Article

Efficient Listening and Sleeping Scheduling Mechanism Based on Self-Similarity for Duty Cycle Opportunistic Mobile Networks [†]

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Abstract: In opportunistic mobile networks (OppNets), nodes should be in listening state to discover the neighbors for opportunistic message forwarding. While in OppNets, contacts between nodes are sparse, most of the node's energy is consumed in idle listening state, which highlights the need for energy saving in contact probing. Duty cycle operation can be applied to address this problem. However, it may cause the degradation of network connectivity when the state of node is turned to be sleeping. In this paper, we propose an adaptive scheduling mechanism based on self-similarity, in which *LMMSE* predictor is used to predict the future contact information. The state of a node will be set as listening or sleeping adaptively according to the predicted result of future contacts with other nodes. Finally, we validate the effectiveness of the proposed mechanism by conducting a large amount of trace-driven simulations, which show that the proposed mechanism outperforms the random working mechanism and periodical working mechanism in terms of the number of effective contacts, delivery ratio, transmission delay and cost.

Keywords: opportunistic mobile networks; self-similarity; duty cycle; scheduling mechanism

1. Introduction

In the recent decade, with the popularity of mobile devices and the rapid development of communication technologies, the message exchange without the support of wireless infrastructure has become more and more popular [1]. Opportunistic Mobile Network (OppNet) is a type of challenged network, in which contacts between nodes are intermittent, the links between nodes are constantly changing, and there may never exist the connection from a source node to destination [2,3]. In OppNets, the nodes can exchange data with each other when they are within mutual wireless transmission range, and the store-carry-forward approach is a data transmission mode for all nodes [4–7]. In this approach, each node stores data to be sent, then forwards to the encounter nodes [8].

To facilitate such data exchanges, nodes in OppNets have to be in listening state to find the neighboring nodes. Generally speaking, the inter-contact interval is much longer than contact duration [9]. Therefore, most of the energy is consumed in idle listening state during inter-contact intervals. According to the measurement result shown in the architecture for Delay Tolerant Network (DTN) throwboxes [10,11], 99.5% of the total energy is consumed for contact probing. Thus, it is important to improve efficiency and save energy for contact probing.

The duty cycle operation is a quite effective method in energy saving. With the duty cycle operation, the state of node can switch between listening and sleeping. The duty cycle operation

can be classified into two categories, synchronous and asynchronous duty cycle operations [12]. The synchronous operation requests that the nodes in the network should keep listening state or sleeping state synchronously, which may cause enormous communication overhead. In contrast, the asynchronous method, which allows the nodes in the network operate independently, is a more viable option. Nevertheless, the duty cycle operation may inevitably lead to the decline of the network performance when the node switch to sleeping state for energy saving. That is because when the node switches to sleeping state, many contacts will be missed, which means the opportunities for exchanging data are lost. Consequently, it is necessary to investigate the impact of duty cycle operations on network performance in the OppNets. Currently, some research work [13,14] focus on investigating the effect when the working schedule based on the duty cycle operation is randomly selected. Simulations show that the design of the working schedule based on the duty cycle operation has a great impact on the performance of the OppNets. Consequently, it is quite significant to design a proper scheduling mechanism to save energy and improve network performance.

In addition, if we have the knowledge of the distribution of the inter-contact time, the contact between nodes will be predicted with high accuracy, which is helpful for energy saving in contact probing. In [15–17], some statistical researches have been done to analyze the characteristics of contact between nodes in OppNets, and Chen et al. in [17] conducted a detailed analysis of the traces of mobile nodes and achieved the result that the inter-contact intervals are self-similar. Based on the above works, in this paper, we design the energy efficient adaptive scheduling mechanism with the inter-contact interval having self-similarity as the assumption. The adaptive scheduling mechanism uses the mathematical method named *LMMSE* (Linear Minimum Mean Square Error) [18] to predict the future inter-contact interval based on contact histories, and the nodes' state can be adaptively switched between the listening and sleeping state according to the predicted result.

The rest of the paper is structured as follows. In Section 2, we introduce the related work in this research area. Then we briefly describe the network model in Section 3. Section 4 introduces the motivations of our study. We give a detailed description on our proposed adaptive scheduling mechanism in Section 5, and evaluate the performance of the proposed adaptive scheduling mechanism by conducting a large mount of trace-driven simulations in Section 6. Finally, Section 7 concludes this paper.

2. Related Work

In OppNets, the nodes opportunistically exchange their information when they encounter each other. In order to enable such information exchanging process, the nodes must probe the environment to discover their neighbors. If the nodes keep contact probing frequently, it will consume large amounts of energy. Wang et al. [19] made measurements on a Nokia mobile phone and concluded that the neighbor discovery process was as energy-intensive as making a phone call. Hence, for limited power supply, the nodes should have their energy saved in contact probing.

