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Currency Boosts Content Dissemination in Noncooperative Ad-hoc Networks

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***Abstract*— In most of research works on the wireless ad-hoc network, it is often assumed that all nodes in the network are cooperative to relay packets. However, it is natural for nodes to be reluctant to cooperate by force due to the consumption of resources. Thus, a concept of noncooperative ad-hoc networks is being widely accepted in the latest research works. For the noncooperative ad-hoc networks, a framework which stimulates nodes to mutually cooperate was proposed by W.Yuen. It was shown that the framework utilizes more net capacity of the network than the multi-hop cooperative ad-hoc network does by exploiting data diversity and eliminating redundant bandwidth wastes for the multi-hop packet relays.**
In this paper, we suggest a content dissemination protocol which adopts currency and we show that adopting currency outperforms the previously proposed one through extensive simulations.

I. Introduction

When we assume the ubiquitous computing environment in the near future, it is natural and obvious that the wireless ad-hoc network plays an important role among all kinds of communication networks. It is well known that the noncooperative ad-hoc network which consists of mobile devices from different owners will be widely deployed in the personal communication area. In that area, there is no administrator who forces the nodes in the network to achieve the unified goal by cooperating as it usually does in the military or emergency situations. In the noncooperative ad-hoc network, since the nodes do not have the responsibility to forward packets or share packets with other nodes, to make the network active, reward methods to stimulate the nodes to cooperate are required. In [2],[3], currency was appeared to stimulate selfish nodes to cooperate and two types of general reward methods were suggested. One is packet purse model. When a node wants to transmit packets to others, it should borrow bandwidth and battery resources of intermediate nodes by rewarding for the resources. Thus the source node should load enough amount of currency on packets to reward all intermediate nodes whenever it transmits packets to a receiver. Another one is packet trade model. When a node wants to receive packets from other nodes, it should buy packets with higher cost from an intermediate node which had bought the packets from the former node. In the sequel, through the buy and sell chain from the source to the receiver, all intermediate nodes can be rewarded by the cost difference and the receiver finally rewards all nodes.

Another approach to stimulate the cooperation of ad-hoc nodes was made on [1]. They suggested an alternative way of reward which is based on mutual direct exchanges of contents between two nodes excluding the use of multi-hop transmissions. While the mutual exchange occurs, the resource consumption in both of the nodes caused by transmitting contents is rewarded by the contents that both of the nodes gather. To make this method between two nodes to be practical, under the assumption that the nodes in the network have common interests for a content and enough mobilities, they established a framework that a source node disseminates a content by splitting it to the large number of fragments. Then, the other nodes can collect the fragments to complete the content by downloading it from the source node or exchanging fragments with neighbor nodes recursively by moving according to the mobility. Although this approach excludes multi-hop transmissions, since large numbers of simultaneous fragment exchanges can occur in the whole network area, it significantly improves the dissemination rate in the network compared to the rate adaptation or the power control technique in the multi-hop ad-hoc networks [4], [5].

In this paper, we propose a currency-adopted content dissemination protocol and quantify the effect of currency on a content dissemination. Realization of framework of currency is beyond our scope. Intuitively, by introducing currency, we can get an option on the exchange that a node can receive a fragment by paying a currency instead of transmitting a fragment. It can be seen as a slight change but it makes huge difference on the performance of dissemination as it is proven and shown in section 4 and 5.

In section 2, we describe proposed protocol and propose an enhanced system model in section 3. After we analyze the protocol in section 4, we compare our protocol with the previous method with simulation results and explain the results in section 5. Finally, conclusions and further works are given in section 6.

II. Proposed Protocol Implementation

In this section, we describe our protocol for its control packets and working procedures. To exchange fragments or currency, first of all, matching of two nodes is required. While designing our protocol, the hardest part was how to match two nodes under asynchronous and unknown topology. When a node(A) sends a packet to another node(B) to match with, if the node(B), already sends a packet to the other node, a *matching chain* is made and it may cause large delay to match nodes efficiently. To solve this problem, we propose a *first contract first reply* algorithm to increase the rate of matching among the nodes. The algorithm is described in the following procedure description part.

