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Incentive for Opportuni tic Network

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Ab tract **Ad hoc network and peer-to-peer y tem typically require many users to participate, to leverage the full benefits of the y tem. In thi paper we con ider incentive for opportuni tic network . A an example, con ider an electronic coupon y tem, where provider   end out coupon , which are pa ed from u er to u er. U er receive bonu point for each redemption to encourage participation. We define a general model for such bonus point -ba ed coupon cheme and derive an optimal trategy to allow a u er to determine how many bonu point   he hould a k for when pa ing the coupon. We al o how that our optimal trategy i very robu t again t all other u er trategie , and that there i a trong incentive for u er to follow our optimal trategy.**

I. Introduction

Many y tem , uch a ad hoc network , peer-to-peer y tem , and opportuni tic network require many u er to participate to leverage the full benefits of the system. However, in many ca e , u er may be required to provide *their own re ource* (e.g., memory, bandwidth, battery power) for other to use, without getting any direct benefit from that. An abstract if you help me now, I will help you later - tyle motivation, may not be sufficient to encourage participation. Such free-riding [1], [2] ha been ob erved in peer-to-peer network , and work on mobile ad hoc network ha propo ed everal *incentive cheme* [3], [4] to encourage participation.

In thi paper, we examine an electronic coupon y tem a an example of incentive for opportuni tic network . In thi y tem, a provider end out a coupon which i pa ed from user to user, until a user finally redeems the coupon (e.g., purcha e the adverti ed product). To encourage u er participation, the provider give out bonu point (e.g., frequent flyer miles) to all users who participated in passing the coupon to the redeemer. Although the propo ed bonu point cheme i very general, we con ider it from the point of view of opportuni tic network , where information propagate with little or no u er interaction. Therefore, incentive cheme   hould al o be very general ince they cannot rely on u er interaction, but mu t in tead rely on general propertie of the application in que tion.

The contributions of this paper are two-fold. First, we define a general model for uch bonu point -ba ed cheme and derive an optimal trategy which allow each u er to determine how many bonu point   he hould a k for when pa ing the coupon. Second, we how that our optimal trategy i extremely robu t again t all other u er trategie , and that there i a trong incentive for u er to follow our optimal trategy.

Thi paper i organized a follow . In Section II we give an example of an electronic coupon y tem and develop a formal model for such systems. In Section III we define an optimal trategy, both in linear pa ing chain and pa ing tree . Section IV inve tigate the effect of u er behavior on the optimal trategy. In Section V we di cu the implication of our re ult on electronic coupon cheme . Section VI di cu e related work. Finally, Section VII conclude the paper.

II. Electronic Coupon Example

The y tem we con ider i adPASS [5], which pread electronic coupon among intere ted u er in mobile environment . A provider end out coupon which adverti e ome product via an acce point in talled in the hop. U er carry mobile device which tore the coupon according to the u er' preference . Later, when a u er A who ha coupon meet another u er B with imilar intere t , A can pa the coupon on to B. A a reward for thi , the provider ha allocated ome number of bonu point to the coupon and A i allowed to claim ome of the e point for her elf. B can al o pa the coupon on, or go to the hop to redeem the coupon. When ome u er goe to redeem the coupon, *all* u er who were involved in the chain thi coupon took from the provider to the redeeming u er will get the bonu point they took when they pa ed the coupon on. If nobody redeem the coupon, no bonu point are given out.

A. Bonu Point Model

If a u er redeem the coupon, e.g., purcha e the advertized product, all the u er who participated in pa ing the coupon from the provider to the actual buyer get the point they have taken. We call thi equence of u er the *pa ing chain*, or chain. A chain alway tart from the provider and end in a u er who redeem the coupon. For a u er A, we call all the u er between the provider and A a *up tream u er* and all u er after A in the chain are *down tream u er* .