In previous research, many works have been done to reduce energy consumption in the contact probing. Qin et al. [20] investigated the impact of contact-probing schedule on link duration and the transmission capacity of DTNs, and proposed a model for calculating the optimal contact-probing rate with limited energy. In [21], the authors proposed two adaptive algorithms for dynamically adjusting the Bluetooth parameters based on past perceived activity in the ad-hoc network. Their experiments showed that the proposed adaptive algorithms can reduce energy consumption by 50% and have up to 8% better performance than a static power-conserving scheme. In addition, there are some works [22,23] that have dealt with the energy conservation issue in DTN routing, which paid attention to the extra energy consumption due to more packet copies used in routing, and thus, the energy constraint was expressed as the limitation on the number of duplicate packet copies.

The studies mentioned above focused on the conservation of energy related with contact-probing and packet copies [22–24]. However, the energy wasted in the idle listening state is much more than

that used in contact-probing. To this end, some studies have investigated how to decrease the energy consumption in idle listening state. Trullols-Cruces et al. [13] proposed the Power Saving Management (PSM) techniques, which enabled the lifetime of the nodes to be extended and showed the conditions in which a node can be in sleeping state with no impact on the contact processing. The simulation results showed that the mathematical model was accurate and the contact rates in DTNs can be quite low, and the wireless radio can be turned off for energy conservation according to the operation regions. In [25], the authors introduced a technique of increasing the battery lifetime for a PDA-based phone by reducing its idle power, in which the wireless interfaces of the devices would be shut down when they were not being used. In [26], the authors proposed the cooperative duty cycling (CDC) base on a mobility pattern in which several nodes periodically encountered at certain hot spots and they would be well-connected. From theoretical analyses and simulations, CDC had a good performance in terms of energy conservation with no decline of data delivery performance.

In contrast to the above existing studies, we pay attention to the self-similarity feature in opportunistic mobile networks. Making use of the predictability of self-similarity, we propose an adaptive scheduling mechanism to switch the states of each node between sleeping and listening states for energy conservation.

3. Network Model

Similar to [27], we assume that there are N nodes in a dynamic network environment in which each node periodically performs a scheduling mechanism. Each node in the network can adjust its state between the listening or sleeping state. The scheduling mechanism can be expressed as a tuple, $T_i = <b_i, T, T_{slot}>$. T is the length of a period, which can be divided into multiple slots. b_i is the bitmap of node i and each bit in b_i represents that node i is in the listening or sleeping state at the time of the corresponding slot, 1 and 0 represent the listening and sleeping states respectively. T_{slot} represents the duration of each slot. In this paper, it is supposed that all nodes in the network have the same D for the duty cycle operations, which can be defined as $D = T_w/T_p$, where T_w is the number of listening slots in T, and T_p denotes the total number of slots in T. Then, the scheduling mechanism of node and the state of node in each slot can be shown in Figure 1.
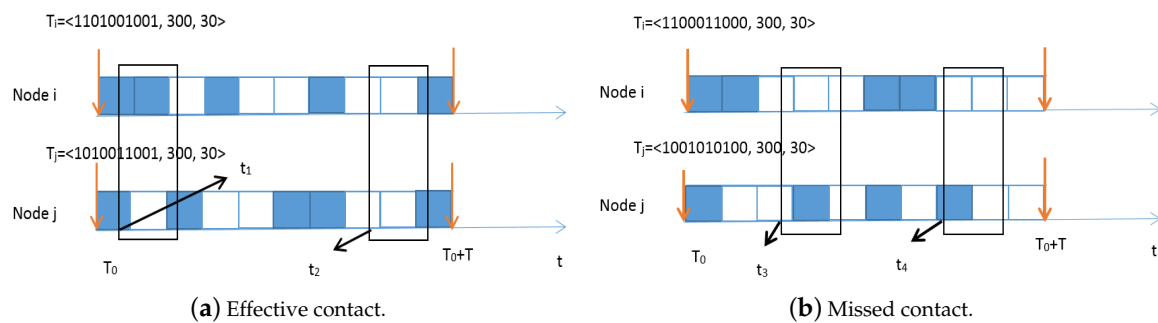

Figure 1. Effective (**a**) and Missed (**b**) Contacts between nodes i and j, where blue slots represent the listening state and the white slots represent the sleeping state.

In Figure 1a, nodes i and j execute the scheduling mechanism of $T_i = <1101001001, 300, 30>$ and $T_j = <1010011001, 300, 30>$ respectively at time T_0 to $T + T_0$, where 1 and 0 represent the listening and sleeping states respectively. We set $T = 300$ s, $T_{slot} = 30$ s, and $D = 50\%$. Hence, in Figure 1a node i is in listening state when the slot number is 1, 2, 4, 7, 10 and in sleeping state in other slots. Nodes in listening state can send a message to discover the contacts and exchange data with the neighbors. In contrast, nodes in the sleeping state will shut down their wireless radio to conserve energy and cannot communicate with other nodes.

4. Motivations

In duty cycle OppNets, the contacts can be classified into two categories: the effective contact and the missed contact. The contact is effective when two nodes are both in the listening state at a certain time in the contact duration. As shown in Figure 1a, contacts at time t_1 and t_2 are the effective contacts, and the contacts at time t_3 and t_4 in Figure 1b are the missed contacts because the two nodes are not both in listening state for the contact duration.

