



Title	Fair packet forwarding in opportunistic networks
Author(s)	Fan, X; Xu, K; Li, VOK
Citation	The 73rd IEEE Vehicular Technology Conference (VTC Spring), Budapest, Hungary, 15-18 May 2011. In Proceedings of IEEE VTC Spring, 2011, p. 1-5
Issued Date	2011
URL	http://hdl.handle.net/10722/142815
Rights	Creative Commons: Attribution 3.0 Hong Kong License

Fair packet forwarding in opportunistic networks

Xiaoguang Fan, Kuang Xu, Victor O.K. Li
The University of Hong Kong, Pokfulam, Hong Kong, China

Abstract—Most replication-based packet forwarding algorithms in opportunistic networks neglect the fairness issue on the success rate distribution among all participants. In this paper we discuss the fairness evaluation on success rate, and propose a new fair packet forwarding strategy which operates as a plugin for traditional utility-based routing protocols. We compare the performance of our strategy with several well-known routing schemes via both a synthetic contact model and real human mobility traces. We find that our strategy improves the balance of success rates among users while maintaining approximately the same system throughput. In addition, our scheme reduces the cost of traditional utility-based routing protocols.

I. INTRODUCTION

Fairness is a fundamental concept of human society, and is important in many areas such as economics and sociology. In network engineering, fairness is also a significant metric to evaluate the allocation of network resources [1]. In opportunistic networks [2], epidemic routing and wait-for-destination schemes are two strategies which aim to maximize the throughput and minimize the cost, respectively. However neither of them can optimize both the throughput and the cost. In order to find a balance between these two schemes, many routing protocols use a “utility” metric at each node to make forwarding decisions. Upon encounter, a best-next-hop heuristic is utilized to guarantee that messages are only forwarded to those nodes with higher utilities. Relying on the contact history information, social-based forwarding algorithms like PROPHET [3], SimBet [4] and FairRouting [5] involve social analysis in the calculation of utility to better choose the relay nodes.

However most of these multi-copy utility-based forwarding strategies focus solely on raising average throughput and reducing total cost while neglecting the fairness issue. In other words, the variance of throughput and cost are ignored. [5] [6] take fairness into consideration and focus on the unfair traffic load distribution among nodes. Here we try to evaluate fairness in term of user satisfaction. We believe that each individual node cares about the delivery success rate of itself more than the average throughput of the whole system. One would consider he is treated unfairly if he perceives his experience to be different from those around him. Thus the unbalanced throughput distribution would cause the dissatisfaction of nodes whose success rate is below the average throughput. Figure 1 shows the success rate distribution of PROPHET in one mobility trace¹. The average throughput, indicated by the horizontal line, is about 0.46 but the success rate varies significantly among nodes. The difference between the

¹The dataset we select includes 36 students equipped with bluetooth mobile devices for 11 days in Cambridge University [7].

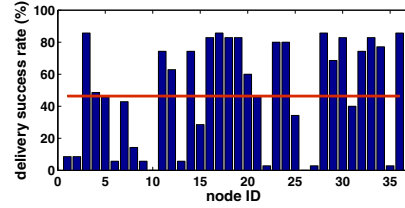


Figure 1. Success rate distribution of PROPHET for the Cambridge dataset.

maximum and the minimum is 0.85 and almost one third of the nodes have success rate lower than 0.1. If we build an opportunistic networking application for this trace, PROPHET may not be a good choice since almost 1/3 of the users suffer a big gap on throughput below the mean.

The work in [8] studies the balancing between nodes’ capabilities and responsibilities in online social search. In this paper, we study the scenario of opportunistic networks, aiming to balance the success rate distribution for packet forwarding. We propose a fair packet forwarding strategy which could be considered as a plugin for all multi-copy utility-based routing protocols in opportunistic mobile networks in order to improve their fairness on delivery success rate. We firstly give a definition of fairness on throughput and then introduce two mechanisms of our algorithm based on packet priority, including a lower utility tolerance mechanism and a message duplication restriction mechanism. Finally we utilize our algorithm and three other utility-based routing protocols to simulate asynchronous messaging in both a synthetic contact model and real experimental human mobility traces. We find that our scheme improves the balance of success rates and enhances the fairness among users while maintaining approximately the same system throughput. In addition, it reduces the cost of traditional multi-copy utility-based forwarding algorithms, rendering the proposed scheme not only fair but also efficient.