The rule for pa ing the coupon are a follow :

1) The provider et the initial number of point .
2) Each u er mu t take at lea t 1 point when he pa e the coupon onward .
3) If only 1 point remain , the coupon cannot be pa ed.
4) If everal down tream u er redeem the ame coupon, up tream u er get the point for *each* redemption.
5) If a u er redeem a coupon, he can get point for the ame coupon if he had pa ed it before redeeming it.

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B. Formal Model

Let B be the number of point in a coupon that u er A receive . U er A might get the coupon from the provider or from another u er. For A, there i no difference between the e ca e and only the remaining point B matter.

A ume that u er A decide to take b point , with $1 \leq b < B$. We al o a ume that the probability that any u er redeem the coupon i p. For implicity, we a ume that thi probability i the ame for all u er and that the u er are independent from each other. We a ume that the redemption probability i independent of the number of point remaining in the coupon (i.e., u er redeem the coupon becau e the coupon i of intere t and not ju t imply to get bonu point).

Since each u er ha to take at lea t 1 point from the coupon, the length of the passing chain is finite. Denote the length of the down tream chain from u er A a N. See Section III on how the length of the chain can be calculated.

Then, the expected number of point A can get from all the redemption in her down tream chain i :

$$\begin{aligned} E[\text{point if } b \text{ taken}] &= \sum_{i=1}^{N} bi \binom{N}{i} p^i (1-p)^{N-i} \\ &= bNp \end{aligned} \qquad (1)$$

Equation (1) allow u to calculate the expected number of bonu point gained by a ingle u er in a traight-forward manner, given the length of the down tream chain and the amount of point taken. Note that the redemption probability p ha no effect on b and N which are determined by the trategy of the u er. Hence, our a umption that p i the ame for all u er ha no effect on the u er behavior.

III. Strategies

We now derive an optimal trategy and di cu how it can be applied in practice. We a ume that the goal of a u er i to maximize the number of bonu point he earn . A can be een from equation (1), the redemption probability doe not affect the trategy of the u er, which i the amount of point taken by the u er that determine the maximum number of people in the down tream chain.

We first derive the optimal strategy for a *linear* pa ing chain, that i , each u er pa e the coupon to only one other u er. In Section III-C, we will derive the optimal trategy for the ca e where u er can pa the coupon to multiple u er .

A. Optimal Strategy for Linear Pa ing Chain

Con ider the ca e where there i only 1 point left in the coupon. In thi ca e, the coupon cannot be pa ed on and the chain end . Similarly, when there are 2 point left, the only po ible olution i to take 1 point and pa 1 point on. Since users try to maximize their own benefit, we assume that the u er will try to pa the coupon onward .

With 3 point remaining, a u er A can either take 1 or 2 point . If u er A take 2 point , then only 1 point remain and the chain after the current u er ha length 1. If u er A

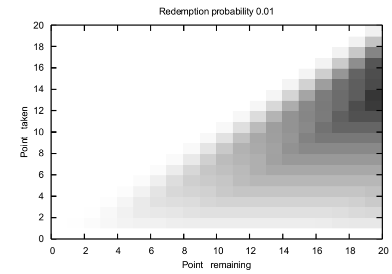

Fig. 1. Optimal trategy for 1 20 point

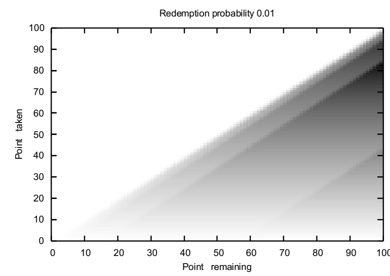

Fig. 2. Optimal trategy for 1 100 point

take 1 point, then two point remain, and the above trategy for 2 point re ult in a chain of length 2. In both ca e , the expected number of gained point given by equation (1) i $2p$. Since the two trategie have the ame expected number of point gained, they are equal for that u er.

With 4 point remaining, a u er A ha three po ibilitie : take 3, 2, or 1 point . We can calculate that the expected number of gained point are $3p$, $4p$ and $3p$, re pectively.[1] The trategy Take 2 dominate , and the optimal trategy for 4 remaining point i to take 2 of them.