We analyzed the contact in duty-cycle OppNets in the example of Figure 1, and found that, when the duty cycle operation is randomly chosen, many contacts would be missed. As shown in Figure 2a, the states of node i and node j are randomly configured, and their contact at time t_5 will be missed. We want to decrease the number of missed contacts, and each node can adaptively schedule its states to find its neighbours.
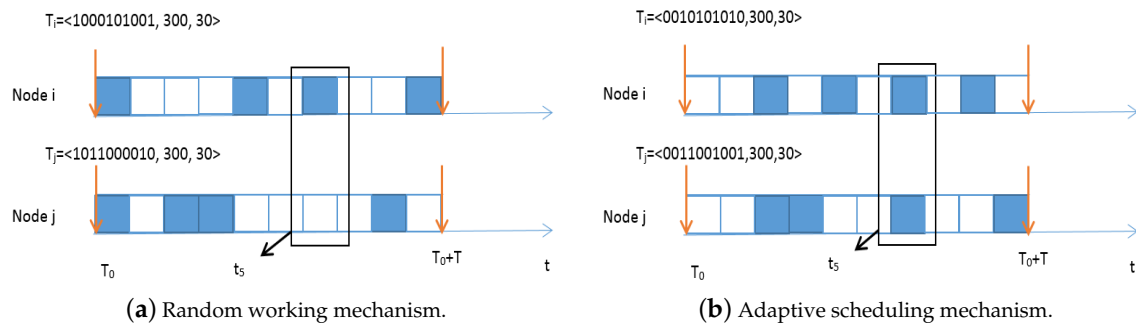

(**a**) Random working mechanism.

(**b**) Adaptive scheduling mechanism.

Figure 2. Contact comparison between random working mechanism (**a**) and adaptive scheduling mechanism (**b**).

As we know that knowing the characteristics of the OppNets is the key to designing effective protocols, applications and working mechanisms. Among the properties, the distribution of the inter-contact time is particularly important, since it is a good indicator of network connectivity. The inter-contact time is the duration between two consequent contacts of a certain node pair, the number of inter-contact time events indicates that the number of disconnection and reconnection events have occurred.

As we mentioned before, it was verified from experiments that the inter-contact intervals had the distribution feature of self-similarity [17]. Since the self-similarity feature has mathematical predictability, we try to predict the future contact information based on the history inter-contact intervals. According to the possibility of future contacts between nodes, each node can choose to be in listening or sleeping state in each time slot, and the number of missed contacts will decrease. As shown in Figure 2b, the states of nodes i and j are adaptively configured based on the predicted contact information, and the contact occurs at time t_5 will become the effective contact. Hence, in order to achieve this purpose, we aim to design an adaptive scheduling mechanism based on self-similarity in the following section.

5. Adaptive Scheduling Mechanism Based on Self-Similarity

Experimental analysis in [17] shows that the inter-contact intervals has the distribution of self-similarity. In this paper, we proposed an Adaptive Scheduling Mechanism based on Self-Similarity (ASMSS) for efficient contact probing. Firstly, we use the *LMMSE* predictor to predict the future inter-contact interval based on the contact history of nodes. Then, nodes can adaptively schedule the listening and sleeping states in each period based on the predicted result. The *LMMSE* predictor is described as follows.

5.1. The LMMSE Predictor

It is supposed that $f(i)$ is the ith inter-contact interval of the past visited $m \times n$ inter-contact intervals. There are n continuous measurement periods, each measurement period has the length of time τ, and m is the number of samplings in each measurement period. The predictor keeps track of the aggregate series samples, measured in the past n measurement period. It is supposed that $f^m(k), 1 \leq k \leq n$, is the aggregate series sample of inter-contact interval samples, which is taken in the $(n+1-k)$th most recent measurement period, as is given in Equation (1).

$$f^m(k) = \frac{1}{m} \sum_{i=(k-1)m+1}^{km} f(i) \tag{1}$$

Based on the past $m \times n$ contact intervals, we predict the aggregate series sample in the next interval as a weighted sum of the past n average samples, which is denoted as $f^m(n+1)$ shown in Equation (2).

