Incentive for Opportunistic Network

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Abstract 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 opportunistic network. A an example, con ider an electronic coupon y tem, where provider end ou t coupon, which are pa ed from u er to u er. U er receive bonus point for each redemption to encourage participation. We define a general model for such bonus point -ba ed coupon cheme and derive an optimal strategy to allow a u er to determine how many bonus point he should a k for when pa ing the coupon. We al o how that our optimal strategy i very robust again t all other u er strategies, and that there i a strong incentive for u er to follow our optimal strategy.

I. INTRODUCTION

Many y tems, such a ad hoc network, peer-to-peer y tem, and opportunistic network require many u ers to participate to leverage the full benefits of the system. However, in many cases u ers may be required to provide their own resource (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 freeriding [1], [2] ha been ob erved in peer-to-peer network, and work on mobile ad hoc network has prop ed several incentive cheme [3], [4] to encourage participation.

In thi paper, we examine an electronic coupon y tem a an example of incentive for opportunistic network. In thi y tem, a provider end a ou t a coupon which i pa ed from user to user, until a user fi nally redeems the coupon (e.g., purchase the advertised product). To encourage u er participation, the provider gi n bonus point (e.g., fre- quent flyer miles) to all users who participated in passing the coupon to the redeemer. Although the prop ed bon ou point cheme i ve ry general, we con ider it from the point of view of opportunistic network, where information propage with little or no u er interaction. Therefore, incentive cheme shoul d be ve ry general since they cannot rely on u er interaction, but mu t in lead rely on general propeties of the application in que tion.

The contributions of this paper are two-fold. First, we define a general model for such bon ou point -ba ed cheme and derive an optimal strategy which allow each u er to determine how many bonus point he should a k for when pa ing the coupon. Second, we how that our optimal strategy i very robust again t all other u er strategies and that there i a strong incentive for u er to follow our optimal strategy.

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 strategy, both in linear pa ing chain and pa ing tree. Section IV inve stigate the effect of u er behavior on the optimal strategy. In Section V we di cu the implication of our re ult on electronic coupon cheme. Section VI di cu e related work. Fi nally, Section VII concl u e the paper.

II. ELECTRONIC COUPON EXAMPLE

The y tem we con ider i adPASS [5], which pr ed electronic coupon among intere ted u ers in mobile environment. A provider end out coupon which advertise e om product via an acce point in talled in the hop. U er carry mobile device which to re the coupon according to the u er prefer ence. Later, when a u er A who ha post one more coupon meet another u er B with imiper int er, A can pa the coupon on to B. A a reward for the, the provider ha allocated ome number of bonus point to the coupon and A i allowed to claim one of the e points for her elf. B can al o pa the coupon on, or go to the hop to redeem the coupon. When ome u er go to redeem the coupon, all u ers who were involved in the chain thi coupon took from the provider to the redeeming u er will get the bonus point they took when the coupon on. If nobody redeem the coupon, no bonus point are given out.

A. Bonus Point Model

If a u er redeem the coupon, e.g., purchase the advertised product, all the u ers who participated in pa ing the coupon from the provider to the actual buyer get the point they have taken. We call thi sequence 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 ers between the provider and A a up tream u er and all u ers after A in the chain are down tream u ers.

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 one point when he pa e the coupon onward.
3) If only one point remain, the coupon cannot be pa ed.
4) If ev eral down tream u ers 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 ha pa ed it before redeeming it.
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 u me that u er A decide to take \( b \) point, with \( 1 \leq b < B \). We al o a u me that the probability that any u er redeem the coupon i \( p \). For simplicity, we a u me that this probability i the ame for all u er and that the u er are independent from each other. We a u me that the redemption probability i independent of the number of point remaining in the coupon (i.e., u er redeem the coupon becu e the coupon i of intere t and not ju t imply to get bonus 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 stream chain from u er A a \( N \). See Section II 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 stream chain i:

\[
E[\text{point if } b \text{ taken}] = \sum_{i=1}^{N} bi \left( \frac{N}{i} \right) p^i (1-p)^{N-i} \quad (1)
\]

Equation (1) allow u to calculate the expected number of bonus point gained by a ing u er in a straight-forward manner, given the length of the down stream chain and the amount of point taken. Note that the redemption probability \( p \) ha no eect on \( b \) and \( N \) which are determined by the strategy of the u er. Hence, our aumption that \( p \) i the ame for all u er ha no eect on the u er behavior.