We proceed in this paper as follows. Methodology is described in Section II, simulation and evaluation in Section III, and conclusion in Section IV.

II. METHODOLOGY

In this section, we firstly describe the metric we use to evaluate fairness, then introduce the packet priority design, and finally give an overview of our algorithm, detailing the two mechanisms to guarantee fair throughput distribution.

A. Fairness definition

According to equity theory, people evaluate fair treatment by comparing the ratios of contributions and benefits of each person in the whole system [9]. Here we assume that people make the same contribution for the organization. For example,

they make the same payment for the message sending service of the system. Thus the major concern of an individual node is the message success rate, which is the benefit each user gains from the system. Suppose there are N nodes in the system. The message success rate of node n_i , $i = 1, 2, \dots, N$, is the proportion of successfully delivered messages out of all messages generated from node n_i .

There are three measures for fairness in the literature, namely, variance, max-min fairness and Jain's fairness index.

- *Variance* is used to measure how far the values are from the average. It ranges from 0 to infinity and one cannot easily understand the level of fairness solely from the value of variance.
- *Max-min fairness* [10] is the ratio of the maximum and the minimum among all values. Although it is bounded, changes of individual values may not be readily observed since the metric only focuses on the upper and lower bounds.
- *Jain's fairness index* [11] is calculated as follows:

$$Fairness = \frac{\sum_{i=1}^N x_i^2}{N \cdot (\sum_{i=1}^N x_i)^2}, \quad (1)$$

where N is the number of users and x_i is the resource or throughput allocation for user i . Jain's fairness index ranges from 0 to 1. 1 stands for complete fairness and 0 represents definite unfairness. Moreover, this fairness index is continuous since any slight change in x_i changes the value of the index.

We choose Jain's fairness index as our metric due to its appropriate interpretation of fairness and here x_i in Equation 1 should be the message success rate of node i .

B. Packet priority

In order to solve the problem of unfairness on delivery success rates, we need to firstly analyze why the inequity happens. Due to the heterogeneity of contact rates in opportunistic mobile networks, nodes may have various links with others, depending on their social circles and mobility patterns. For instance, the person who is popular may have numerous connections with others, and thus messages generated from him could be easily distributed and transmitted to the majority of destinations. In contrast, one who has few friends may not have a great chance to send messages to the right place. In order to balance the success rate between the strong and the weak, we assign a priority to each packet when it is generated according to the historical information of the source node. The priority of message m from the source node n_i could be calculated as:

$$P_{n_i}(m) = \frac{SR_{average} - SR(n_i)}{SR_{max} - SR_{min}}, \quad (2)$$

where $SR(n_i)$ represents the message success rate of node n_i , and SR_{max} , SR_{min} , $SR_{average}$ are the maximum, minimum and mean success rates, respectively. Equation 2 shows that

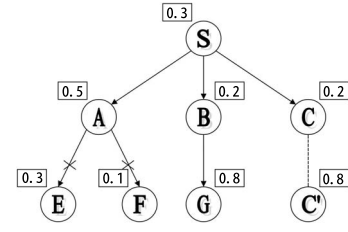


Figure 2. Examples of routing under utility-based forwarding schemes.

a message from the node with low success rate would gain a high priority and the priority value is inversely proportional to the success rate of the source. Note that the success rate data we mention here are all collected from historical contact information. Later we will implement packet priority in our protocol design in order to offset the unfair treatment on success rate caused by network topology.

C. Protocol design

Our protocol consists of two mechanisms, namely, lower utility tolerance mechanism and message duplication restriction mechanism.

1) Lower utility tolerance mechanism

Traditional utility-based forwarding algorithms follow the principle that a message should only be forwarded to a node with higher utility since higher utility always means a higher probability for successful message delivery. However, this greedy heuristic may get trapped in local optimal, and prevents messages from being transmitted to the best relay. Moreover, since the utility is time-variant, a node with low utility is very likely to increase its level of utility value in the future due to the uncertainty of mobility traces. The problems are illustrated in Figure 2. The number in the box is the utility value. Suppose node S wants to find good relay nodes to forward message m since it cannot contact the destination directly. It meets A , B and C , successively. According to traditional utility-based forwarding scheme, S will forward m solely to A since A is the only one whose utility is greater than S . After that A meets E and F , successively, but neither of them is good to be the next hop. Thus message m is held in A with the utility 0.5. In contrast, after meeting S , B contacts G whose utility is 0.8 and the utility of C also increases to 0.8 with time. Thus if S chooses B or C as the next hop, the final utility of the node where message m is held will increase to 0.8. The example indicates that the best-next-hop decision based on utility comparison may not be a good choice to increase the probability for successful message delivery. Here we introduce the lower utility tolerance mechanism, which allows a node to forward messages to others with lower utility probabilistically. When node A encounters node B , it will forward the message m to node B with probability $p(m)$:

$$p(m) = \begin{cases} 1 & U_A(m) < U_B(m) \\ e^{-\frac{U_A(m) - U_B(m)}{T}} & U_A(m) > U_B(m) \end{cases} \quad (3)$$

where $U_A(m)$ and $U_B(m)$ are the utilities of nodes A and B on message m , respectively. Here a parameter T is defined

to control the value of $p(m)$ based on packet priority. For message m from the source node n_i , the initial value of T may be expressed as follows:

$$T(m) = \gamma \cdot P_{n_i}(m), \quad (4)$$

where $P_{n_i}(m)$ is the priority of message m and γ is a fixed parameter. Moreover, when the message approaches its destination, the effect of lower utility tolerance mechanism will be reduced and the probability of forwarding messages to the node with lower utility should be reduced. Here we decrease T according to a geometric law:

$$T_{k+1}(m) = \alpha T_k(m), \quad (5)$$

where $\alpha \in (0,1)$ and $T_k(m)$ is the value of T for message m at its k th hop.

2) Message duplication restriction mechanism

Multi-copy forwarding algorithms allow nodes to create a fixed number of replicas for each message. The goal is to gain a satisfactory network throughput while keeping the cost under control. However, most of the schemes assign the same limit on the number of copies while neglecting the various demand of replicas for different message sending requests. To balance the success rates, we intend to create more replicas for messages from nodes with low success rate in order to further enhance the chance of successful message delivery while reducing the copies of messages from nodes with high success rate so as to avoid unnecessary waste on message duplication. Suppose the number of copies created by a node for message m is $K(m)$. Based on packet priority, $K(m)$ is expressed as follow:

$$K(m) = \lceil f(P(m)) \rceil, \quad (6)$$

where $P(m)$ is the priority of m and $\lceil \cdot \rceil$ is the ceiling function. Here we consider $f(P(m))$ as a linear function:

$$f(P(m)) = A \cdot P(m) + B, \quad (7)$$

where A and B are the slope and intercept of the function, respectively.

Combining the two mechanisms mentioned above, we give a formal statement of our algorithm in Algorithm 1.

III. SIMULATION AND EVALUATION

In this section we evaluate our fair packet forwarding algorithm with three typical social-related utility-based forwarding schemes in a synthetic contact model and two human mobility datasets.

A. Dataset description

For the synthetic contact model, we assume that the probability of contact between two nodes is determined by the underlying social structure among nodes in the opportunistic network. Here we build the contact process following the small-world network in [12]. According to the small-world network, N nodes are arranged in a ring and each node connects to its K nearest neighbors. In order to be consistent

Algorithm 1: Fair packet forwarding algorithm

```

Let  $n_1, \dots, n_N$  be nodes and  $m_1, \dots, m_M$  be messages
Initialization:  $\forall m_k$ , assign  $P(m_k)$ ,  $T(m_k)$  and  $K(m_k)$ 
On contact between nodes  $n_i$  and  $n_j$ 
Consider  $m_k$  held by  $n_i$ 
if the destination of  $m_k$  is  $n_j$  then
    forward  $m_k$  from  $n_i$  to  $n_j$ 
else
    if  $K(m_k) \geq 1$  then
        update utility  $U_{n_i}(m_k)$  and  $U_{n_j}(m_k)$ 
        if  $U_{n_i}(m_k) < U_{n_j}(m_k)$  then
            forward  $m_k$  from  $n_i$  to  $n_j$ 
        else
            forward  $m_k$  to  $n_j$  with probability
             $p = \exp\left(-\frac{U_{n_i}(m_k) - U_{n_j}(m_k)}{T(m_k)}\right)$ 
        end
    end
    if  $m_k$  is forwarded then
         $T(m_k) \leftarrow \alpha T(m_k)$ 
         $K(m_k) \leftarrow K(m_k) - 1$ 
    end
end

```

with the real mobility traces on the number of devices shown in Table I, we assign $N = 80$ and $K = 8$. For a new contact, we choose the source uniformly from all nodes. Then the destination of the contact is selected uniformly either from the nodes which have direct links from the source with probability $p = 0.9$ or from other nodes with probability $1 - p = 0.1$. The essence of the small world contact model is that people always communicate with their friends while occasionally meeting some strangers out of their social circles.