In a imilar way, we can continue with larger number of point remaining, and we can compute the optimal trategie for any given value of B. Figure 1 and 2 how the optimal trategie for 1 20 and 1 100 point remaining, re pectively.

In these figures, the x-axis shows how many points are remaining in the coupon when the u er receive it, and the y-axi how the po ible amount of point the u er can take for her elf. The color at a point (x, y) indicate the expected number of bonu point gained by the u er, a uming he took y point from the remaining x point . Darker color indicate higher amount of gained point .[2]

A we can ee, the optimal choice of point i typically to take about 60 80% of the remaining point . Thi i e pecially

[1] The ca e where A take only 1 point divide into two po ibilitie , depending on whether the next u er take 1 or 2 point . The e two po ibilitie give the expected number of gained point a $3p$ and $2p$.

[2] The figures show redemption probability of 0.01. As stated in Section II-B, thi only affect the numerical value , but not the optimal trategy.

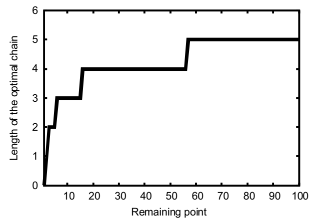

Fig. 3. Length of the optimal linear chain

clearly vi ible on the right ide of Figure 2, where the remaining number of point i large. Figure 1 how a clo e-up of the left ide of Figure 2 and we can ee that al o there, the optimal number of point to take i about 70% of the remaining point .

The optimal trategie are calculated through exhau tive earch, which make real-time calculation on mall portable devices difficult. However, since the optimal number of points to take i independent of the u er' other action , the point can be pre-calculated and tored in a table. Thu , the actual calculation on the u er' device i a imple table lookup.

Figure 3 how the length of the optimal chain a a function of the remaining point . The chain are typically quite hort with only a few u er participating in the di tribution.

Figure 3 al o allow u to determine the optimal trategy for the provider when deciding how many point to in ert in the coupon initially. For example, point between 16 and 56 all re ult in a chain of 4 people, hence a provider would choo e 16 point , ince thi minimize the amount of point the provider need to give out in thi interval. The re ult in Figure 3 clearly how that the provider would choo e the amount of initial point from a mall et of po ibilitie .

B. Equal Optimal Strategie

A the example with 3 remaining point in Section III-A how , the optimal trategy i not alway unique. Such equal optimal trategie are equal to the u er who i faced with the choice, but, for the up tream u er , the choice could make a difference. We have evaluated the frequency of uch equal, optimal trategie and di covered that they do not occur very frequently. For the range of 1 100 point remaining, we ob erved that uch equal optimal trategie happen in only a few ca e (maximum 3, depending on the deci ion at uch equal point). Furthermore, the effect on the expected number of gained point i relatively mall, making dilemma of equal optimal trategie mo tly negligible.

C. Optimal Strategy for a Pa ing Tree

The above optimal trategy applie when each u er can pa the coupon to only one other u er. In reality, a ingle u er could pa the coupon to everal other u er , who pa it on to everal other , etc. Thi re ult in a *pa ing tree*. In thi ection, we will inve tigate how the optimal trategy need to be modified in a passing tree.

When a u er A pa e an coupon onward , the remaining amount of point B', determine the maximum depth of the pa ing tree, ince each u er mu t take at lea t one point. However, u er A cannot know how many branche there are in the tree. If the depth of the tree i at mo t B' and each level ha k branche , the complete pa ing tree ha at mo t $N = \sum_{i=0}^{B'-1} k^i$ u er , which all are po ible redeemer . However, ince k i unknown,[3] the value of N needed for equation (1) cannot be determined by u er A. Hence, it i not po ible to define an optimal strategy at run-time. However, after the coupon ha been pa ed a far a po ible, we can compute the trategy that *would have been* optimal.

