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Abstract

This paper proposes a rating based scheme for encouraging user participation in ad-hoc mobile phone mesh networks. These networks are particularly attractive for remote/rural areas in developing countries as they do not depend on costly infrastructure and telecom operators. We evaluate our scheme using extensive simulations and find that our proposed scheme is successful in enhancing the network throughput.

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1. Introduction

Peer-to-peer mesh networks for mobile phones have recently been proposed as an alternative to the traditional base-station cellular model [1]. In the proposed system there are no base stations or telecom operators or centralized control of any sort. Specially designed mobile phones can start communicating directly with each other, when they are within range of one another[1]. Since the range is quite limited, intermediary phones can also relay communication between two devices that are out of range from each other. Thus, mobile units form ad-hoc mesh networks and the more the number of units the larger the network can scale[2].

Such ad-hoc peer-to-peer phone networks have tremendous value for applications where the base-station model is not feasible for a variety of reasons. In rural areas, where user density might be low, scale economies might not justify expensive base-station towers. Another application where such networks can be very valuable is in disaster-hit regions. When the traditional communication networks are down, the mesh mobile phones can still communicate with each other in a totally decentralized manner. In this study we will concentrate on the first application – providing cheap and quick connectivity to rural regions.

While the technological challenges (routing, admission control etc) of allowing mobile handsets to form such local networks seem to have been solved to an extent [1], this study focuses on yet another aspect – incentives for participation -- which is very vital for such a network to work. Since most calls and data have to be routed through intermediaries, it is essential that users collaborate with each other. Such issues do not arise in a conventional cellular network, where all communication is channeled through a base-station. In the proposed network however, individual users have to be willing to route traffic for the benefit of other users. Given that routing such traffic for others will mean consumption of one's own limited resources (like power), there might be a rational tendency to behave selfishly. Especially in rural settings in developing regions, where mobile phone users have to deal with erratic power supply and in some cases travel a kilometer or more to charge their

[1] Within a kilometer of each other if they use TerraNet technology [1] for example.
[2] Such networks cannot scale indefinitely. In TerraNet's proposal for example, there can be 7 intermediaries who relay the voice data to the destination, before the latency gets too high for reasonable quality.

phones, draining away their battery to route other people's traffic might not sound very appealing. In such a situation, it might be tempting for the user to conserve his/her device's power by either switching it off when not in use, or if the user is more skilled -- tamper with it so that the device does not forward other's traffic. If enough users are selfish instead of altruistic, the entire network can come crashing down.

This paper studies the incentives for user participation in such a network. We propose a rating based scheme that encourages users to participate fully in the network. Using simulations, we evaluate the effectiveness of the proposed scheme. To the best of our knowledge, this is the first paper to study incentives for participation in ad-hoc peer-to-peer mobile-phone networks. We find that our rating based scheme is effective in encouraging users to keep their phone switched ON more than they normally would have. This results in a reasonably good network throughput of around 70%, where-as in the absence of such an incentive scheme the network performance suffers dramatically.

The rest of the paper is structured as follows: In section 2 we compare P2P mobile-phone networks to two related networks, MANETS and multi-hop cellular networks. Section 3 contains a discussion of related work. We describe our system model and simulations in sections 4 and 5 respectively and results are presented in section 6. We conclude in section 7.

2. P2P Mobile-Phone Networks

While traditional cellular networks operate on a centralized model where all communication between any two hand-sets travels through a base-station, the recently proposed P2P phone networks are totally decentralized. With no central authority or entity, the phones form ad-hoc P2P mesh networks. Two phones within range of each other can directly talk to each other. If they are out of range from each other, then one or more phones in-between them can act as relays and transmit the data between them. Such a network can be connected to the outside world via a computer with an internet connection

There are of-course advantages and disadvantages to this model. The obvious advantage for rural regions is that locals need not wait for service providers to set-up costly infrastructure and related services, before they have a functioning phone network. If there are enough mobile phones in the region, a viable network will spring up quite automatically. Assuming a handset range of around 1 KM and a maximum hop-count of 7 [1], a network area of approximately 8 sq kilometers can be covered, provided there are enough users in the area to act as relays. However with a totally decentralized model, well designed routing protocols and solutions for security and privacy issues are crucial for its success. Further, as with almost any peer-to-peer network, incentives for the users to participate in the network must be carefully considered.

