t)]$$
$$= \lambda m(t)n(t)[\alpha(t)+\beta(t)-2\alpha(t)\beta(t)]$$

3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- **Probability of establishing a connection *P(t),* when a phone with message encounters another phone without message**

$$P(t) = \alpha(t)(1-\beta(t)) + \beta(t)(1-\alpha(t))$$
$$= \alpha(t) + \beta(t) - 2\alpha(t)\beta(t)$$

- ***m(T)* could be calculated as follows:**

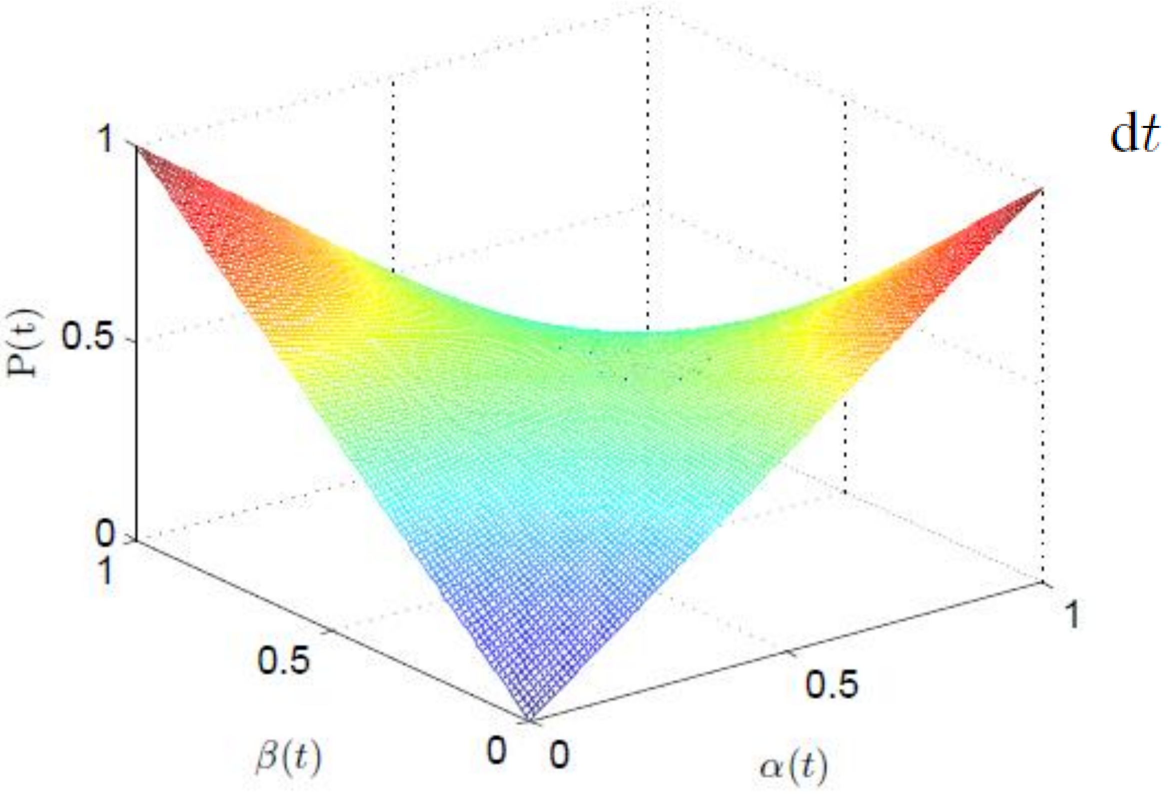
$$m(T) = \frac{N}{(N-1)e^{-N\lambda \int_0^T P(t)\mathrm{d}t} + 1}$$

where *m(t)* and $\int_0^T P(t)\mathrm{d}t$ **have a positive correlation**

3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

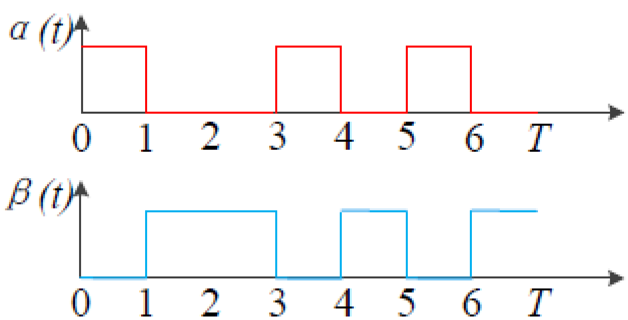
- **Connection probability distribution *P(t)***