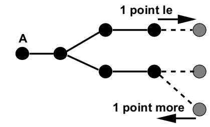

Fig. 4. Modifying trategy in a pa ing tree

Given that the u er know an optimal trategy for a linear chain but not for a tree, the natural que tion to a k i : Should the u er deviate from the known optimal trategy? . We will now derive condition for determining when to tay with the optimal trategy and when to deviate from it. Note that the e condition can only be applied *after* the coupon ha been redeemed, but we can u e them to determine whether uch deviation would make en e in general.

A ume that u er A receive an coupon with B point and that the optimal trategy from Section III-A take b^* point and re ult in a chain of N^* u er . Hence, the optimal expected amount of gained point i b^*N^*p. Since p doe not affect the optimal trategy, we will di card it in order to implify the equation in the following.

The ituation i hown in Figure 4. A ume that the current tree contains all the nodes in the figure. If user A were to take 1 point more, the grey u er would no longer be part of the tree, ince there would not be enough point left in the coupon for them to receive it. Likewi e, if the current tree wa ju t the black u er and A took 1 point le , the tree *might* grow to include the grey u er . However, in thi ca e, there are no guarantee that the tree would actually grow, ince any of the black u er might decide to take 1 point more than a umed in the tree in Figure 4.

Let's consider the first case of user A taking more points and making the tree hallower. A ume that u er A take $b = b^* + b'$ point and that thi mean that n' u er are removed from the tree. Then, it i better to *tay with the optimal linear trategy* if

$$\begin{aligned} b^*N^* &\geq (b^* + b')(N^* - n') \\ n' &\geq \frac{N^*b'}{b^* + b'} \end{aligned} \tag{2}$$

Hence, if the number of lo t u er i greater than $\frac{N^*b'}{b^*+b'}$, it i better *not* to deviate from the optimal trategy.

Let' now con ider the econd ca e of u er A taking le point and making the tree deeper. A ume that u er A take

[3] Al o B' i in principle unknown, ince u er A cannot be ure that all the ub equent u er follow the optimal trategy.

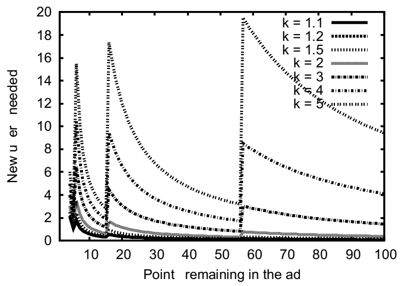

Fig. 5. New u er required to deviate from the optimal trategy

$b = b^* - b'$ point and that thi mean that n' u er are added to the tree. Then, it i better to *tay with the optimal linear trategy* if

$$b^*N^* \geq (b^* - b')(N^* + n')$$
$$n' \leq \frac{N^*b'}{b^* - b'} \tag{3}$$

In other word , unle giving up b' point bring at lea t n' new u er , it i better to tay with the optimal trategy.

Given that the optimal trategy i relatively greedy , i.e., it tend to take a large amount of point , we now concentrate on evaluating when taking le point (and gaining u er) would be beneficial.

A ume that the u er decide to take one point le than the optimal trategy indicate . Then, the tree need to get at lea t $n' = \frac{N^*}{b^*-1}$ new u er in order to re ult in the ame number of point gained by the u er. In Figure 5 we plot the value of thi , for everal different branching factor k. We have a umed that the re ulting pa ing tree are full k-ary tree for the value of k shown in the figure.[4]

A we can ee from Figure 5, the number of new u er needed varie greatly with the number of point in the coupon. The pike in Figure 5 coincide with the tep in Figure 3, which ha the following implication .

Since the tep in Figure 3 are the likely amount of point given out by the provider, the number of new u er required to be reached by the coupon i mo t likely given by the value of the pike in Figure 5.