A. Control Messages and States

The proposed protocol has simple control messages described below.

1) **eXtended Hello (xHello / xHello_matched)** : is used to notify its existence, its content list and its state for matching to its neighbor nodes.
2) **Contract** : is used to indicate an intention of matching with one of its neighbor nodes.
3) **Contract Reply (Accepted / Rejected)** : is used to indicate that a trial of contract is accepted or not.

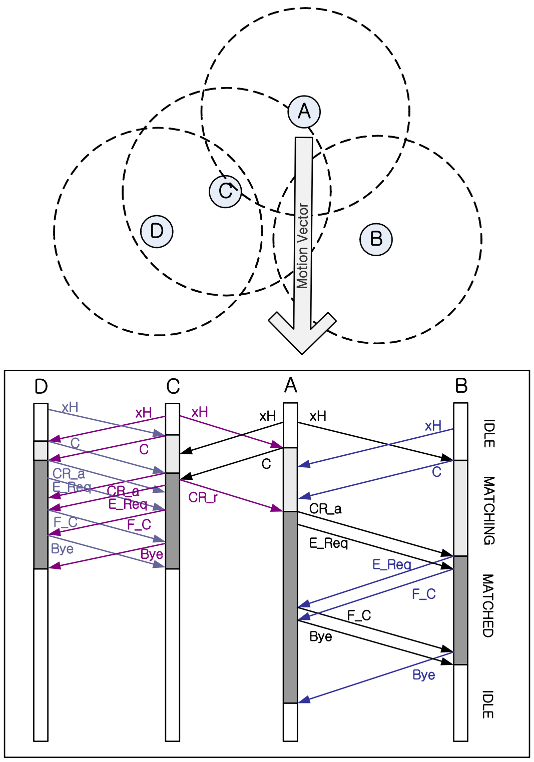

Fig. 1. Protocol procedure : when all the nodes try to match

Sending a **Contract Reply (Accepted)** to a node means that it is matched from that moment.

4) **Exchange Request**: is used to request a fragment or a currency to its matched node.
5) **Fragment/Currency** : is used to send a real fragment or a currency which is requested by its matched node
6) **Bye** : is used to notify that the match is ended to make a node free to accept a new contract from another node.

A node which participates in the content dissemination has states described below.

1) *IDLE* : A node which is not trying to match and is not tried to be matched is in *IDLE* state.
2) *MATCHING* : A node which is trying to match and is tried to be matched is in *MATCHING* state.
3) *MATCHED* : A node which is matched with another node is in *MATCHED* state.

B. Procedure Description

When a node in the *IDLE* state identifies neighbor nodes in *IDLE* state by receiving **xHello**s, it tries to match with the node whose **xHello** has arrived first. This is the main idea of *first contract first reply* algorithm. To support this, we force nodes to wait to receive a reply in *MATCHING* state when they sent requests. It is simplest way to break *matching chain* problem. This procedure is shown in Fig. 1 and described below.

1) Nodes in *IDLE* state should compete with others to be matched. At first, nodes in *IDLE* state send **xHello**.
2) Due to the asynchronous characteristic of ad-hoc nodes and the geographical distances, in example, node C receives **xHello** from node D first. And node D receives **xHello** from node C.