3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

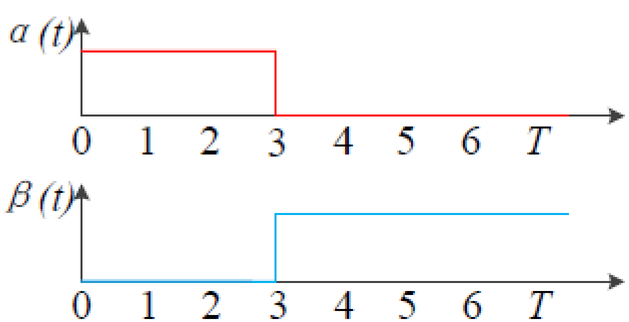
- **The optimal solution: at each time *t, α(t)* and *β(t)* satisfy *α(t)=1, β(t) =0* or *α(t)=0, β(t) =1*, shown in the following example:**



Y-Y: 1-1, 1-0, 0-1, 0-0
Y-N: 1-1, 1-0, 0-1, 0-0
N-N: 1-1, 1-0, 0-1, 0-0

Y: Yes, N: No
1: Hotspot, 0: Client

- **Because *m(t)* increases along with *t,* in order to minimize the total energy consumption, a better solution is shown as follows:**



3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message

- **When the energy is sufficient, the total energy consumption is achieved as follows:**

$$\begin{aligned}\Omega_{sum} &= \int_0^T (m(t)\alpha(t) + n(t)\beta(t))\mathrm{d}t \\ &= \int_0^{T'} m(t)\mathrm{d}t + \int_{T'}^{T} n(t)\mathrm{d}t \\ &= NT' + \frac{2\ln[(N-1)e^{-N\lambda T'} + 1]}{\lambda}\end{aligned}$$

- **To minimize Ω_{sum}, the optimal switching time is *T'*, which is the time satisfying *m(T')=N/2.***