Although phone mesh networks are a fairly new phenomenon they are related to two other kinds of networks – MANETS and multi-hop cellular networks.

2.1 MANETS vs. Phone Mesh networks

Traditional mesh networks (also known as MANETS - Mobile Ad-hoc NETworkS) are a popular research topic and have been studied significantly [2]. Initially conceived for military purposes, these networks comprise of mobile devices (computers, PDAs and sensors) which form ad-hoc data networks without centralized control or infrastructure. Most deployed MANETS use the ad-hoc mode of IEEE 802.11 standard (Wi-Fi). While MANETS are used primarily for data packets, phone mesh networks can be used for voice as well as data. A MANET study would typically assume an area of around 1 sq. KM whereas a P2P phone networks can span much larger areas , approximately upto 8 sq. KM. Applications for MANETS are typically limited to military settings or disaster relief with day-to-day applications still a rarity. P2P mobile-phone networks on the other hand have a very promising application for the common man -- they could potentially be the driving force for bridging the digital divide in rural areas. Telecom operators are usually hesitant to venture out to rural areas, because the demand is spread out and the costly infrastructure needed makes their venture less profitable. In India for example, rural mobile penetration is only at around 15% of the population whereas urban penetration is above 70 % [10].

2.2 Multi-hop Cellular Networks vs. Phone Mesh networks

Multi-hop cellular networks (MCNs) were originally conceived as a hybrid between the traditional single-hop cellular networks and ad-hoc mobile multi-hop networks (MANETs).

In MCNs mobile nodes can communicate directly with each other if they are within range, or they can communicate with a base-station. An intermediary mobile node can act as a relay, so that a node out of range from a base-station (BS) can still access the network. The BS is in-charge of routing and keeping track of the various mobile nodes within its range. While MCNs still rely on base-stations for the backbone network and centralized routing decisions, phone mesh networks are totally decentralized with no central intelligence or coordination.

Figure 1 provides examples of multi-hop cellular networks and phone mesh networks.

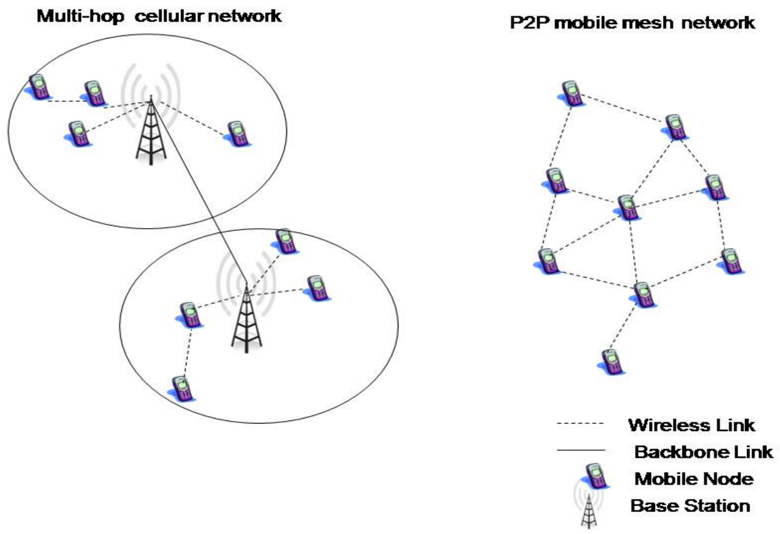

Figure 1: Multi-hop cellular network and P2P mobile mesh network

3. Related Work

Considerable work has been done in incentives for cooperation in the related fields of mobile ad-hoc networks (MANETs) and multi-hop cellular networks.

Srinivasan et.al [3] uses a game-theoretical approach to study cooperation among nodes in an ad-hoc network. They consider different classes of nodes with different power constraints, and propose a mathematical framework for studying user behavior in this scenario. Their proposed strategies however require each node in the system to know the number of users in each class and the energy constraint in each class. Given that a MANET system is totally decentralized, such information may be difficult to collect – especially if nodes have the incentive to relay incorrect information about themselves.

The Sprite project [4] proposes a credit based system for MANETs where a Credit Clearance Service (CCS) determines the charge and credit to each node in the system. Since such a system revolves around a central authority, it is not suitable for a totally decentralized system like ours.