The new u er needed (the pike) are typically rea onable. For example, a tree with depth 4 and branching factor 5 (the highe t pike) would require about 20 new u er . Given that there are already $5^4 = 625$ u er in the tree, the chance that allowing the tree to extend by one level would bring in 20 u er eem very high. However, if u er A at the root of the tree decide to take one point le , but u er B next in the tree decide to follow the optimal trategy, u er B will take the point that wa not taken by A. Hence, A will actually be wor e off for deviating from the optimal trategy.

Furthermore, if there are only a few point left in the coupon, the required number of new u er i quite high compared to what i fea ible. For example, with low branching factor ($k < 2$) and 6 point remaining, we would need over 2 new u er . Becau e of the low branching factor, we could only a ume to get about 1 or 2 new u er , hence the deviation cannot be justified. Same applies to the other branching factors for mall number of remaining point .

The above example highlight that although deviating from the optimal strategy is in some cases justifiable from a mathematical point of view, we al o need to take into account u er behavior. We will now turn to inve tigating the effect of u er behavior and we will return to the i ue of deviating from the optimal trategy in Section V.

[4]For non-integer value of k we a umed a tree with $\sum_{i=0}^{B'-1} k^i$ u er .

IV. Effect of User Behavior

The optimal trategy allow a u er to determine how many point to take in any ituation. Since the optimal trategy i independent of the redemption probability p, the above calculation can be u ed to determine the amount of point to take to maximize the number of gained point .

However, the optimal trategy a ume that all u er follow the optimal trategy. If down tream u er tend to take *le* than the optimal amount, then the total amount of gained point for the up tream u er will increa e becau e the chain will be longer. Conver ely, if the down tream u er are greedy, the chain will be horter and the up tream u er will not get a many point a they expected. We now inve tigate the en itivity of the optimal trategy to other po ible trategie followed by other u er .

We consider 6 different types of users, defined as follows:

- Rational (R): Follow the optimal trategy (take *opt* point).
- Greedy (G): Take more point than the optimal trategy ay . A *pure greedy* (P-G) u er alway leave only 1 point.
- Altrui tic (A): Take le point than the optimal trategy ay . A *pure altrui tic* (P-A) u er alway take only 1 point.
- Random (RND): Take a random amount of point , uniformly di tributed between 1 and $B - 1$.

For the normal greedy and altrui tic trategie , we a ume that the u er take a random amount of point , uniformly di tributed in the appropriate interval ($]opt, max - 1]$ for greedy and $[1, opt[$ for altrui tic).

A. Population with Two Type of U er

We first compare each of the 6 user types (rational, (pure) greedy, (pure) altrui tic, and random) pairwi e with all the other type . We a ume a population which con i t entirely of the given type and we inve tigate what happen when a ingle u er from another type come into play.

The re ult are hown in Table I. We how the amount of gained bonu point by the u er type on each row again t a population indicated by the column. The value are averaged over 200 individual run . In the imulation, we had one u er of the type given on the row take a many point a her trategy dictate . Then he would pa the coupon on, and each u er in the chain would u e the column- trategy to decide how

U er	R	G	A	RND	P-G	P-A
	Opponent' trategy					
R	**4.20**	**2.18**	**5.23**	**4.30**	1.68	13.44
G	3.23	1.99	3.88	4.04	**1.77**	7.73
A	2.37	1.11	3.15	2.35	0.81	**18.09**
RND	2.37	1.29	3.20	2.90	0.95	16.59
P-G	0.99	0.99	0.99	0.99	0.99	0.99
P-A	0.06	0.03	0.08	0.07	0.02	0.99

TABLE I

TWO TYPES OF USERS. REDEMPTION PROBABILITY $p = 0.01$ AND INITIAL BONUS POINTS $B = 100$.

many point to take. We a umed that the coupon get pa ed a long a there are point remaining.

The be t trategy again t the given population (column) i given by the bolded entrie . The actual numerical value are specific to the parameters of the simulation; however, the ranking applie to all combination of parameter .