$$\hat{f}^m(n+1) = \begin{bmatrix} a_1 & a_2 & \cdots & a_n \end{bmatrix} \begin{bmatrix} f^m(1) \\ f^m(2) \\ \cdots \\ f^m(n) \end{bmatrix} \tag{2}$$

where $\begin{bmatrix} a_1 & a_2 & \cdots & a_n \end{bmatrix}$ are the *LMMSE* coefficients and can be expressed as

$$\begin{bmatrix} a_1 & a_2 & \cdots & a_n \end{bmatrix} = \begin{bmatrix} R(n-1) & R(n-2) & \cdots R(0) \end{bmatrix}$$
$$\times \begin{bmatrix} R(0) & R(1) & \cdots & R(n-1) \\ R(1) & R(0) & \cdots & R(n-2) \\ \cdots & \cdots & \cdots & \cdots \\ R(n-1) & R(n-2) & \cdots & R(0) \end{bmatrix}^{-1} \tag{3}$$

where $R(n)$ is the covariance function of the time series, and can be estimated (due to the property of asymptotically second-order self-similarity) in practice as

$$R(i) = \frac{1}{n} \sum_{t=i+1}^{n} f^m(t) f^m(t-i), 0 \leq i \leq n-1 \tag{4}$$

where n is the number of aggregate series samples kept. Both m and n are tunable parameters. Note that the Hurst parameter H that characterizes the LRD property has been implicitly calculated in the covariance function R(i). Then each node can predict the future inter-contact interval of the node pair with the $m \times n$ inter-contact intervals recorded in the node buffer at the beginning time of each period. More information about the *LMMSE* predictor can be found in [18].

5.2. The Proposed ASMSS

The work in [28] has shown that each node can predict future contact information based on its history contact information. For a given node, we define its expected Encounter Value (*EV*) as the number of nodes that it may encounter in the future. In this paper, we design the *ASMSS* based on expected encounter value. In order to calculate the expected *EV*, we divide the period T into s slots, and the length of each slot is $T_{slot} = T/s$. Then each node can calculate the *EV* in each slot at the beginning time of the period and denote to be $EV_i(x), \forall i \in N, x \in [1, s]$. For the *EV* calculation, each node should keep records of the contact times with other nodes and then calculate and store the inter-contact intervals in the node buffer. We take an example of node i, the intercepted $m \times n$ history inter-contact intervals with node j are denoted as $\Gamma_{ij} = \{\chi_{ij}^1, \chi_{ij}^2, \cdots, \chi_{ij}^{m*n}\}$. Then, we use the *LMMSE* predictor to predict the coming inter-contact interval with the Γ_{ij}. Assuming the predicted result between nodes i and j is t_{ij}, the last contact time is t_{ij}^0, and the beginning time of a certain

period is $t(t > t_{ij}^0)$, we can calculate the value of x, which means node i and node j are expected to encounter with each other in the xth slot of this period, based on the Equation (5). Also, the $EV_i(x)$ can be calculated with the value of x based the Equation (6). Finally, node i can get the final result of $EV_i(x)(x \in [1, s])$ in each slot with all encountered nodes taken in account.

$$x = (t_{ij} - (t - t_{ij}^0))/T_{slot} \tag{5}$$

$$EV_i(x) = \begin{cases} EV_i(x) + 1, 1 \leq x \leq s \\ EV_i(x) \quad , \quad x > s \end{cases} \tag{6}$$

According to the *LMMSE* predictor and Equations (5) and (6), each node in the network can get the expected *EV* in each slot of a certain period. Then, each node can choose T_w slots to be in listening state, and these T_w slots have the highest value of the expected *EV*. This process will be repeated at the beginning time of each period, and each node can adaptively configure its scheduling mechanism at the beginning time of each period. The process flowchart of *ASMSS* can be shown in Figure 3.
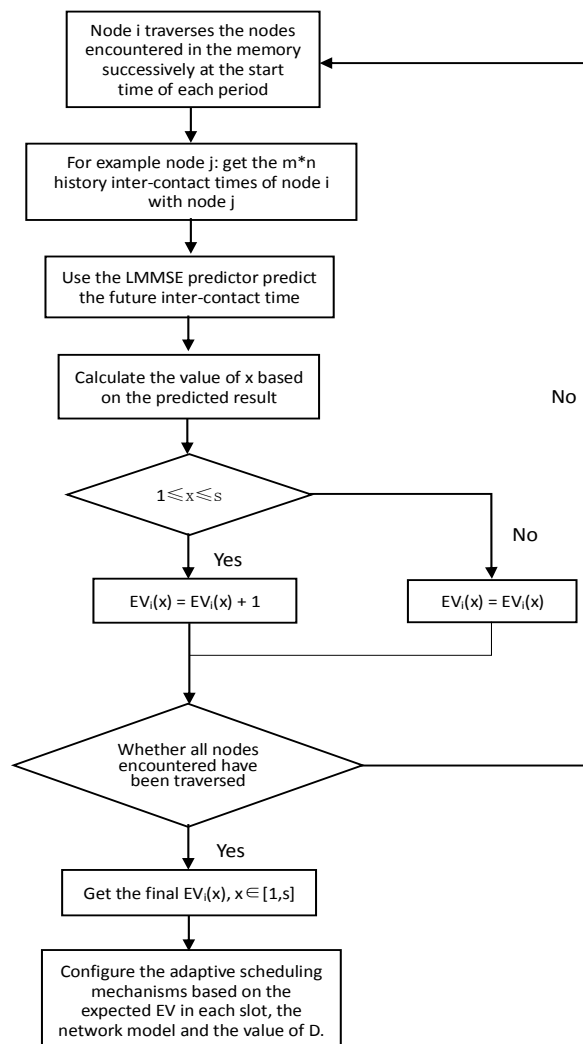

Figure 3. The flowchart of the *ASMSS*.