The Terminodes project [5, 6] comes closest to our work in terms of a pure decentralized design philosophy and use of tamper proof hardware. They assume that a tamper-proof hardware at each node keeps track of a virtual currency called nuggets. A sender would load a packet with nuggets before sending it and each relay node would be paid a nugget for participating. The proposed scheme works under the assumptions that each node generates packets continuously and that generated packets cannot be buffered – they have to either be sent immediately or dropped. Both these assumptions are invalid in our system. Firstly, users cannot be expected to use their phones continuously – their will be peak times and lag times and high-volume users and low-volume users of the system. Secondly, some amount of buffering will be possible – a user may decide to delay a non-urgent call till the time its phone has acquired a better reputation and the call has a higher chance to go through successfully. Moreover, in the Terminodes project, the billing is done on a per packet basis where-as in our scheme, we look at calculations on a per session basis which is more suitable for voice sessions.

The CONFIDANT protocol [7] enables nodes to find out about the behavior of other nodes and maintain a reputation system. Nodes broadcast information about selfish nodes and selfish nodes may have their requests ignored. While such a system does not rely on a tamper-proof hardware, the overheads of broadcasting node behavior and maintaining individual information about each node may lead to significant overheads.

Incentive studies in multi-hop cellular networks [8, 9] propose charging and rewarding schemes but assume a central authority like an Internet service provider or a network operator who makes sure that all nodes follow the proposed rules. Again, in our network such schemes are not viable due to the lack of a central authority.

4. System Model

We assume a network of N mobile nodes, where each node may be ON or OFF at a given point in time. Our system is measured in discrete time slots – each node either stays on or off for an entire time slot. We also assume that nodes exchange data-packets (voice can be easily modeled as an extension to this system, since we assume that end-to-end links remain alive for an entire slot).

At the beginning of each time slot, multiple sessions are initiated. For each session, two unique nodes (from the set of ON nodes) are randomly selected as the source and destination. 'L-1' other nodes are randomly selected as the relay nodes which link the source to the destination. Note that these nodes may be ON or OFF. It is important to include OFF nodes also in the random selection, to ensure that in situations where there are not enough ON nodes in the network, the session is unable to go through.

If ON, each relay node either participates in that session or refuses to participate, depending on the embedded relay policy described later. If all the relay nodes are ON and all agree to participate in the session, then the data reaches its destination. If even a single relay node does not agree to participate then that session is aborted. It is to be noted that once an end-to-end link is formed between the source and destination, that link is assumed to remain stable for that entire time slot. One session is limited to one time-slot.

We assume that users have the choice of switching their phones ON or OFF (as in any real world situation), depending on their perceived gains. Given such a system, it is easy to see that users may be tempted to keep their phones OFF when they do not want to communicate with anyone and if they are not expecting any important/urgent incoming data. In a bid to conserve power (which as we mentioned earlier is a scare commodity in many rural settings), users may quickly use their phone and then switch it off. This of-course will prove detrimental to the operation of such a network, as it relies on user-participation to function.

4.1 Incentive Structure

We propose the following rating based scheme to “incentivize” users to participate in the network (that is to keep their nodes ON even if they are not using it for themselves). Since the network is totally decentralized with no controlling authority or coordinating entity, the incentive structure has to work via information stored and decisions taken at individual mobile nodes only.

At the beginning of a node’s entry to the network, each node is provided a rating M (Max rating). The rating of a node is assumed to be embedded in the device (in a tamper-proof hardware) and cannot be altered by the user, although the user can check to see what the current rating is. At each time slot, the rating of a node decays at a fixed rate. The only way a node can prevent the decay of its rating is by acting as a relay for other people’s data. Every time, a node acts as a relay its rating is increased by a fixed amount. The policy that decides whether or not a node should participate in a session (that is act as a relay) is assumed to be embedded in the device and again cannot be tampered with by the user.

We propose the relay policy Reciprocative and also experiment with two extreme policies Selfish and Altruistic.