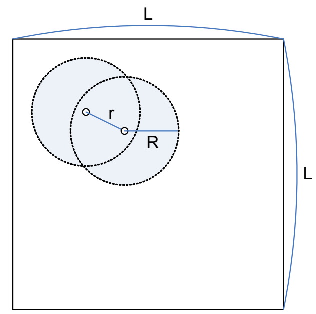

Fig. 2. Illustration of the radio range model

3) While node C and D are trying to match with each other by sending **Contract**, node C additionally receives **xHello** from node A.
4) At that moment, since node C cannot determine whether node D accepts or rejects its **Contract**, node C waits the reply from node D and delays to send **Contract** to node A.
5) When node C receives **Contract Reply (Accepted)** from node D, the state of node C changes to *MATCHED* and node C sends **Contract Reply (Rejected)** to node A. Then, node A tries to match with the node B which is waiting to be replied from node A.
6) Node A and B are matched. Then each pair of nodes follows the procedure of **Exchange Request - Fragment/Currency - Bye** to exchange fragments or currency.

III. Ad-hoc System Model

In this section, we propose a general ad-hoc model shown in Fig. 2 It is enhanced from a previous model which has discrete locations.
We define a model area as a square as shown in Fig. 2 whose side length is L. Let radio ranges of nodes be R. N number of nodes are floating in this area to collect fragments from a source node or other nodes also collecting the fragments. Since we cannot track all the motions of nodes in the network, we assume that a node exists on a certain position in the area with statistically same probability.

When a node matches with a node among n number of its neighbor nodes, not only the other $n-1$ nodes but also the nodes which exist in the range of the matched neighbor node should share the medium due to the RTS/CTS in *IEEE 802.11 MAC*. Thus the distance r shown in Fig. 2 determines the number of nodes affected by the communication of two matched nodes.

IV. Performance Analysis

In this section, we would derive the *collecting probability* μ which is a probability of gathering a fragment to complete the content. The probability μ depends on the number of fragments that a node have, thus μ is redefined as $\mu_i(t)$ for the state which currently have i number of collected fragments at time t. Following the implemented protocol, *collecting probability* is expressed as a product of *matching probability*(P_M) and *exchange probability*$(P_{E_i}(t))$ as shown below. *matching probability* is a probability of being matched by winning a competition of matching among neighbors and *exchange probability* is the probability of guaranteeing the inequality of the fragment lists of matched nodes to exchange a fragment or a currency so that it depends on i at time t.

$$\mu_i = P_M P_{E_i}(t) \tag{1}$$

To derive P_M, we need to estimate the number of neighbor nodes in a communication area of a node. It is assumed that N number of nodes in the $L \times L$ size of the network area have random starting positions with random motion vectors. It can be assumed that all positions in the area are equiprobable for a node to exist statistically.

If a node exists on a certain position in the area, it has a communication area of πR^2 around it where R is the radio range of a mobile node. Thus, we can define a probability $p_{area} = p_a$ which is a probability of being in the communication range of a node which equally means the probability of being a neighbor node. Additionally, we can define a probability of being a neighbor node of matched nodes $p_{matched-area} = p_{ma}$ depending on the distance of matched two nodes r where $r = [0, R]$.

$$\begin{aligned} p_a &= \frac{\pi R^2}{L^2} \\ p_{ma} &= \frac{2(\pi R^2 - (R^2 cos^{-1}(\frac{r}{2R}) - r\sqrt{R^2 - (\frac{r}{2})^2}))}{L^2} \end{aligned} \tag{2}$$

With this probability, using binomial distribution, a probability of the number of neighbor nodes of two matched nodes can be calculated. Excluding matched two nodes, up to $N-2$ nodes can be neighbor nodes.

$$P[N_m = n] = \binom{N-2}{n} (p_{ma})^n (1 - p_{ma})^{N-2-n} \tag{3}$$

Considering the effect of *RTS* and *CTS* in the ad-hoc network, all of the neighbor nodes in the matched area should not be matched not to disturb the communication of matched nodes. This assumption represents the wireless medium sharing.