The real human mobility tracesets which we denote as *MITreality* and *Infocom06*, respectively, are collected by two research projects, Reality Mining [13] at MIT and Hagggle [7] at Infocom2006 conference. In these experiments, Bluetooth-enabled mobile devices logged contacts with each other by doing Bluetooth device discovery periodically. We choose the time period from March 1 to March 25 in 2005 for *MITreality* as it does not contain long holiday periods, and select a data session from 8:00 am to 1:00 pm on April 24 2006 for *Infocom06* since it includes meeting and lunch time. The post-process datasets utilized are summarized in Table I.

Experimental dataset	SmallWorld	MITReality	Infocom06
No. of devices	80	80	77
No. of contacts	10000	4000	30000
Average No. of contacts/pair	3.165	1.266	9.990

Table I
CHARACTERISTICS OF THREE DATASETS

B. Simulation setting

We implement three typical utility-based routing protocols, which are based on different measures of utility metric, in our contact-driven simulation platform.

PROPHET [3]: Based on contact frequency, utility is defined as delivery predictability which increases a certain

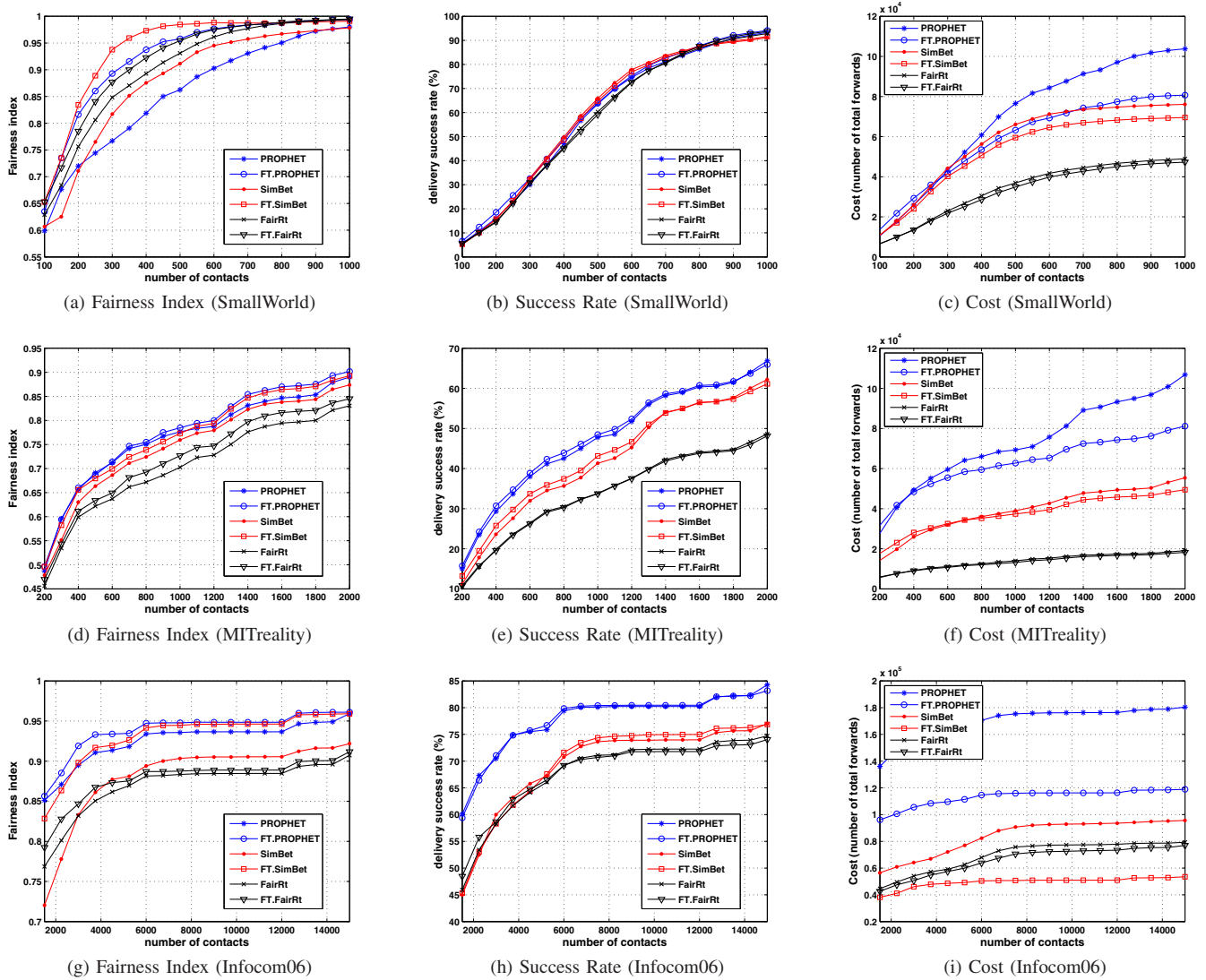


Figure 3. Network performance comparison.

amount by instant encounter and decreases exponentially with time. The transitive property derived from the notion of *weak tie* [14] is also involved in the calculation of the utility. We set the parameters $P_{init} = 0.75$, $\beta = 0.25$, $\sigma = 0.98$ following the author’s suggestion.

SimBet [4]: Utility is evaluated by combining two social measures (betweenness centrality and similarity) according to the potential social graph of contact traces. Betweenness of a node is defined as the proportion of shortest paths between all possible pairs that pass through this node [15]. Similarity is the total number of common friends between nodes. We set the parameter $\alpha = 0.5$ according to the author’s suggestion.