For ease of understanding, we provide an example for the scheduling mechanism of node N_0. It is assumed all nodes that ever encountered with N_0 to be $H = \{N_1, N_2, \cdots, N_{10}\}$ at the beginning time of

a certain period. There are 10 slots in each period, and $T = 300$ s, $T_{slot} = 30$, $D = 30\%$. Then, the next inter-contact interval of each node pair can be figured out based on the *LMMSE* predictor, and the slots expected to encounter neighbours can be calculated with Equation (5). If N_0 and N_1 are expected to encounter with each other in the second slot of this period, it can be expressed as $x\{N_0, N_1\} = 2$. Similarly, we have $x\{N_0, N_2\} = 4$, $x\{N_0, N_3\} = 2$, $x\{N_0, N_4\} = 7$, $x\{N_0, N_5\} = 9$, $x\{N_0, N_6\} = 7$, $x\{N_0, N_7\} = 2$, $x\{N_0, N_8\} = 4$, $x\{N_0, N_9\} = null$, $x\{N_0, N_{10}\} = 7$, where *null* represents that N_0 and N_9 will not encounter in this period. Based on Equation (6), we can get the $EV_{N_0}(1) = 0$, $EV_{N_0}(2) = 3$, $EV_{N_0}(3) = 0$, $EV_{N_0}(4) = 2$, $EV_{N_0}(5) = 0$, $EV_{N_0}(6) = 0$, $EV_{N_0}(7) = 3$, $EV_{N_0}(8) = 0$, $EV_{N_0}(9) = 1$, $EV_{N_0}(10) = 0$. Finally, we can choose three slots with the highest value of EV to be listening state according to the value of D, which are slots 2, 4 and 7 respectively. According to the definitions, the corresponding scheduling mechanism of N_0 in this period can be denoted as $T_{N_0} = <0101001000, 300 \text{ s}, 30 \text{ s}>$ shown in Figure 4.
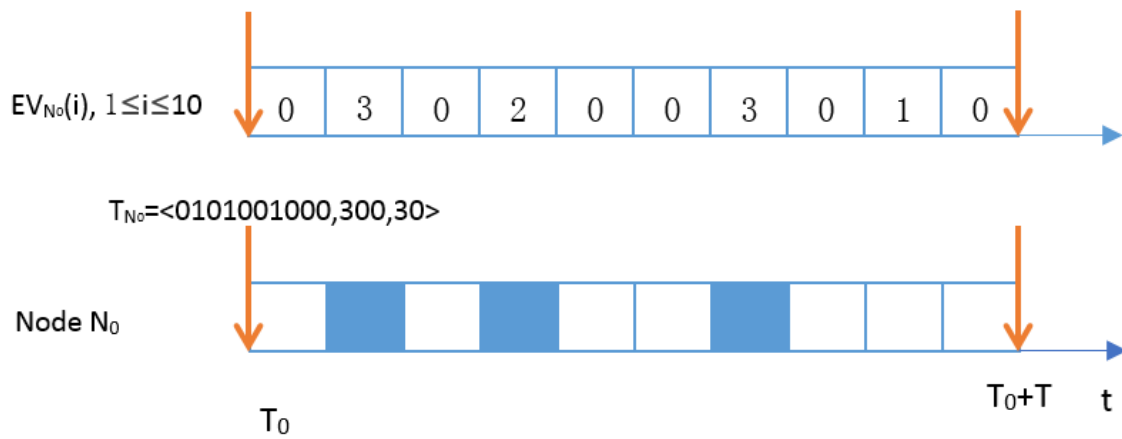

Figure 4. An example of the Adaptive Scheduling Mechanism based on Self-Similarity (*ASMSS*).

Based on the *ASMSS* design for the duty cycle OppNets above, we can find that node i need to update the last contact time of all the nodes ever encountered in order to calculate the expected EV for each slot in each period. However, nodes in the network will inevitably miss some contacts with other nodes due to the duty cycle operation, or the contact is found with a delay when the nodes are both in sleeping state at the beginning of their contact, as shown in Figure 1. It is difficult for the nodes in the network to obtain the exact last contact time of all the nodes ever encountered. Since the inter-contact time between nodes is much longer than the contact duration and the discovery delay between nodes is less than the contact duration, we only consider the missing contacts and ignore those delayed contacts.