Since the probability P_M for a certain node is equivalent for all nodes statistically, following recursive equation can be derived. Due to the complexity of an integral for the variable r, we approximate the equation as shown below.

$$\begin{aligned} P_M &= (N-1)p_a \int_0^R \frac{2r}{R} \sum_{n=1}^{N-2} P[N_m = n](1 - P_M)^n \mathrm{d}r \\ &\simeq (N-1)p_a \sum_{n=1}^{N-2} E'[P[N_m = n]](1 - P_M)^n \end{aligned} \tag{4}$$

where

$$E'[P[N_m = n]] = \binom{N-2}{n} E[p_{ma}]^n (1 - E[p_{ma}])^{N-2-n} \tag{5}$$

$$E[p_{ma}] = \int_0^R (\frac{2r}{R}) \frac{2(\pi R^2 - (R^2 cos^{-1}(\frac{r}{2R}) - r\sqrt{R^2 - (\frac{r}{2})^2}))}{L^2} \mathrm{d}r \tag{6}$$

After approximation, it is feasible to obtain numerical values of P_M for our simulation scenario although it is still not a closed form.

The *exchange probability* P_{E_i} is expressed as shown below.

$$P_{E_i}(t) = \frac{1}{2} P_{EM_i}(t) \frac{N-1}{N} + P_{ES_i}(t) \frac{1}{N} \tag{7}$$

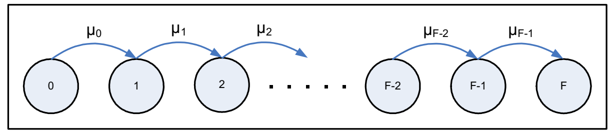

Fig. 3. Markov chain model

where $P_{EM_i}(t)$ is the *exchange probability* for a node to exchange with other collecting nodes and $P_{ES_i}(t)$ is the *exchange probability* for a node to exchange with the source node. $P_{EM_i}(t)$ and $P_{ES_i}(t)$ contribute $P_{E_i}(t)$ according to the ratio of the collecting nodes and the source node in the network. We derive P_{EM_i} in the aspect of two matched nodes instead of each node. This is the reason why we took $1/2$ on $P_{EM_i}(t)$. $P_{EM_i}(t)$ described below consists of five terms related to the fragment lists of two matched nodes where i and j indicate the number of fragments that the node and its matched node have. Each of the terms indicates respectively that fragment lists of two nodes are unequal when $i = j$, different fragments exist in both of fragment lists when $i > j$, one of fragment lists includes all the fragments of the other when $i > j$ and two of previous cases occur when $i < j$. For the case that one list includes all fragments of the other is meaningful only with currency, since collecting a fragment occurs in one of the two nodes. Thus, for that case we do not multiply by 2.

$$\begin{aligned} P_{EM_i}(t) = {} & 2(1 - \frac{1}{\binom{F}{i}})P[i=j,t] + [2(1 - \frac{\binom{j}{i}}{\binom{F}{i}}) + \frac{\binom{j}{i}}{\binom{F}{i}}]P[i<j,t] \\ & + [2(1 - \frac{\binom{i}{j}}{\binom{F}{j}}) + \frac{\binom{i}{j}}{\binom{F}{j}}]P[i>j,t] \end{aligned} \tag{8}$$

Relatively P_{ES_i} is very simple. Once a node matches with the source node, it always collects a fragment.

$$P_{ES_i} = 1 \tag{9}$$

The probabilities in the above equation are defined below. $P[i = j, t] = P[f(t) = i]P[f(t) = j]$ where $f(t)$ is the number of collected fragments at time t. Thus $P[i > j, t]$ and $P[i < j, t]$ can be expressed as shown below.

$$\begin{aligned} P[i > j, t] &= \sum_{j=0}^{i-1} P[f(t) = i]P[f(t) = j] \\ P[i < j, t] &= \sum_{j=i+1}^{F} P[f(t) = i]P[f(t) = i] \end{aligned} \tag{10}$$

Derivation of a time-varying probability density function $P[f(t)]$ is left for the future work.