A we can ee, the rational u er get the highe t amount of gained bonu point again t all the four ba ic type . Hence, a u er wanting to maximize her gained point   hould u e the rational trategy, regardle   of the other . The value in the table cover only the ca e where only 1 u er i of the different type. We al o ran the experiment for other mixe of u er and found out that the rational trategy alway ha   uperior performance when compared to the other ba ic trategie .

In general, we conclude that of the 4 main trategie rational i the be t, followed by greedy, random, and altrui tic. The pure greedy and pure altrui tic trategie u ually exhibit very poor performance.

The exception to the dominance of the rational trategy are again t a population of pure greedy or pure altrui tic. In a pure greedy population, a ingle greedy u er will get more point than a ingle rational u er. However, our experiment indicated that a   oon a the fraction of rational (or greedy) u er in the population of pure greedy u er i above 10%, rational trategy again dominate . The explanation i a follow . In a population of pure greedy users, all chains are of length 2, since the first user in the chain will take all but 1 point. Therefore, the first u er hould take a much a   he can, while guaranteeing the chain length of 2, i.e., take all but 2 point . The greedy trategy which take more than the rational trategy i therefore better.

The good performance of the altrui tic trategy again t the pure altrui tic trategy i explained a follow . In a population of pure altrui tic u er , all chain have their maximum length, ince all u er take only 1 point. For example, with 20 point remaining, a rational u er will take 14 and the chain ha length 6, which give the expected bonu point of $6 \cdot 14p = 84p$. If the u er take , ay 10 point , then the chain ha length 10. In thi ca e, the expected amount of gained of bonu point i $10 \cdot 10p = 100p$. The good performance of the altrui tic trategy again t the pure altrui tic trategy prevail over a larger range of altrui tic u er .

B. Population with Multiple Type of U er

We now inve tigate u er population with more than two type of u er . We leave pure greedy and pure altrui tic out becau e of their poor performance.

We performed a imilar experiment a in Section IV-A, where we vary the fraction of different type of u er . In each of the experiment , we had all four type of u er repre ented and we compared how a given u er type doe in that population. The re ult are hown in Table II. We how 5 different population mixe . The column heading indicate what percentage of the population wa of a given u er type had in the experiment. We report the re ult for an even mix and population where one u er type wa in majority. We al o performed the experiment for other population mixe and the re ult were imilar to the one here.

A Table II how , a rational u er ha the highe t expected number of gained bonus points in all cases. This confirms the dominance of the rational trategy, which we already ob erved with the compari on of two u er type in Section IV-A.

V. DISCUSSION

We now di cu   deviating from the optimal trategy a well a the implication of our re ult on electronic coupon cheme .

A. Deviating from Optimal Strategy

A di cu ed in Section III-C, deviating from the optimal strategy can be justified from a mathematical point of view. However, thi depend on the other u er *not changing* their trategie . In light of the re ult from Section IV, it appear that the rational trategy dominate over all other trategie . This dominance of the rational strategy makes the justifications behind the deviation highly que tionable.

Since the rational trategy dominate , we can a ume that mo t (or all) of the u er would follow that trategy. In a pa ing tree, ome u er might a ume a low branching factor, which favor   taying with the optimal trategy. If a u er decide to deviate by taking le   point , ub equent u er might decide to take tho e point , ince that i the optimal trategy. Hence, the u er who deviated would lo e, ince the length of the chain would not increa e.

In fact, other u er taking the point left by the deviating u er i almo t guaranteed. We ee that from the left ide of Figure 5, which how that when only a mall number of point are left, deviation doe not pay off. Hence, the u er near the end of the chain (or leave of the tree) have a trong incentive to follow the optimal trategy. Point not taken by up tream u er are likely claimed by them. Therefore the length of the chain doe not change a anticipated by the u er who deviated.

Becau e of the above rea on , we conclude that deviating from the optimal trategy i likely not to pay off, hence u er are better off by u ing the optimal trategy.

B. Practical Con ideration

A   hown in Figure 3, the chain through which the coupon pa   i not very long. The number of point initially put in the coupon naturally depend on what i the value of the point , which is specific to the actual bonus point scheme.