III. Strategies

We now derive an optimal strategy and di cu how it can be applied in practice. We a u me that the goal of a u er i to amize the number of bonus point he earn. A can be seen from equation (1), the redemption probability doe not aect the strategy 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 stream chain.

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

A. Optimal Strategy for Linear Pa ing Chain

Conider 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 solution i to take 1 point and pa 1 point on. Since users try to amize their own benefit, we assume that the u er will try to pa e 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 take 1 point, then two point remain, and the above strategy 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 strategie 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 ibilities: take 3, 2, or 1 point. We can calculate that the expected number of gained point are 3p, 4p and 3p, re ectively. The strategy Take 2 dominate, and the optimal strategie for 4 remaining point i to take 2 of them.

In a simiar way, we can conue with larger number of point remaining, and we can compute the optimal strategie for any given value of \( B \). Figure 1 and 2 how the optimal strategie for 1 20 and 1 100 point remaining, re ectively.

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

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

\[1\]The ca e where take only 1 point divide into two po ibilities, depending on whether the next u er take 1 or 2 point. The e two po ibilities 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, this only aect the numerical value, but not the optimal strategie.
clearly visible on the right side of Figure 2, where the remaining number of point $i$ large. Figure 1 how a close-up of the left ide of Figure 2 and we can see that all of there, the optimal number of point to take $i$ about 70% of the remaining point.

The optimal strategie are calculated through exhaustive search, which make real-time calculation on mall portable devices difficult. However, since the optimal number of points to take $i$, independent of the user's other action, the point can be pre-calculated and stored in a table. Thus, the actual calculation on the user device is a simple table lookup.

Figure 3 shows the length of the optimal chain as a function of the remaining point. The chain are typically quite short with only a few user participating in the distribution.

Figure 3 al o allow us to determine the optimal strategie 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 choose 16 point, since the minimize the amount of point the provider need to give out in this interval. The re ult in Figure 3 clearly show that the provider would choose the amount of initial point a mall ed of poibility.

B. Equal Optimal Strategie

A the example with 3 remaining point in Section III-A how the optimal strategie is not always unique. Such equal optimal strategie are equal to the user who i faced with the choice, but, for the up stream user, the choice could make a difference. We have evaluated the frequency of such equal, optimal strategie and di covered that they do not occur very frequently. For the range of 1 100 point remaining, we observed that such equal optimal strategie happen in only a few case (maximum 3, depending on the decision at the equal point). Furthermore, the effect on the expected number of gained point i relatively small, making dilemma of equal optimal strategie mo tly negligible.

C. Optimal Strategie for a Pa ing Tree

The above optimal strategie applies when each user can pay the coupon to only one other user. In reality, a single user could pay the coupon to several other users, who pass it on to everal other, etc. The reult in a pa ing tree. In this section, we will investigate how the optimal strategie need to be modified in a passing tree.

When a user A pa e an coupon onward, the remaining amount of point $B'$, determine the maximum depth of the pa ing tree, since each user must take at least one point. However, user A cannot know how many branches there are in the tree. If the depth of the tree $i$ at most $B'$ and each level $k$ branches, the complete pa ing tree ha at most $N = \sum_{i=0}^{B'-1} k^i$ users, which are all possible redeemers. However, since $k$ is unknown, the value of $N$ needed for equation (1) cannot be determined by user A. Hence, it is not possible to define an optimal strategie at run-time. However, after the coupon ha been pa ed a far a posible, we can compute the strategie that would have been optimal.