For the missed contacts, if the contact between node i and j in the last period is missed, then the last contact time of node i and j, t_{ij}^0 will not update in the current period, which results in inaccurate calculation of EV of nodes i and j in the current cycle. However, as time goes on, the EV of node i and j will be significantly reduced. Figure 5 shows the Complementary Cumulative Distribution Function (CCDF) of the inter-contact time in the Infocom6. As shown in the figure, we can find that when the inter-contact time is larger than 2 h, the cumulative distribution of the inter-contact time is less than 8%, which means that when the inter-contact time is greater than 3 h, the EV between the nodes i and j in the current period will be close to 0. In summary, the proposed mechanism is still valid for the network in which nodes have missed contacts.
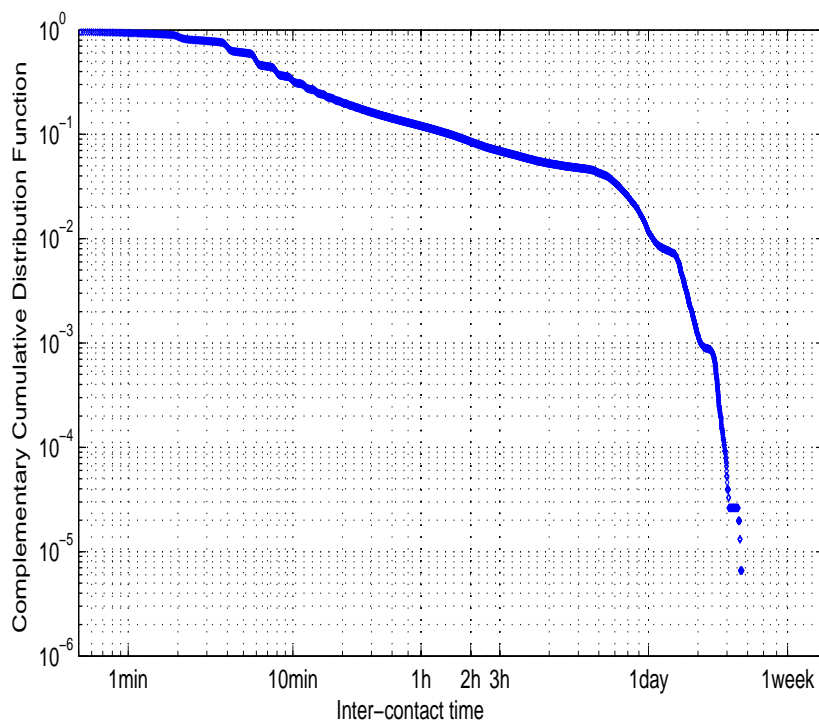
Figure 5. The Complementary Cumulative Distribution Function (CCDF) of inter-contact time in the *Infocom6*.

6. Performance Evaluation

To evaluate the effectiveness of the *ASMSS*, a large amount of simulation experiments have been done with the opportunistic network environment (ONE) [29], which is one of the wildly used simulators for OppNets. In this paper, we focus on energy saving through efficient contact probing in OppNets. In the simulation, there are two methods to show the effectiveness of our proposed mechanism. The first method is to measure the energy consumption of each node in the network with the given network performance. However, in the real environment or datasets, it is impossible to set a fixed value for the network performance. The second method is to measure the network performance with every node given the same energy consumption. As is mentioned in the Network Model, we assume that all nodes have the same D for the duty cycle operations, and the D denotes the energy consumption of nodes. Herein, similar to the work in [27], the second method is used in our simulation. That is, with the various duty cycles, performance comparison is done for our proposed mechanism *ASMSS* and the other mechanisms.

6.1. Simulation Setup

We use the epidemic routing protocol to compare the performance of the *ASMSS* with the random working mechanism and the periodical working mechanism. In the random working mechanism, nodes in the network randomly choose the corresponding slots to be listening or sleeping according to the value of D for duty cycle operation. In the periodical working mechanism, nodes in the network choose to be listening or sleeping in the beginning time of the experiment randomly, and perform this chosen mechanism periodically. In epidemic routing protocol, packets are simply flooded to the nodes in the network. We conduct the simulations with the *Infocom6* dataset which is used for node activity driving and can be downloaded from CRAWDAD [30], and last updated in August 2016. In *Infocom6* trace, users carry the portable devices equipped with bluetooth to record the contacts with other devices. The detailed information about the *Infocom6* is listed in Table 1. In the simulation, we set

the T to be 5min and T_{slot} to be 30 s. Other related parameters in the simulation are listed in Table 2. Then we evaluate the performance in terms of the following indicators.

Table 1. Trace properties.

Trace	*Infocom6*
Device	iMote
Network type	Bluetooth
Duration (days)	4
Granularity (seconds)	120
No. of internal contacts	170,601
No. of devices	98
Contact frequency/pair/day	6.7%

1. **The Number of Effective Contacts**: the number of effective contacts of the nodes in the network within a certain period.
2. **Delivery Ratio**: the ratio of the number of data packets successfully reached the destination node and the amount of data packets sent by the source node within a certain time.
3. **Delivery Delay**: the average time it takes for a packet to reach the destination after it leaves the source.
4. **Delivery Cost**: the average number of data transmitted by nodes in the network.

Table 2. Simulation parameters.