Comparing $P_{E_i}(t)$ of the proposed method with a method which does not have currency, we can find the difference in P_{EM_i}. Let $P_{EM_inc}(t)$ be $P_{EM_i}(t)$ for the method of no currency. Then the difference $P_{EM_i}(t) - P_{EM_inc}(t)$ is shown below.

$$P_{EM_i}(t) - P_{EM_inc}(t) = \frac{\binom{j}{i}}{\binom{F}{i}} P[i<j,t] + \frac{\binom{i}{j}}{\binom{F}{j}} P[i>j,t] \tag{11}$$

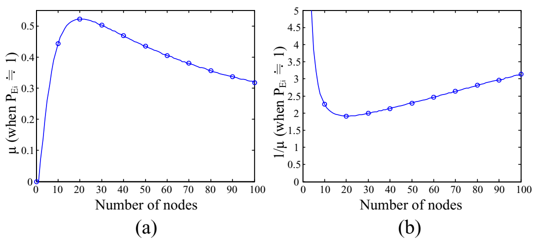

Fig. 4. (a) μ, (b) $1/\mu$ against number of nodes

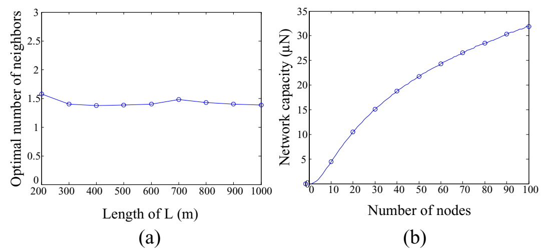

Fig. 5. (a) Optimal number of neighbors, (b) Network capacity

Since $P_{EM_i}(t) - P_{EM_inc}(t) \simeq 0$ for most of i, it is easy to make a mistake by approximating it as zero. However, there are critical exceptions shown below.

$$P_{EM_i}(t) - P_{EM_inc}(t) = \frac{\binom{j}{0}}{\binom{F}{0}} P[j>0,t] = P[j>0,t] \quad for \ i=0$$
$$P_{EM_i}(t) - P_{EM_inc}(t) \simeq \frac{\binom{F}{i}}{\binom{F}{i}} P[j=F,t] = P[j=F,t] \quad for \ i \simeq F \tag{12}$$

For the case $i = 0$, $P_{EM_inc}(t) = 0$ whereas $P_{EM_i}(t) = P[j > 0, t]$, thus the method without currency should only depend on the probability $P_{E_i}(t) = P_{ES_i}(t)/N$ to collect the first fragment. For certain nodes located far from the source node, it could be much harder to collect the first fragment according to the velocity and motion vector. This can make a large variance on start time of collecting fragments. Another troublesome case is $i \simeq F$, $j = F$. Since i is close to F, considerable portion of nodes would have completed the collection. Since the nodes who complete the collection would not participate the dissemination in a method without currency, nodes who have not completed the collection should have to depend on the source node again. This may delay the completion critically and incur large variance on completion time.

Here, we plotted $\mu_i(t) \simeq P_M$ by approximating $P_{E_i}(t) \simeq 1$ as shown in Fig. 4 (a). From Fig. 4 (a), we can find that there is an optimal density which maximizes $\mu_i(t)$ for a given L and R. For our simulations where L and R are $670m$ and $100m$, putting 20 nodes in the network is optimal. Moreover, optimal number of the neighbor nodes can be derived as $N\frac{\pi R^2}{L^2}$. After plotting the optimal number of the neighbor nodes as shown in Fig. 5 (a), we can assure that 1.4 to 1.5 is the optimal number of neighbor nodes for our protocol and settings.
An interesting observation is that the network capacity μN increases according to the number of nodes as shown in Fig. 5 (b) although the *collecting probability* μ of the node decreases as the density of the nodes increases.