4.2 Relay Policies

Reciprocative Relay: When a node receives a request to take part in a session, it also receives the current rating of the source node – the node where the request originated. The probability that the node will agree to act as a relay for that session depends on the rating of the source node, and is calculated as follows:

Assuming a Max rating M = 1000,

$800 < \text{Rating}_{source} <= 1000$ Probability(AGREE) = 1

$600 < \text{Rating}_{source} <= 800$ Probability(AGREE) = 0.99

$400 < \text{Rating}_{source} <= 600$ Probability(AGREE) = 0.96

$200 < \text{Rating}_{source} <= 400$ Probability(AGREE) = 0.90

$0 < \text{Rating}_{source} <= 200$ Probability(AGREE) = 0.85

$\text{Rating}_{source} = 0$ Probability(AGREE) = 0

The above numbers have been chosen so that enough calls get accepted but at the same time, selfish users get sufficiently punished. For example, a node with a rating of 700 and 7 relays in the session has a $(0.99)^7 = 0.93$ chance of a successful session where as a node with a rating of 400 has only a $(0.90)^7 = 0.47$ chance of a successful session. Moreover, if the session has lesser number of relays then the chances of a successful session increases. Note that we have assumed that all the relay nodes were ON.

The Reciprocative policy can be implemented with minimum overheads by piggybacking the rating number of the source with the request for taking part in a session. Since the extra data is a single number, the size of the request will not change significantly

We also implemented two extreme relay polices to understand the best-case and worst-case scenarios.

Selfish Relay: The node refuses all requests by others to forward data.

Altruistic Relay: The node agrees to all requests by others to forward data.
Figure 2 illustrates how the rating of two nodes A (selfish policy) and B (altruistic policy) might expect to fluctuate over time (assuming linear decay of rating). Both nodes start with a max rating of M. The rating of the selfish node is expected to quickly reduce to zero as it does not take part in any relays and hence does not accumulate any additional points. The ratings for the altruistic node is expected to fluctuate between M and a lower point, depending on the demand for its services to relay data.

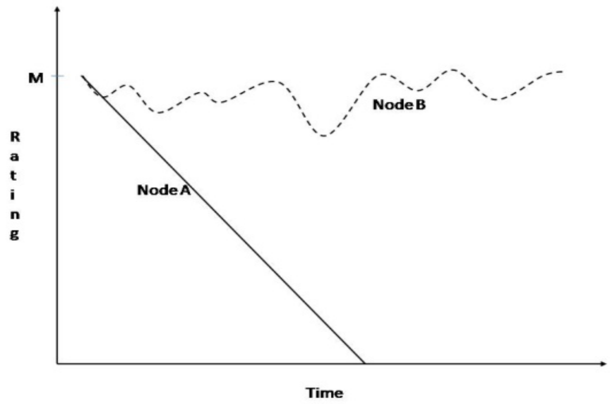

Figure 2: Expected ratings of two nodes: A- Selfish and B-Altruistic, over time

It is difficult to predict the generic behavior of the rating of a node following the Reciprocative policy, which we evaluated via simulations described in the next section.

4.3 User Behavior

Given the above relay policy (Reciprocative), a rational user who normally might have acted selfishly has to now decide between letting others use its device as a relay at least some of the time or quickly loose its rating. Being purely selfish will quickly eliminates the user from the network, as others will not relay its calls at all (when Reciprocative is being used) once its rating reaches zero. The rational user may however decide to keep the phone switched off (and hence conserve power), till a time that the rating reaches a certain lower threshold (where only a certain percentage of its requests are being met). At this point the user may decide to turn the phone ON to increase its rating to a desired upper threshold. We model this kind of behavior in our simulations and call it the Adaptive user behavior.

In our simulations, apart from the three relay policies, we model three kinds of users: Adaptive, Selfish, and Altruistic.

Adaptive User: The adaptive user keeps the phone OFF till its rating reaches a lower threshold, and then keeps it ON till the rating reaches an upper threshold.

Selfish User: Phone is OFF most of the time, except to occasionally send/receive calls/data.

Altruistic User: Phone is kept ON all the time. Typically such a user may not face a major power constraint, and would not mind keeping the phone ON most of the time.

5. Simulations

We studied multiple scenarios with different permutations of relay policies and user behavior. Table 1 provides the parameters used for the simulations. Each experiment was repeated 5 times and the results presented are the average of the 5 runs. The standard deviation in all cases was observed to be less than 3%.