Parameter	Value
Simulation duration (seconds)	343,000
Bluetooth interface	SimpleBroadcastInterface
Bluetooth transmitSpeed (bytes per second)	250 k
Bluetooth transmitRange (meters)	10
Node bufferSize	5 M
TTL of the messages-msgTtl (minutes)	300
MessageEventGenerator interval (seconds)	1000, 2000
Message size	1 k

6.2. Performance Comparison of Three Mechanisms

We use the epidemic routing protocol to compare the performance of the *ASMSS* with the random working mechanism and the periodical working mechanism in *Infocom6* trace. In opportunistic routing, if the contacts between nodes can be efficiently discovered, the opportunity for message forwarding will increase, which can improve the network performance to some extent. Under each one of the above three working mechanisms, the nodes with the same value of duty cycle will have the same energy consumption in contact probing. With various values of duty cycle, the number of contacts discovered under the three working mechanisms is shown in Figure 6, and data transmission performance with epidemic routing is shown in Figure 7.
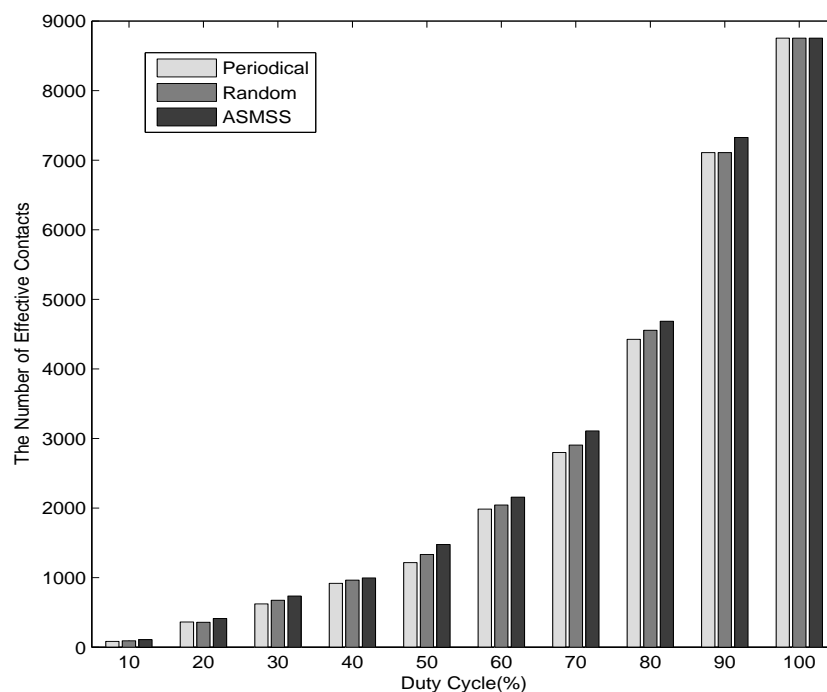
Figure 6. Effective Contacts *ASMSS*.

From Figure 6, we can find that the number of the effective contacts increases as the duty cycle increases in the three working mechanisms. The number of the effective contacts of the *ASMSS* is more than the other two working mechanisms when the duty cycle is the same. Compared with random and periodical working mechanisms, for *ASMSS* the number of effective contacts increased by 7.2% and 12.1% respectively, in average. The main reason behind is that the *ASMSS*, which is proposed based on the self-similarity of the inter-contact time, uses the past contact history to predict the future contact time. Then, the state of a node can be set adaptively according to predicted result of future contacts with other nodes. Hence, many missed contacts in the random working mechanism and the periodical working mechanism turn out to be the effective ones.

Figure 7 shows the performance comparison of the *ASMSS*, the random working mechanism and the periodical working mechanism in terms of delivery ratio, delivery delay, and delivery cost. In the figure, when the duty cycle increases from 10% to 100%, the delivery ratio and the delivery cost rise correspondingly. In contrast, the delivery delay decreases in all working mechanisms. That is because when the duty cycle increases, there are more contacts to be effectively discovered, and there are more chances to exchange data. When the duty cycle is less than 70%, the *ASMSS* has better performance than the other two, which means the proposed mechanism gives the nodes more effective contacts for data delivery than the other two mechanisms. When the duty cycle exceeds 70%, we find that these three working mechanisms are almost the same shown in Figure 7, that is because that there are few contacts missed in this situation for all mechanisms. Under epidemic routing, compared with random and periodical working mechanisms, the delivery ratio of *ASMSS* increased by 27.1% and 87.8%, the delivery cost decreased by 2.9% and 3.8%, and the delivery delay decreased by 4.1% and 8.8%, respectively.
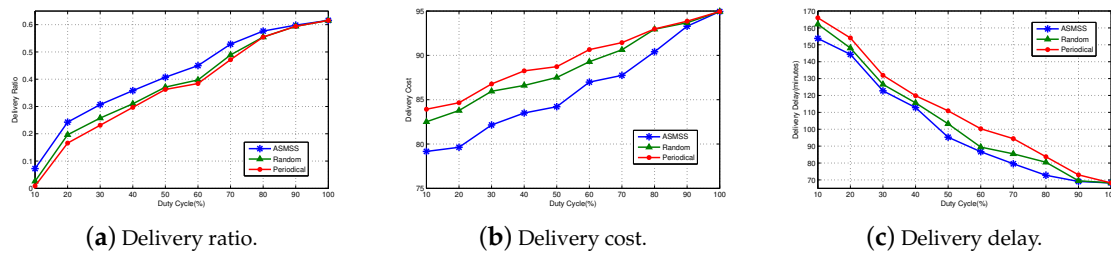
(**a**) Delivery ratio. (**b**) Delivery cost. (**c**) Delivery delay.