$$T' = \frac{\ln(N-1)}{N\lambda}$$

3. Communication Strategy

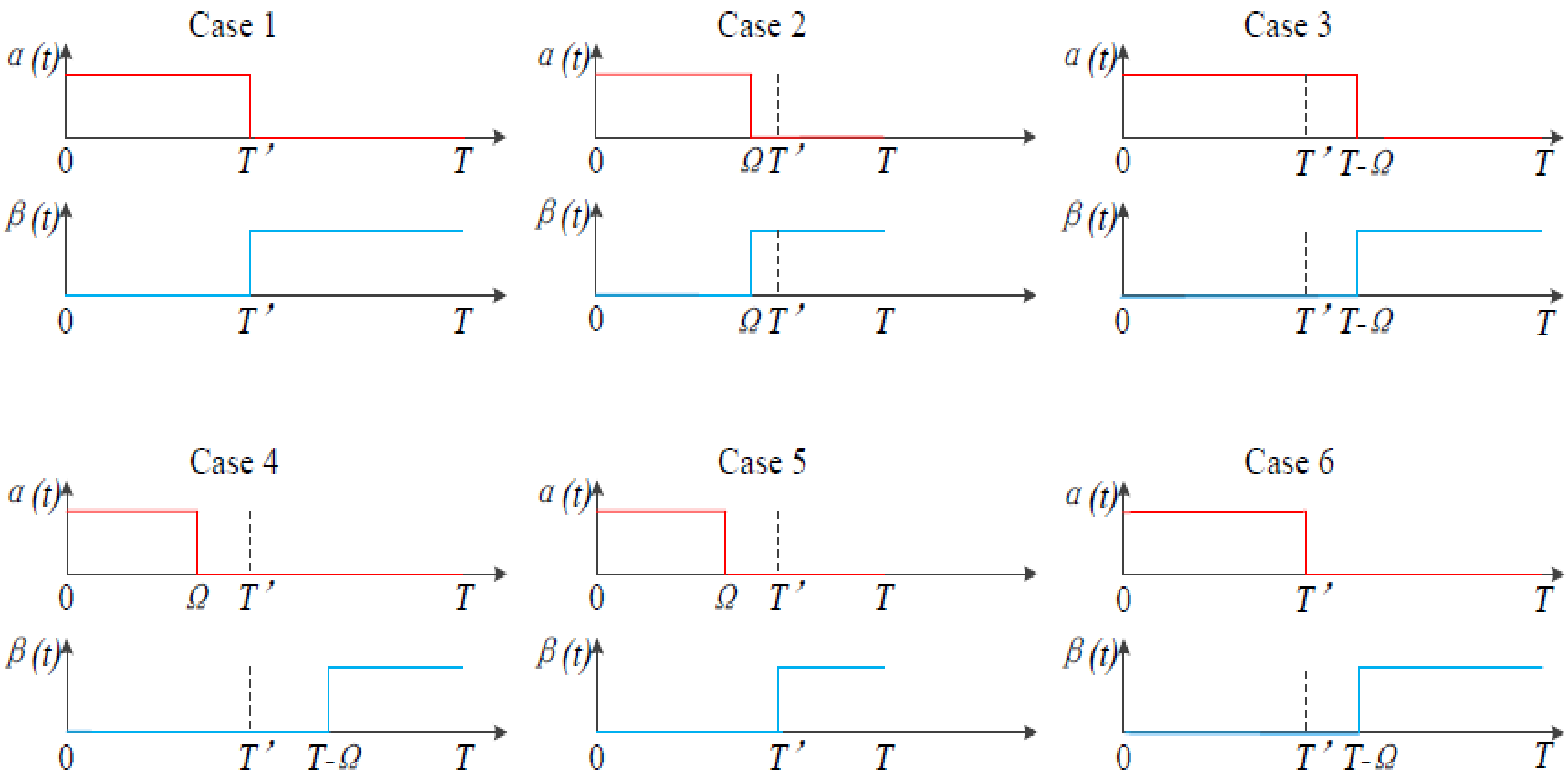
3.4 Phone-to-phone Communication of Single Message

- **Under different constraint conditions, the optimal switching time, $T' = \frac{\ln(N-1)}{N\lambda}$, can be achieved as follows:**

Constraint Condition		Optimal Switching Time
$\Omega \geq \frac{T}{2}$	Case 1: $\Omega \geq T'$ and $\Omega \geq T - T'$	$T_1' = T_2' = T'$
	Case 2: $\Omega < T'$ and $\Omega \geq T - T'$	$T_1' = T_2' = \Omega$
	Case 3: $\Omega \geq T'$ and $\Omega < T - T'$	$T_1' = T_2' = T - \Omega$
$\Omega < \frac{T}{2}$	Case 4: $\Omega < T'$ and $\Omega < T - T'$	$T_1' = \Omega$ and $T_2' = T - \Omega$
	Case 5: $\Omega < T'$ and $\Omega \geq T - T'$	$T_1' = \Omega$ and $T_2' = T'$
	Case 6: $\Omega \geq T'$ and $\Omega < T - T'$	$T_1' = T'$ and $T_2' = T - \Omega$

