Incentives for P2P File Sharing in Mobile Ad Hoc Networks

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***Abstract*—P2P overlay networks are a natural fit for MANETs because both are decentralized and have dynamic topologies. Most nodes in P2P file sharing networks are *freeloaders*, nodes that do not contribute to the network. In order to have a useful P2P network, it is important that nodes not only share files but also forward data. In this paper we present Incite, an incentive scheme for P2P file sharing over MANETs in which nodes cooperate with one another based on their reputation and energy levels. Simulation results show that Incite allows more file downloads than typical P2P networks, is fairer, and uses less energy per downloaded byte.**

I. Introduction

In addition to their popularity, peer–to–peer (P2P) networks have many applications, such as file sharing, Voice–over–IP (VoIP), gaming, and instant messaging. It seems to be a natural fit to operate a P2P overlay on a mobile ad hoc network (MANET) since both types of networks are fully decentralized, both must dynamically organize themselves, both must deal with frequent topology changes, both attempt to be resilient to failure, and both perform the routing function.

Despite the similarities between P2P networks and MANETs, there are some differences. P2P networks tend to be very large–scale with millions of simultaneous users, and are designed as overlays for deployment on the "edge" of the Internet, where the nodes are generally immobile. On the other hand, MANETs tend to have far fewer nodes, the devices are severely resource–constrained in comparison, links between nodes usually have higher delay, energy consumption is of great concern, and the mobile users are also geographically nearby one another.

Figure 1 illustrates a peer–to–peer overlay on a MANET. The dark circles represent nodes participating in the overlay network, while light circles are not part of the overlay. The dashed lines show how the overlay network is logically connected, with potentially multiple hops of the underlying MANET links providing the connections.

Both MANETs and P2P networks require nodes to help one another in order to make the network useful. P2P file sharing networks require nodes to share files, and MANETs require nodes to forward data. Unfortunately, helping others comes at a cost. By sharing files and forwarding data, mobile nodes are using their energy, bandwidth, CPU, and other resources. When resources are used by others, there is less available for the node itself. This gives rise to *selfish nodes* and *freeloaders*. Selfish nodes do not forward data, and freeloaders are users that download files for themselves, but do not share anything in return. To entice users to share files and forward data, many

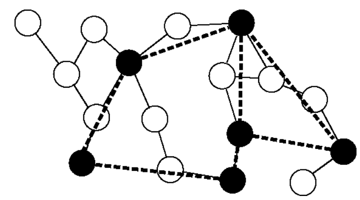

Fig. 1. An example of a peer–to–peer overlay running on a MANET

incentive schemes have been proposed. The idea behind such schemes is to encourage users to contribute files and forward data for others by rewarding users who do so and punishing those who do not.

A good incentive mechanism for P2P overlays on MANETs must encourage both the sharing of files and forwarding of data by intermediate nodes. Also, nodes must be allowed to rehabilitate themselves if they have behaved poorly in the past. This prevents nodes from being permanently blacklisted, a situation which degrades the quality of the P2P network since the more contributing users there are, the better for everyone. In addition, due to the resource–limited and battery–powered devices used in MANETs, the incentive system should also have low computational requirements, low message overhead, consider energy consumption, and aim for simplicity.

We propose Incite, an incentive scheme which meets the criteria of a "good" incentive mechanism as just described. Users cooperate with one another based on their remaining energy, and also on the reputation of the requesting node. Each node has a reputation index which is based on how many times it has cooperated with others both in terms of sharing files and also in terms of forwarding data. When a node is requested to upload a file or forward data, it will do so only if it has sufficient energy remaining, and also if the reputation of the requesting node is within a certain threshold of its own. In this case, a simple calculation will determine the probability of cooperation. If the node has low energy or the requesting node has a low reputation, then the probability of cooperation is much lower.

In this manner, nodes have an incentive to cooperate in order to increase their reputation level. A higher reputation increases the chances of a successful file download. If a node has a low reputation because of past behavior, it can simply cooperate more in the future and its reputation will increase. In a typical P2P network, a majority of nodes are freeloaders, and a small percentage are altruistic, meaning that they share data unconditionally [1]. Simulation results show that peers are able to download more files when using Incite than they would by relying on altruistic users, as in a typical P2P network. Furthermore, peers are able to download more for each Joule of energy expended than in a typical P2P network. The next section examines some existing incentive schemes. Section 3 describes Incite in detail. Section 4 presents our simulation results, and Section 5 gives our conclusions.