Table 1: Simulation Parameters

Parameter	**Name**	**Value**
Max Rating	R_{Max}	1000
Rate of Rating Decay	D	1/Time slot
Rate of Point (Rating) Accumulation	P	4/successful relay
Number of Nodes	N	100
Number of Relays (links) per Session	L	7
Duration of Simulation (Number of Time slots)	T	10000
Lower Threshold for Rating	R_l	850
Upper Threshold for Rating	R_u	1000
No. of sessions initiated per time slot		5

We measured the percentage of successful sessions, that is how many of the 50,000 sessions that were initiated were successfully completed. We also measured the percentage of nodes that were switched ON and the average rating of the nodes, as the simulation progressed. Evaluated together, these three parameters give a fairly good idea of the performance of the relay policy, for different kinds of user behaviors.

We also experimented with scenarios with multiple user behavior.

6. Results

Figure 3 plots the number of successful sessions for the three kinds of user behavior, when Reciprocative relay was used. As expected, in the best case scenario when all users were Altruistic (that is kept their nodes ON always), all the sessions were successful. The decay in the node rating was more than made up by the points accumulated by successful participation. Hence, in spite of Reciprocative relay, 100% of the sessions were successful. When all users are adaptive (the more realistic scenario), the success rate was around 70%. Some session requests were rejected because of the poor ratings of users. Again as expected, when all users were selfish (only occasionally switched on their phones) the system failed miserable.

The results show that Reciprocative relay (which is designed to incentivize users to behave Adaptively instead of selfishly) can bring the system to a relatively flourishing state where 70% of the sessions are successful.

Figures 4 and 5 plot the average rating of nodes over time and the number of ON nodes over time, for Reciprocative relay. Altruistic and Selfish node behavior is self-explanatory. For the case when all nodes are Adaptive, the number of ON nodes fluctuates, but does not fall below 90%, which ensures a thriving network. Similarly, the average rating of a node, when nodes are adaptive, hovers around 80 %. That is, Adaptive nodes are able to balance their rating to ensure an acceptable level of successful sessions. These results show that for Reciprocative relay and Adaptive user behavior the system is stable over time.

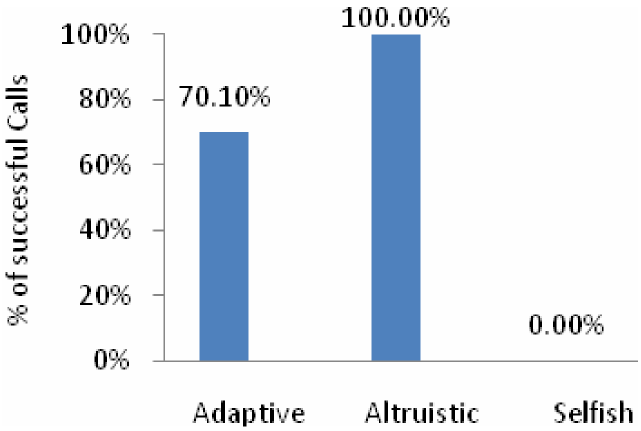

Figure 3 : Percentage of successful sessions for different user behaviors

We also experimented with various ratios of rating decay (D) to point accumulation (P). A ratio of 1:4 yielded the best results. For lower ratios the average rating of a node decays over time which ultimately brings the network to a halt. For higher ratios, all nodes have very high ratings and hence switch OFF their phones. This obviously adversely affects the throughput of the system. We note that a 1:4 ratios worked well for the current parameters under consideration, like the frequency of sessions initiated. For good results this ratio will have to be adjusted according to the expected load of a particular network.

Figure 6 plots the percentage of successful sessions when there are two kinds of users in the system – Altrusitic users and either Selfish or Adaptive.

As can be seen, as the number of altruistic users decrease, the system performance goes down. However, it goes down much more drastically when users turn Selfish, than when users turn Adaptive. Hence, even when all users turn Adaptive, the system still performs relatively well (70%), where as even with a small percentage of selfish nodes (10%) the throughput of the network drops drastically to 7%.