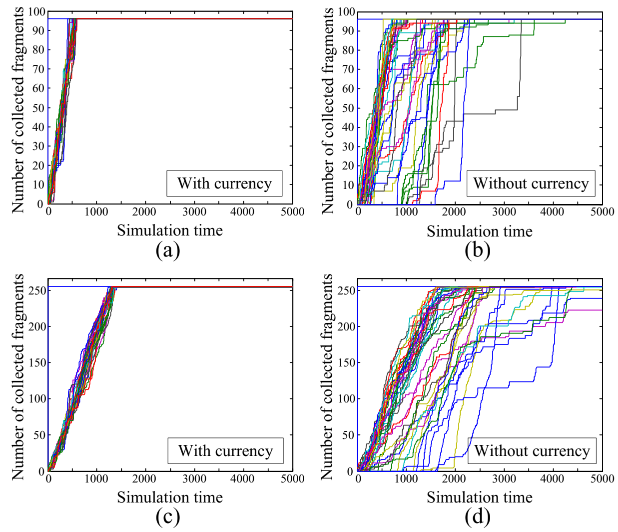

Fig. 6. Fragment collection pattern comparison of 50 nodes (a) (b) F=96, (c) (d) F=256

The expected dissemination completion time $E[T_{complete}]$ is derived from a simple analysis of markov chain by introducing a slot time $T_f{\cdot}S$ which means averaged fragment transmission time where S is a size of a fragment and T_f is the time taken to transmit the unit size of a fragment.

$$\begin{aligned} E[T_i] &= \mu_i(T_fS) + (1-\mu_i)\mu_i 2(T_fS) + (1-\mu_i)^2\mu_i 3(T_fS)\cdots \\ &= \frac{T_fS}{\mu_i} \end{aligned} \tag{13}$$

$$\begin{aligned} E[T_{complete}] &= E[T_0] + E[T_1] + \cdots + E[T_{F-2}] + E[T_{F-1}] \\ &= (T_fS)\sum_{i=0}^{F-1}\frac{1}{\mu_i} \end{aligned} \tag{14}$$

From this analysis, we found that $E[T_{complete}] \propto 1/\mu_i$ as shown in Fig. 4 (b) and it is proportional to the size of a fragment S and proportional to the number of fragments F since $\mu_i \simeq \mu$ for most of i.

V. Simulation Results and Comparisons

In this section, we examine the effect of currency through simulations using *NS-2*. Our simulations were done under $670m \times 670m$ area with $100m$ of a wireless range with default parameters of the *IEEE 802.11 MAC* in *NS-2*. We used random-waypoint mobility model.

A. Dissemination Characteristics

In Fig. 6, the fragment collecting patterns are described compared to the method without currency. We set 50 nodes to collect 96, 256 fragmented content where a fragment is built up with 10 packets and a size of a packet is 2kB. Graphs in the left side of Fig. 6, show the simulation results of proposed protocol and the other side shows the results of a method without currency. In Fig. 6(b)(d), as we have analyzed in the section 4, considerable number of the nodes in a method without currency start collecting fragment very slowly compared to the group of nodes which start early. Moreover, completion times of nodes are distributed in long range that it cannot be guaranteed to complete within a tight bound. On the other hand, with the help of currency, in Fig. 6(a)(c) we can verify

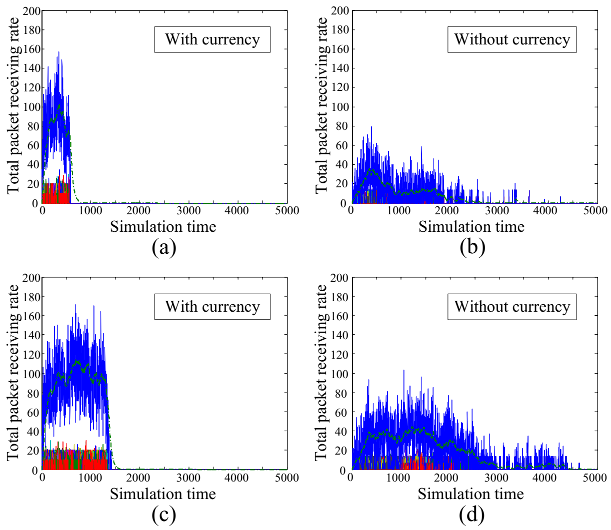

Fig. 7. Total packet receiving rate comparison of 50 nodes (a) (b) F=96, (c) (d) F=256