FairRouting [5]: Utility is assessed in terms of interaction strength which is based on long term and short term robustness. The aggregated interaction strength is further defined to identify sustainable long term tie by excluding ephemeral relationship. As mentioned in Section I, FairRouting improves the balance of traffic load by controlling the queue size, and

is different from our focus on the fairness of success rate.

Aiming to gain fair throughput we denote our schemes as *FT.PROPHEt*, *FT.SimBet* and *FT.FairRouting*, each of which is obtained by implementing fair packet forwarding strategy on the corresponding protocols mentioned above. In order to define packet priority, we obtain the historical success rate distribution of the three traditional routing schemes from the first half of the total contacts in each trace.

C. Results and discussion

The metrics we are concerned with are (1) *fairness index*, which is stated in Section II-A; (2) *system throughput*, which is the proportion of successfully delivered messages out of all generated messages; and (3) *cost*, which is the total number of forwards. Figure 3 shows these metrics versus the number of contacts in each dataset. *SmallWorld* results are shown in Figure 3 (a)-(c), *MITreality* in Figure 3 (d)-(f), and *Infocom06* in Figure 3 (g)-(i). Notice that here our concern is not the difference of performance metrics among

the three traditional utility-based forwarding algorithms, but the comparison between each original routing protocol and its revised version with our fair packet forwarding strategy. The parameters of our strategy for different traditional routing schemes are shown in Table II.

Parameter		α	γ	A	B
SmallWorld	PROPHET	0.001	0.001	11	3
	SimBet	0.95	0.1	12	3
	FairRouting	0.1	1	8	3
MITreality	PROPHET	0.01	0.01	11	4
	SimBet	0.15	2	11	4
	FairRouting	0.1	10	10	2
Infocom06	PROPHET	0.75	5	18	5
	SimBet	0.75	1	12	3
	FairRouting	0.85	100	8	4