II. Related Work

There are few incentive schemes for peer–to–peer overlays in MANETs. CHUM, proposed by Zhu and Mutka [2] is aimed at allowing MANET users to share access to Internet services, not at file sharing networks. Users maintain trust values for one another which combine their own observations with recommendations from others. On top of this is a credit scheme in which nodes can borrow from one another and obtain larger credit limits if they are "good" (based on their trust values). A downside to CHUM is that nodes must maintain trust histories and credit limits for all other peers, which can create lots of data traffic and increase energy consumption.

In a previous work [3], we have proposed a credit–based incentive scheme for P2P file sharing in MANETs. After receiving responses to their query, users choose the best file server by evaluating a Cobb–Douglas utility function which indicates their preference for a lower cost download, or a shorter delay. The credits going to the file server as well as intermediate nodes en route. The price of the file is based on its popularity as well as its availability within the network. Intermediate node pricing is based on demand for forwarding, so that the pricing scheme is dynamic. The file server and intermediate nodes also estimate the delay for downloading.

In mobile ad hoc networks there are two basic classes of incentive mechanisms: reputation-based and credit-based. In reputation-based systems, nodes earn a reputation based on past behavior. When they forward packets their reputation increases and when they don't forward packets, their reputation decreases. Nodes with a low reputation are avoided in path selection, and in some schemes are punished. In order to do this, nodes must monitor their neighbors and alert others when they feel a node is not cooperating [4]. Misbehaving nodes are avoided when selecting paths. Other schemes attempt to punish misbehaving nodes by not forwarding their traffic [5], [6]. These schemes require observations to periodically be sent network-wide, which creates excessive network traffic and increases energy expenditure. In credit-based schemes nodes earn some form of credit when they forward packets and spend credit to send their own data [7]. Some, such as Sprite [8] and PIFA [9], require nodes to maintain receipts of packets sent and received and periodically send these to a centralized server which determines the amount of credit owed and deserved. Centralized servers are an impractical requirement in MANETs.

Most peer–to–peer network incentive systems are also based on either reputation– or credit–based schemes, however there are some which are exchange–based. Buchegger and Le Boudec [10] propose a system in which peers maintain both a reputation rating and a trust rating about all other peers they are interested in and periodically exchange this information, using a modified Bayesian approach to merge ratings. Liao et al. [11] propose that each byte uploaded gives a certain number of credits, each byte downloaded uses a certain number of credits, and each second online gives a certain number of credits (awarded at $\frac{1}{10}$ the value of downloading). This encourages users to share files, and also to stay online. Anagnostakis and Greenwald [12] focus on an exchange or barter economy with n-way trades. Peers examine their incoming request queue and see if a node on there has something they want. This is a 2-way exchange. Extending this to a directed graph and looking for a cycle of length n, results in an n-way exchange. Moreton and Twigg [13] combine the ideas of reputation and credit systems into a "stamp trading" system in which a node issues as many of its own branded stamps as it pleases. Other nodes can trade these stamps, and do so based on its exchange rate. If a node does not provide good service, the value of its stamps goes down and when it later wants a service, its stamps may be devalued to the point that nobody will exchange them. While this is a novel idea, a large drawback to this system is maintaining the exchange–rates, which would need to be centralized or require a lot of overhead to maintain in a distributed fashion.

Most of the incentive systems described in this section focus on forwarding data at the MANET–level, or sharing files at the P2P–level. In a P2P overlay running on a MANET it is important for both of these to take place. None of the systems discussed meet all of the criteria of a "good" incentive mechanism. The closest is our previous work, which falls short on the goal of simplicity. The next section presents Incite, an incentive scheme for P2P file sharing in MANETs that makes use of reputation and energy information, and meets the stated criteria.

III. Incite

Incite encourages both the sharing of files and forwarding of data by including this information when determining a node's reputation. Nodes are able to rehabilitate themselves if they have behaved poorly in the past by simply cooperating more in the future. The calculation made by nodes to determine reputation information relies only on local information, thereby reducing the number of messages that must be transmitted, which in turn reduces energy consumption. When deciding whether or not to cooperate with a download request, nodes perform a simple calculation, meeting the low computational requirement, and also consider their energy level. Thus Incite meets the criteria of a "good" incentive mechanism. The remainder of this section describes Incite in detail.

Suppose that a node wants to download a file. It sends a query through the network, and assuming there are multiple successful responses, the node selects a server and attempts to download the file. In this paper, we use the term *client* to refer to the node that wishes to download the file, and the term *server* to refer to the node that is uploading the file.