Given that the user know an optimal strategie for a linear chain but not for a tree, the natural queion to a k i: Should the user deviate from the known optimal strategie? We will now derive condition for determining when to stay with the optimal strategie and when to deviate from it. Note that the condition can only be applied after the coupon ha been redeemed, but we can use them to determine whether such deviation would make sense in general.

A user that user A receive an coupon with $B$ point and that the optimal strategie from Section III-A take $b^*$ point and reult in a chain of $N^*$ users. Hence, the optimal expected amount of gained point i $b^*N^*p$. Since $p$ does not affect the optimal strategie, we will di card it in order to simplify the equation in the following.

The situation is shown in Figure 4. A user that the current tree contains all the nodes in the figure. If user A were to take 1 point more, the grey user would no longer be part of the tree, since there would not be enough point left in the coupon for them to receive it. Likewise, if the current tree were to the black user A and took 1 point left, the tree might grow to include the grey user. However, in this case, there are no guarantees that the tree would actually grow, since any of the black users might decide to take 1 point more than a umaed in the tree in Figure 4.

Let’s consider the first case of user A making more points and making the tree hollower. A user that user A make $b = b^* + b'$ point and that i mean that $n'$ users are removed from the tree. Then, it is better to stay with the optimal linear strategie if

$$b^*N^* \geq (b^* + b')(N^* - n')$$

Hence, if the number of lost users is greater than $\frac{N^*n'}{b^* + b'}$, it is better not to deviate from the optimal strategie.

Let’s now consider the second case of user A taking less points and making the tree deeper. A user that user A takes $b = b^* - b'$ points and that the

$$n' \leq \frac{b^*N^*}{b^* + b'}$$

At $b = b'$, in principle unknown, since user A cannot be aware that all the

$$3\text{Al } b = b' \text{ in principle unknown, since user A cannot be aware that all the}$$

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

\[ b = b^* - b' \]

point and that this means that \( n' \) u er are added to the tree. Then, it is better to stay with the optimal linear strategy if

\[ b^* N^* \geq (b^* - b') (N^* + n') \]

\[ n' \leq \frac{N^* b'}{b^* - b'} \]  

(3)

In other words, unle a large amount of point , we now concentrate on evaluating when taking le point (and gaining u er) would be beneficial.

A u a that the u er decide to take one point le than the optimal strategy indicate. Then, the tree need to get at least \( n' = \frac{N^* b'}{b^* - b'} \) new u er in order to re ult in the same number of point gained by the u er. In Figure 5 we plot the value of this, for everal different branching factor \( k \). We have a u a 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 see 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 high 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 strategy, 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 strategy.

Furthermore, if there are only a few point left in the coupon, the required number of new u er is 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. Because of the low branching factor, we could only a u a to get about 1 or 2 new u er, hence the deviation cannot be justified. Same applies to the other branching factors for a small 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 inv e titating the effect of u er behavior and we will return to the issue of deviating from the optimal strategy in Section V.

IV. EFFECT OF USER BEHAVIOR

The optimal strategy allow a u er to determine how many point to take in any situation. Since the optimal strategy i independent of the redemption probability \( p \), the above calculation can be used to determine the amount of point to take to maximize the number of gained point.

However, the optimal strategy a u a that all u er follow the optimal strategy. 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 inc re de a u e the chain will be longer. Conver e, if the down tream u er are greedy, the chain will be shorter and the up tream u er will not get a many point a they expected. We now inv e titage the en ivity of the optimal strategy to other possible strategies followed by other u er.

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

- Rational (R): Follow the optimal strategy (take \( \text{opt} \) point).
- Greedy (G): Take more point than the optimal strategy ay. A pure greedy (P-G) u er alway leave only 1 point.
- Altruistic (A): Take le point than the optimal strategy ay. A pure altruistic (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 altruistic strategy, we a u a that the u er take a random amount of point, uniformly di tributed in the appropriate interval \( (\text{opt}, max - 1) \) for greedy and \( [1, \text{opt}] \) for altruistic.