Figure 7. The comparison of delivery ratio (**a**), delivery cost (**b**) and delivery delay (**c**) based on the epidemic routing protocol in *Infocom6* trace.

6.3. Performance Comparision of Different T

In this section, we investigate the performance of the *ASMSS* when the parameter *T* varies. Then, we conduct experiments to achieve the answer by setting the value of *T* to be 5 min, 10 min and 20 min.

Figure 8 shows that the performance of the proposed *ASMSS* with the different settings of the parameter *T*. With the varying value of *T*, we can find that the delivery ratio increases as the parameter *T* decreases when the duty cycle increases from 10% to 100%. At the same time, the delivery delay and the delivery cost decrease. That is, the *ASMSS* will achieve better performance when the value of *T* is relatively small. In summary, the parameter *T* has a significant effect on the performance of the proposed *ASMSS*.
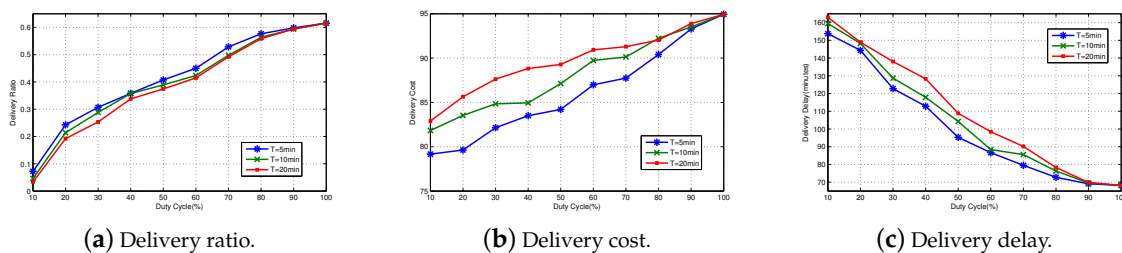

(**a**) Delivery ratio. (**b**) Delivery cost. (**c**) Delivery delay.

Figure 8. The comparison of delivery ratio (**a**), delivery cost (**b**) and delivery delay (**c**) based on the epidemic routing protocol in *Infocom6* trace with the different T.

6.4. Performance Comparison of Different m and n

There are two parameters, *m* and *n*, on the *LMMSE* predictor in the previous section, should be tuned. In related work [18], experiments have been conducted to investigate the total prediction errors by varying the value of *m* and *n*. The result is shown in Table 3, where *n* is set to be 10. Results under other settings and combinations of parameters give similar trends. Hence, we can find that the result in the Table 3 provides us with the basis for setting parameters of *m* and *n*. We suppose that the different setting of *m* and *n* may have an effect on the performance of the *ASMSS*. In this section, we will conduct experiments to study the impact of different *m* and *n* on the performance of the *ASMSS*. In order to reduce complexity, we set *m* to be 6, and compare the performance of the *ASMSS* by setting the different value of *n* when *D* is set to be 50%. The result is shown in Table 4. From Table 4, we find that the delivery ratio, delivery overhead and delivery delay are different but not very different when *n* takes different values. When *n* is 6, the corresponding delivery rate is larger. Hence, we set *m* to be 6 and *n* to be 6 in our experiments. Note that we just choose *m* less than 10 to do experiments for the performance comparison. That is because when the value of *m* and *n* is greater, the calculation complexity is relatively larger. We do not have to pay a huge calculation complexity for a small performance improvement.

Table 3. Predictor errors in lmmse.

	$m = 1$	$m = 2$	$m = 4$	$m = 6$	$m = 8$	$m = 10$
LMMSE	0.10	0.092	0.080	0.078	0.072	0.075

Table 4. Delivery ratio with different settings.

	$n = 2$	$n = 4$	$n = 6$	$n = 8$
Delivery Ratio	0.3855	0.3869	0.4105	0.3899
Delivery Overhead	82.9419	85.2306	84.1749	86.2299
Delivery Delay	97.2503	99.0865	95.8766	97.0855

7. Conclusions

In this paper, we have proposed the *ASMSS* based on the self-similarity of the OppNets. In the proposed mechanism, we use the *LMMSE* predictor to predict the future inter-contact interval based on the history inter-contact intervals recorded in node buffer. The state of a node will be set adaptively according to predicted result of future contacts with other nodes. Simulation results show that, at the same energy consumption of nodes, the *ASMSS* outperforms the random working mechanism and periodical working mechanism in terms of delivery ratio, delivery cost and delivery delay.

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