Once the client has selected a server, it sends a *DLRequest* message to it. Included in the message is the client's reputation index. For simplicity, it is assumed in this paper that nodes will honestly present their reputation information. It is possible to implement the reputation management system in a distributed fashion, but that is beyond the scope of this paper.

If the server was altruistic, it would always choose to cooperate and would agree to upload the file. If the server was a freeloader, it would always refuse to cooperate. If the node is using Incite, the outcome is dependent on the reputation of the client and the remaining energy of the server. This process is described in detail below. If the server agrees to cooperate, it will send back a *Coop* message, otherwise it will send a *No-Coop* message.

Once the server has agreed to cooperate, it must then find a valid path back to the client. To do this, it asks the underlying routing protocol for a neighboring node, call it n_1, that leads to the client. The server then sends a *FwdRequest* message to n_1. Again, whether or not the neighbor cooperates depends on its energy level and the server's reputation index. It if does not cooperate, the server must find another neighbor that does. If n_1 does cooperate, then it must now look for a neighbor, n_2, that is closer to the client and that is willing to cooperate. *Coop* and *No-Coop* messages are also used in this process. In this manner, a complete path back to the client may be found.

A. Cooperation

When a node is choosing whether or not to cooperate, it compares reputation indexes. Let us call the requesting node a and the receiving node b. If the reputation index of a is within a threshold window t of the reputation index of b, i.e. $\text{Rep}_a + t \geq \text{Rep}_b$, then the probability that b will cooperate is given by

$$p_{coop} = E_b \times R_a \qquad 0 \leq E_b \leq 1, \quad 0 \leq R_a \leq 1 \quad (1)$$

where E_b is the remaining energy of b and R_a is the reputation index of node a.

Equation 1 has the desirable property that if b has not consumed much energy then there is a greater likelihood of cooperation, whereas if the remaining energy is low, the probability of cooperation is lower. This allows nodes with little remaining energy to avoid cooperation in an attempt to improve longevity. Also, if a has a high reputation index, the probability of cooperation is higher than the case of a low reputation. This simple equation provides an incentive for nodes to cooperate as much as possible, in order to increase their reputation index.

If the reputation indexes of a and b are not within the threshold window t, then there is still a chance that b will cooperate. The probability of cooperation in this case is given by the exponentially decaying function

$$p_{coop} = Me^{\frac{-1}{M \times E_b}} \qquad 0 \leq E_b \leq 1, \quad 0 \leq M \leq 1 \quad (2)$$

where M is the maximum probability desired for cooperation in this case, and as before E_b is the remaining energy of node b. This function is only likely to induce cooperation when b has plenty of energy remaining. The reputation of a is not used here because this equation is only used when a's reputation index is less than t below that of b's reputation index. Equation 2, while simple, is useful because in the situation where b would usually not cooperate with a due to the difference in reputation levels, for the overall benefit of the P2P file sharing network, it might still make sense for b to cooperate if it has plenty of energy. Equations 1 and 2 have low computational requirements, and help meet the goal of simplicity.

When initiating a download request, the client sends *DLRequest* to a server, along with its reputation index. The server responds with *Coop* or *No-Coop*, depending on the outcome of the process just described. If the server cooperates, it finds a route back to the client by sending a *FwdRequest* message to a neighbor. This neighbor will also respond with either *Coop* or *No-Coop*, depending on the outcome of the process described above. If it cooperates, this neighbor must continue the process until a route to the client is found. When the client is finally contacted, this indicates that a successful route has been found. The client then sends a *EnqueueDL* message to the server, letting it know that a full path has been found and that the file should be placed on its upload queue. If a path from server to client cannot be found, the download fails. The last node which agreed to cooperate informs the client of the failed route discovery with a *PathFailed* message. Pseudo-code describing the actions of each type of node is given in Figure 2.

B. Reputation

The reputation index of a node is calculated as the total number of times a node has agreed to cooperate divided by the total number of times it has received either a *DLRequest* or *FwdRequest* message. When a node cooperates with a *DLRequest*, its cooperation count is increased by ten. If it does not cooperate, the non-cooperation count (the denominator of the index) is increased by ten. This serves to more greatly reward nodes who share files on the network.

To further provide an incentive for nodes to strive for high reputation indexes, when a file is placed on a server's upload queue, it is inserted based on the client's reputation index. The higher the reputation index of the client, the closer the file is placed to the beginning of the queue.

IV. Simulation Results

This section evaluates the performance of Incite for different threshold values and also compares it to networks in which all users are either altruistic or freeloaders. Altruistic users always agree to cooperate, and freeloaders never agree to cooperate.