3. Communication Strategy

3.4 Phone-to-phone Communication of Single Message



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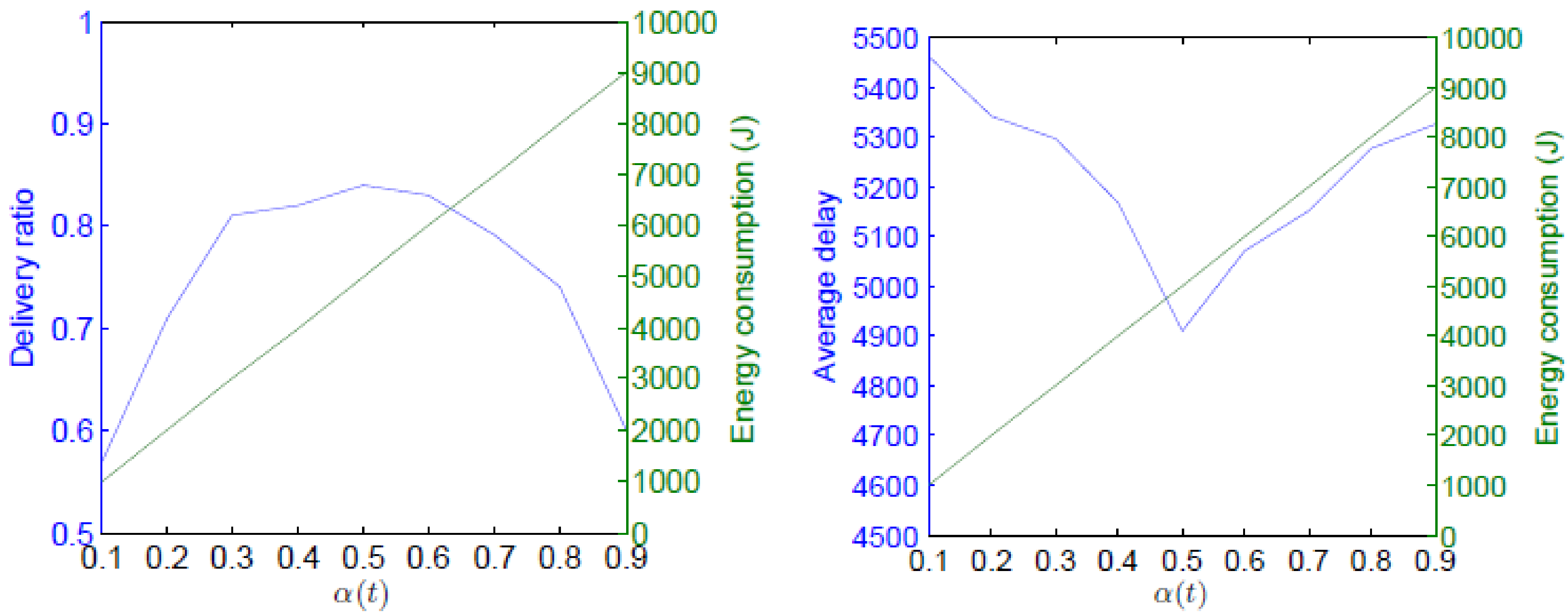
4. Evaluation

4.1 Simulation Parameters (random-waypoint)

Parameter	Value
Simulation time	10,000s
Simulation area	4,500m×3,400m
Number of nodes	100
Transmission range	30m
TTL	10,000s
Interval time of message generation	100s
Hotspot energy consumption rate	1J/s
$\alpha(t)$	$0, 0.1, 0.2, \cdots, 0.9, 1$
Energy constraint	1,000J, 2,000J, $\cdots$, 5,000J