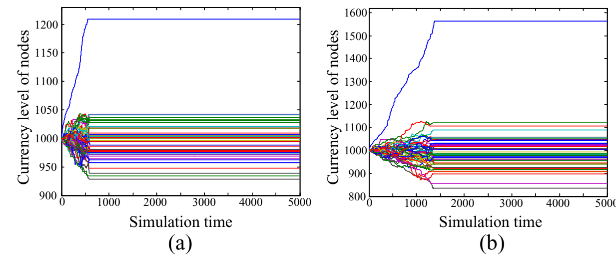

Fig. 8. Currency level variations of 50 nodes (a) F=96, (b) F=256

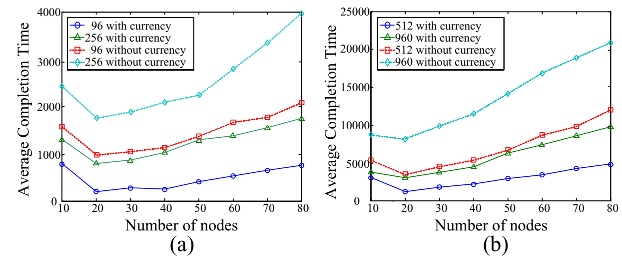

Fig. 9. Average completion time against number of nodes with and without currency (a) F=96, F=256 (b) F=512, F=960

that all nodes start collecting fragment similarly and complete within a tight bound.

In Fig. 7, the total packet receiving rate in the sense of the network capacity is shown. Fig. 7 (a),(c) show the total packet receiving rate of 50 nodes of proposed protocol and Fig. 7 (b),(d) do it for a method without currency. The line in the middle of the graphs is an *EWMA*(Exponentially Weighted Moving Average) of the total packet receiving rate. For the same number of fragments F=96, proposed protocol shows 90 packets per second(pps) whereas the method without currency shows only 20 pps. For F=256, proposed protocol shows 100 pps whereas the other shows 30 pps. The difference of network capacity comes from the difference of the availability of fragment exchanges due to the currency.

In Fig. 8, we can see how the currency level of 50 nodes varies in proposed protocol as time goes by. We gave 1000 amount of currency to all nodes which is enough to receive a content completely. One thing we have to carefully look in Fig. 8 is the amount of the currency earned by the source. For the case of F=256, the source have finally earned 577 after disseminating 256×50 number of fragments to 50 nodes in the network. It means that the source node only transmit the fragments to a node 577 times instead of 12800 times by sharing the loads with all nodes which participate in the dissemination.
Another important thing is that half of nodes finally earned currency even though they have surely spent the currency to complete the content and most of nodes loses less than 100 instead of 256. Since all nodes have equal chance to earn currency if they move statistically identical, currency consumption of nodes would converge to 0. This means that currency can virtually help networks to be drastically active without realizations or with few realizations.

B. Completion Time

In Fig. 9, we compared the average completion time of our method and a method without currency. A method without currency takes more than double time of our method in most cases.

VI. Conclusion

We propose a content dissemination protocol using currency for the noncooperative ad-hoc network. While doing that, to solve the *matching chain* problem, *first contract first reply* algorithm which can make large number of matchings under an asynchronous and unknown network topology is suggested.

Currency is generally assumed to incur overheads instead of benefits to the networks. However, it is shown that depending on the protocol currency can make a huge benefit on the performance by boosting exchanges. It seems similar to the situation in human society that makes circulation of goods much faster by adopting currency after a long period of bartering.

To enhance our currency approach, combining with multi-hop transmissions is left for a future work to help nodes in the dead angle of networks. A resource management scheme with currency on variable values of resources like [6] is also being researched. Furthermore, we are developing effective realization framework of currency and evaluating an overhead effect.

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