A. Simulation Parameters

The simulated MANETs have an area of 1000m $\times$ 1000m, and contain 50 to 100 nodes. Files are randomly placed throughout the network, the average file size is 5 MB, and a transmission rate of 11 Mbps is used. The random waypoint model is used for mobility and a uniform distribution with minimum speed of 1 m/s and maximum speed of 3 m/s is used for nodal velocity. The pause time is uniformly distributed with a mean of 60 seconds, the simulation time is set to 2 hours, and an unstructured Gnutella–like overlay is used [14].

Experiments using Incite vary the threshold value t between 0.01 and 0.09. A maximum probability value of M = 0.2 was used for Equation 2. Each experiment is run several times with the results being averaged. In all experiments, an interval of 5 seconds is used. At each interval, half of the nodes randomly initiate a download attempt from another random node.

Server:

```
receive_DLRequest:
  if Rep_client + t ≥ Rep_server,
       calculate p_coop from Eqn. 1
  else,
    calculate p_coop from Eqn. 2

  if will cooperate {
    send Coop to client
    find neighbor node and send it FwdRequest
  }
  else,
    send No-Coop to client

receive_Coop:
  do nothing

receive_No-Coop:
  find another neighbor node and send it FwdRequest
  if no other neighbor nodes,
    send PathFailed to client

receive_EnqueueDL:
  place file on queue
```

Intermediate Node:

```
receive_FwdRequest:
  if Rep_a + t ≥ Rep_b,
       calculate p_coop from Eqn. 1
  else,
    calculate p_coop from Eqn. 2

  if will cooperate {
    send Coop to a
    find neighbor node and send it FwdRequest
  }
  else,
    send No-Coop to a

receive_Coop:
  do nothing

receive_No-Coop:
  find another neighbor node and send it FwdRequest
  if no other neighbor nodes,
    send PathFailed to client
```

Client:

```
generate_DLRequest:
  send DLRequest to preferred server

receive_FwdRequest:
  send Coop to a
  send EnqueueDL to server

received_PathFailed:
  try another server or give up
```

Fig. 2: Pseudo-code for server, intermediate nodes, and client

To compare Incite to current P2P file sharing networks, experiments are also run in which exist different ratios of altruistic and freeloading users. The ratios used are 40% altruistic-60% freeloader, 25% altruistic-75% freeloader, and 10% altruistic-90% freeloader. The last two are the most realistically seen in typical P2P file sharing networks. A study [1] found that 70% of Gnutella users shared no files and 50% of responses came from only 1% of the users.

The energy consumption model used in the simulations is the linear model proposed by Feeney [15]. Each MAC layer operation takes a certain amount of power as defined by $cost = m \times size + b$ where m is the incremental cost of the operation, b is the fixed cost, and $size$ is the amount of data sent or received. The constants are obtained by physical measurements for a Lucent IEEE 802.11 WaveLAN PC Card from [15] and are summarized in Table I.

TABLE I
ENERGY CONSUMPTION CONSTANTS USED IN SIMULATION

m_{send}	1.89	$mW \cdot sec/byte$
b_{send}	246	$mW \cdot sec$
m_{recv}	0.494	$mW \cdot sec/byte$
b_{recv}	56.1	$mW \cdot sec$
$b_{sendctl}$	120	$mW \cdot sec$
$b_{recvctl}$	29.0	$mW \cdot sec$

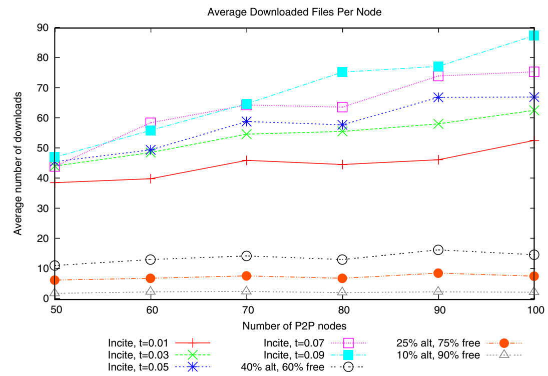

Fig. 3: Average number of downloads per node

B. Simulation Analysis

Encouraging users to contribute to the network, both in the form of sharing files and also forwarding traffic, is the primary goal of the incentive scheme. In particular, looking at how many files have been downloaded by users is a good measure of the level of cooperation.

Figure 3 provides the average number of files downloaded per node. Unsurprisingly, when there are more freeloaders, the number of downloads declines significantly. Incite requires users to contribute in order to download files themselves, therefore it permits many more downloads, and higher threshold values allow more downloads.