4. Evaluation

4.2 Enough Energy (multiple messages)

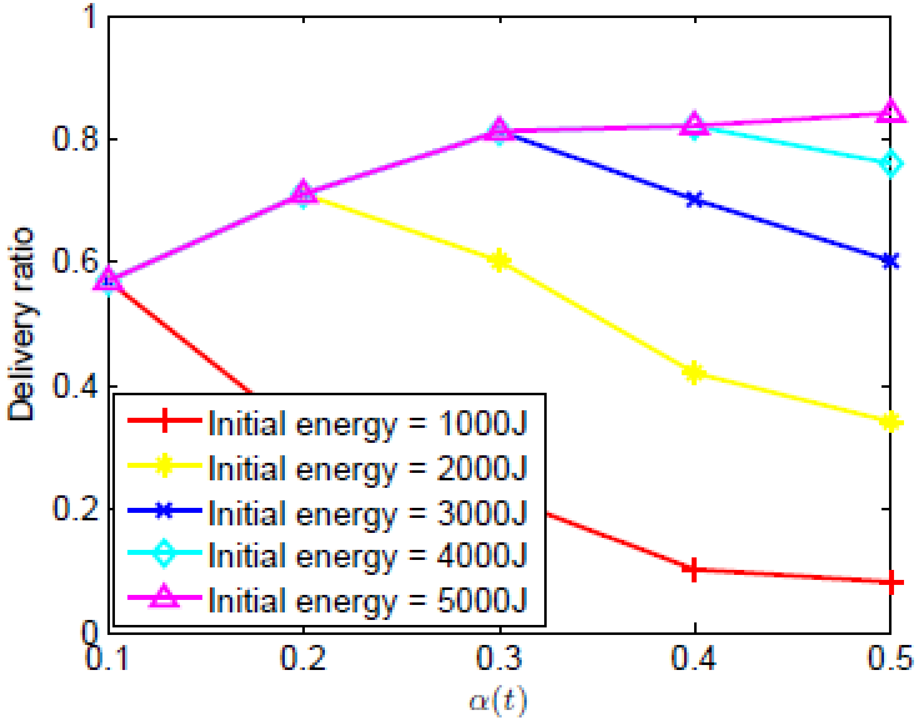


(a) Delivery ratio (b) Average delay

- **EPCWH (*α(t)* = 1/2) achieves the best performance in terms of delivery ratio and average delay**

4. Evaluation

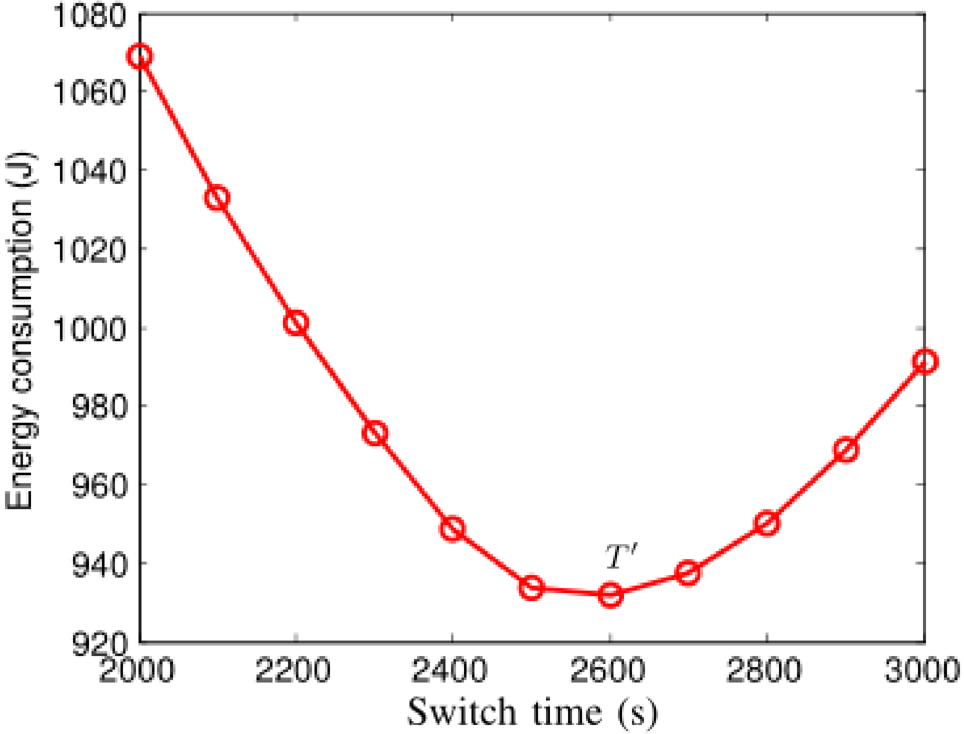
4.3 Not Enough Energy (multiple message)



- **EPCWH ($\alpha(t) = \Omega/T$) achieves the best performance in terms of delivery ratio (Ω=1000, $\alpha(t)$ =0.1 ... Ω=5000, $\alpha(t)$ =0.5)**

4. Evaluation

4.4 Enough Energy (single message)



- **EPCWH obtains the lowest energy consumption only when *T'* = 2600s. Because *N*=100, and *λ*=1/56500, therefore, the simulation result precisely meets the theoretical result**

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5. Future Work

- **Other replication-based routing schemes**
  - **Spray-and-wait, delegation forwarding, etc.**

- **Real network environment**

Thank You