A. Population with Two Type of U er

We first compare each of the 6 user types (rational, (pure) greedy, (pure) altruistic, and random).pairwise with all the other type. We a u a a population which con i t entirely of the given type and we inv e titate what happen when a u er from another type come into play.

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

\( \text{For non-integer value of } k \text{ we a u aed a tree with } \sum_{t=0}^{k^*} k^* u er. \)
man point to take. We aumed that the coupon get paid a long as there are point remaining.

The be t strategy again the given population (column) generated by the bolded entr. The actual numerical value is specific to the parameters of the simulation; however, the ranking applies to all combination of parameter.

A we can ee, the rational u er get the hige t amount of gained bonus point again all the four baic type. Hence, a u er wanting to maximize her gained point should u e the rational strategy, 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 strategy alwaay ha uperior performance when compared to the other baic strategie.

In general, we conclude that of the 4 main strategie rational i the be t, followed by greedy, random, and altiru tic. The pure greedy and pure altiru tic strategie usually exhibit very poor performance.

The exception to the dominance of the rational strategie are again a population of pure greedy or pure altiru tic. In a pure greedy population, a single greedy u er will get more point than a single 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 strategie 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 should take a much a he can, while guaranteeing the chain length of 2, i.e., take all but 2 point. The greedy strategie which take more than the rational strategie i therefore better.

The good performance of the altiru tic strategie again the pure altiru tic strategie i explained a follow. In a population of pure altiru tic u er, all chain have their maximum length, unless all u er take only one point. For example, with 20 point remaining, a rational u er will take 14 and the chain ha length 6, which give the expected bonus point of 6 $\cdot 14p = 84p$. If the u er take, ay 10 point, then the chain ha length 10. In the case, the expected amount of gained bonus point i 10, 10p = 100p. The good performance of the altiru tic strategie again the pure altiru tic strategie prevail over a larger range of altiru tic u er.

### B. Population with Multiple Type of U er

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

We performed a simlar 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 o performed the experiment for other population mixe and the re ult were simlar to the one here.

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

### V. Discussion

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

#### A. Deviating from Optimal Strategie

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

Since the rational strategie dominate, we can a ume that mo t (or all) of the u er would follow that strategie. In a pa ing tree, one u er might a ume a low branching factor, which favor taying with the optimal strategie. If a u er decide to deviate by taking le point, ub equent u er might decide to take the e point, ince that i the optimal strategie. 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 almo t guaranteed. We ee that from the left tide of Figure 5, which show that when only a small 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 strong incentive to follow the optimal strategie. Point not taken by up trea 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 strategie i likely not to pay off, hence u er are better off by u ing the optimal strategie.

#### B. Practical Conideration

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 tive. Becau e the coupon only travel a small number of hop, they are til
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 s 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 imply 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 ble, ince that increa e their chance of getting bon 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 summary, 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 scheme 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, Sarou 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 u e 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 mecha ni m for mobile ad hoc network node a an incentive to forward network package. Mannak et al. [8] conducted a mull u er tudy on u er’ motivation to hare re ouce 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 prep digital adverti ement with embedded coupon among mobile u er in a peer-to-peer manner and reward participati on u er i al o de cri bed by Rat imor et al. [9]. In contra t to our propo ed bon point model, a u er cannot affect hi chance of being rewarded, for example, by cho ing a different trategy, ince the trategy are fixed for all users.

Garyfalo and Almerto de crib e Coupon [4], [10], an incentive scheme that give u er credit for forwarding information to other u er in an ad hoc network. By imulation , they how that it is po ble to achieve a good information preading rate by employing le greedy and aggressi ve 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 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 bon 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 ble trategy 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 invetigating the en ivity 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 .

REFERENCES