Figure 4 shows the download–upload ratio, which gives a measure of fairness. This ratio is calculated by dividing a node's total number of bytes downloaded by the total number of bytes uploaded, from both uploading files and also forwarding data. This ratio indicates how much a given user has taken from the network and also how much it has contributed. If the ratio is high, it indicates the user has been able to take more than he has given. In terms of the individual user, a higher number is better, but for the network overall, a lower number is better because it means that nodes must contribute in order to download. The figure shows that the more freeloading users there are, the higher the ratio. As shown, Incite is much fairer because nodes are required to contribute through the incentive system.

Download time is an important metric when sharing files because users want their downloads to arrive as soon as possible. With Incite, user downloads are ordered based on reputation so that users which have cooperated the most will be placed earlier in the upload queue. Figure 5 shows the average time to complete downloads. Higher threshold window values provide greater delay because they also allow more downloads in total. As more downloads are accepted by the network, upload queue sizes grow. As the number of freeloading users increases, fewer downloads are successfully queued and so the

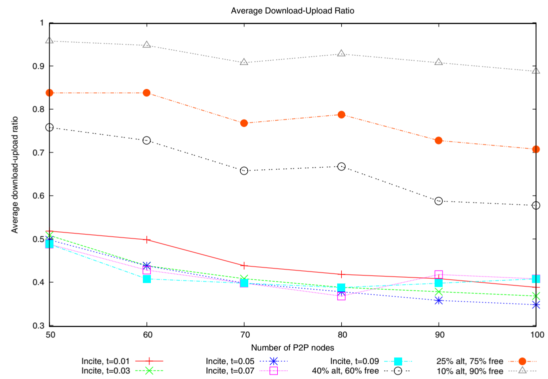

Fig. 4: Average download-upload ratio

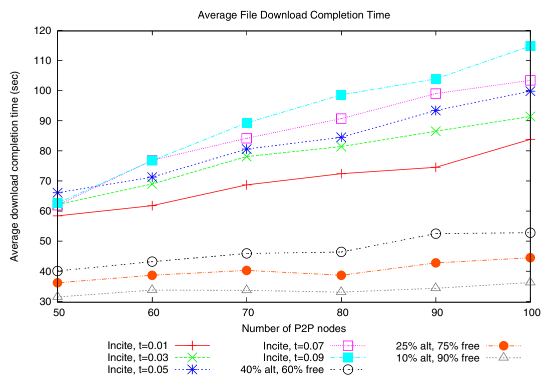

Fig. 5: Average download time

average download time decreases. In this case, even though each download is completed more quickly, the chances of a successful download are much lower. Nodes with a higher reputation are placed earlier in the upload queues and thus have lower delay than those with lower reputation, however due to space constraints this is not shown in more detail.

Considering energy consumption is very important with mobile devices that are energy constrained. When a node has used all of its energy it can no longer participate in the network, so it is important to try and reduce energy consumption as much as possible. Figure 6 shows the average number of bytes downloaded per Joule of energy used. Experiments with Incite have a greater number of bytes downloaded for a given energy use, indicating that Incite is more efficient. This is because fewer download attempts fail due to the incentive system, which encourages users to share files and forward data in order to download files themselves.

V. Conclusions

This paper presented Incite, an incentive scheme for P2P file sharing over MANETs. To download a file, the server agrees to cooperate based on the client's reputation level and on the server's remaining energy. Intermediate nodes attempt find a path from server to client in which all nodes agree to cooperate. Each node maintains a reputation based on how many times it has cooperated in the past, and agreeing to upload a file counts significantly toward the reputation. Simulation results demonstrate that Incite promotes cooperation amongst peers and allows greater numbers of file downloads than relying on

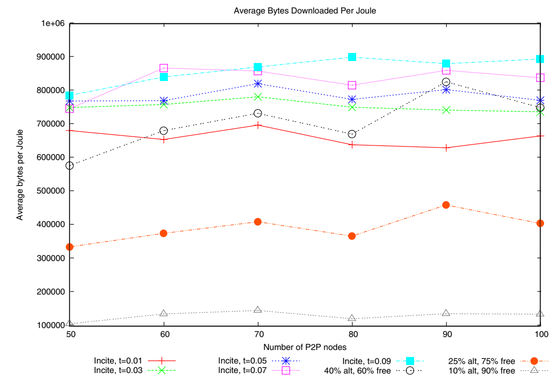

Fig. 6: Average Bytes Downloaded Per Joule

altruistic users. In comparison to typical networks, where most users are freeloaders, Incite allows more downloads, is fairer, and uses less energy per downloaded byte.

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