In general, we ee hort chain a po itive. Becau e the coupon only travel a mall number of hop , they are till

My trategy	Population mix (R/G/A/RND) 25/25/25/25	70/10/10/10	10/70/10/10	10/10/70/10	10/10/10/70
Rational	**3.29**	**3.74**	**2.50**	**3.94**	**3.99**
Greedy	2.78	3.00	2.14	3.35	3.21
Altrui tic	2.05	2.12	1.28	2.65	2.17
Random	2.27	2.17	1.57	2.75	2.38

TABLE II

MULTIPLE TYPES OF USERS. REDEMPTION PROBABILITY $p = 0.01$ AND INITIAL BONUS POINTS $B = 100$.

likely to be of intere t even to the la t u er . In a long chain, it could be that by the time the coupon get to the la t u er, the coupon would no longer be relevant. Al o, in y tem ba ed on one-hop communication (like adPASS), a hort chain of people implie a mall geographical coverage, and coupon would remain in the area where they are of intere t.

Becau e the chain are hort, the coverage i determined by the branching factor of the pa ing tree. U er high in the tree have an intere t in pa ing the coupon to a many other a po ible, ince that increa e their chance of getting bonu points. Given that the first user in the chain usually takes a large number of point , thi i a further incentive for the u er to collect the coupons in the first place.

In ummary, we believe that our re ult are encouraging and confirm the potential of electronic coupon schemes. Further work i required, in particular in term of evaluating the effect of different u er behavior in a large pa ing tree.

VI. RELATED WORK

Incentive cheme are important to (mobile) peer-to-peer network or mobile ad hoc network that are formed by unrelated and selfishly acting nodes, known as free-riders [1]. For example, Saroiu et al. [2] howed that only 7% of client in the peer-to-peer Gnutella network share more that 1000 files. On the other hand, 25% of its users do not share any files and about 75% of the clients share 100 files or less.

Golle et al. [6] have addre ed the incentive i ue in centralized peer-to-peer network . They propo ed and analyzed several micro-payment mechanism to encourage file sharing and reduce the prevalent free-rider problem. Crowcroft et al. [3], [7] propo e a pricing mechani m for mobile ad hoc network node a an incentive to forward network package . Mannak et al. [8] conducted a mall u er tudy on u er' motivation to hare re ource in peer-to-peer network . They found out that 50% of the que tioned u er would hare more, if ome materiali tic incentive , for example earning money, would be provided by the application.

Similar to adPASS, the idea to pread digital adverti ement with embedded coupon among mobile u er in a peer-to-peer manner and reward participating u er i al o de cribed by Rat imor et al. [9]. In contra t to our propo ed bonu point model, a u er cannot affect hi chance of being rewarded, for example, by choo ing a different trategy, ince the trategie are fixed for all users.

Garyfalo and Almeroth de cribe *Coupon* [4], [10], an incentive cheme that give u er credit for forwarding information to other u er in an ad hoc network. By imulation , they how that it i po ible to achieve a good information preading rate by employing le greedy and aggre ive u er behavior, i.e., u er do not take every me age and do not re-broadca t every me age. Again, u er cannot affect their reward , but are forced to u e the equivalent of our pure altrui tic trategy (ee Section IV), which we found to exhibit very poor performance.

VII. CONCLUSION

In this paper, we have defined a general model for electronic coupon y tem ba ed on rewarding u er participation with bonu point . We have derived an optimal trategy which indicate how many point a u er hould take for her elf when pa ing the coupon onward . We have al o compared our optimal trategy again t a number of other po ible trategie and have hown that our optimal trategy i extremely robu t and provide a trong incentive for u er to follow our optimal trategy.

In our future work, we plan on inve tigating the en itivity of the rational trategy in a more complex etting, i.e., larger and non-complete pa ing tree with pa ing of coupon determined by u er mobility and intere t .

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