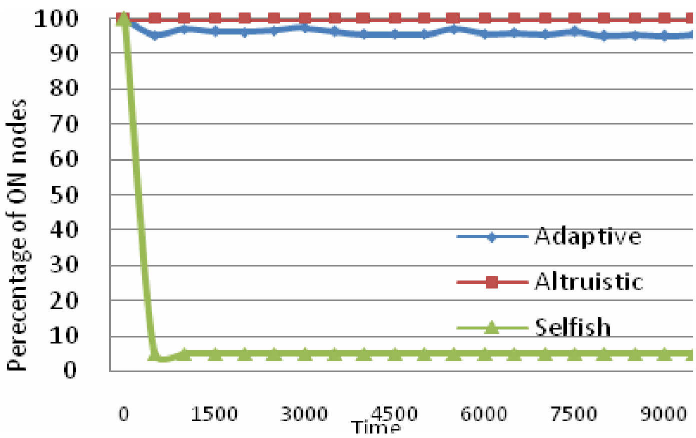

Figure 4: Percentage of ON nodes over time for reciprocative relay and different kinds of user behavior.

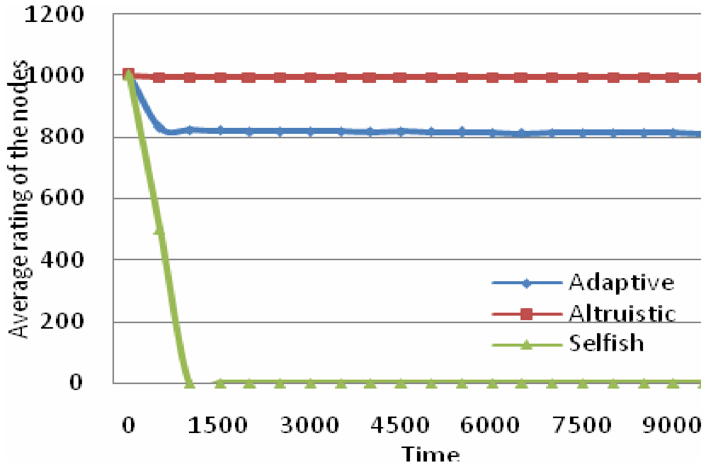

Figure 5: Average node rating over time for Reciprocative relay and different kinds of user behavior.

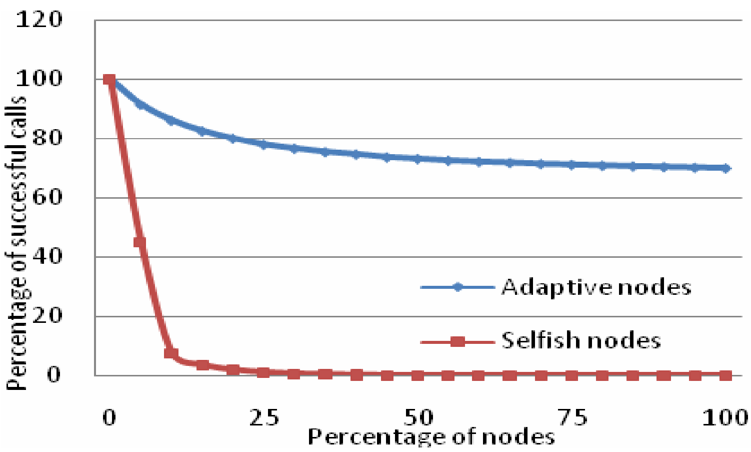

Figure 6: Percentage of successful calls as composition of network changes from altruistic to adaptive/selfish.

7. Conclusions

In this paper we have addressed the problem of incentivizing user participation and cooperation in a peer-to-peer phone network. We have proposed a totally decentralized rating-based scheme where nodes gain points for forwarding other people's data and where the treatment received by a node depends directly on its rating. We find that our scheme is successful in stimulating cooperation among nodes and also in maintaining the throughput of the network and an acceptable level.

A current limitation of our study is that we assume uniform upper and lower thresholds for Adaptive user behavior whereas in reality there might be different bands of users. Some may switch off their phones earlier than others, depending on how much they value power conservation vs. the throughput they receive from the network. Others may prefer to keep their phones on to receive calls, even if they loose power in the process. Our future work will look at modeling multiple user behavior patterns.

We also plan to examine how to include users who are at the margin of the network and may not be asked to relay enough calls and thus not get a chance to better their rating.

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