Table II
PARAMETERS FOR FAIR PACKET FORWARDING STRATEGY

Figure 3 (a), (d), and (g) show the fairness index of the three traditional utility-based forwarding algorithms and our corresponding fair strategies in *SmallWorld*, *MITreality* and *Infocom06*, respectively. We observe that all of our fair strategies enjoy a better fairness index when compared with the original schemes, proving that the algorithm we proposed can indeed enhance the balance of success rate distribution. The system throughput comparison is shown in Figure 3 (b), (e), and (h). We find that our fair packet forwarding strategies perform almost as well as the corresponding traditional routing protocols, and for some schemes like *FT.SimBet* in *MITreality* and *Infocom06*, the throughput is even better than before. In order to further analyze the improvement of fairness on throughput in detail, we take the success rate distribution of SimBet and *FT.SimBet* in *Infocom06* at 15000 contacts as an example, as shown in Figure 4. The x-axis represents the node ID and the y-axis, the success rate. The average throughput of SimBet and *FT.SimBet* shown by the horizontal line in each plot are 77 and 76.64 respectively, which are almost the same. The observation is that *FT.SimBet* greatly increases the success rate of the weak nodes which have low throughput while slightly reducing the performance of the strong nodes. Thus a balance of success rate is achieved while the average throughput is maintained.

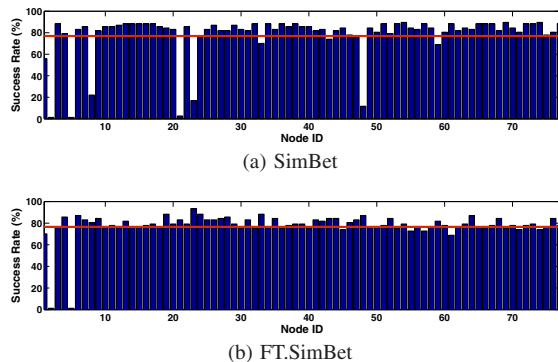


Figure 4. Improvement on success rate distribution

Figure 3 (c), (f), and (i) show the interesting observation that our fair strategies reduce the cost significantly in most

of the cases. Moreover, for some algorithms, like *FT.SimBet* and *FT.PROPHET* in *Infocom06*, the cost is cut down by as much as 50%. As stated in Section II-C, the core idea of our fair strategy is to control the replicas and redistribute them to balance the success rate distribution, thus potentially decreasing the cost. The simulation results prove that our scheme is not only successful on balancing the throughput but also efficient on replica utilization.

To summarize, our proposed fair packet forwarding algorithm improves the balance of success rate distribution and enhances the fairness among users while maintaining approximately the same system throughput. In addition, our scheme reduces the cost of traditional multi-copy utility-based forwarding algorithms. This indicates that the proposed scheme is not only fair but also efficient.

IV. CONCLUSION AND FUTURE WORK

This paper considers fairness in the performance evaluation of routing protocols in opportunistic mobile networks. We propose a fair packet forwarding strategy to improve the balance of success rate distribution among users based on packet priority. Here we assume that the status of each user is the same. For instance, each person makes the same payment for the message sending service. Thus the expected success rate distribution we hope to achieve is a uniform distribution. Furthermore, we plan to build a user-friendly mechanism which allows users to select various levels of success rate by different payments, and design a protocol to realize specific success rate distribution based on different user requests.

REFERENCES

- [1] J. Mo and J. Walrand, "Fair end-to-end window-based congestion control," *IEEE/ACM Transactions on Networking (ToN)*, vol. 8, no. 5, pp. 556–567, 2000.
- [2] A. Lindgren and P. Hui, "The quest for a killer app for opportunistic and delay tolerant networks," in *Proceedings of CHANTS '09*, 2009.
- [3] A. Lindgren, A. Doria, and O. Schelén, "Probabilistic routing in intermittently connected networks," *Service Assurance with Partial and Intermittent Resources*, pp. 239–254, 2004.
- [4] E.M. Daly and M. Haahr, "Social network analysis for routing in disconnected delay-tolerant manets," in *Proceedings of MobiHoc '07*.
- [5] J. Pujol, A.L. Toledo, and P. Rodriguez, "Fair routing in delay tolerant networks," in *Proceedings of IEEE INFOCOM '09*, 2009.
- [6] V. Erramilli, M. Crovella, A. Chaintreau, and C. Diot, "Delegation forwarding," in *Proceedings of MobiHoc '08*, 2008.
- [7] "Haggle project. <http://www.haggleproject.org>," .
- [8] K. Xu, V.O.K. Li, J. Xie, and G.H. Yang, "Capability and responsibility balancing in online social search," in *Proceedings of IEEE GLOBECOM '10*, 2010.
- [9] J.S. Adams, "Inequity in social exchange," *Advances in Experimental Social Psychology*, vol. 2, no. 267-299, 1965.
- [10] MA Marsan and M. Gerla, "Fairness in local computing networks," *Proceedings of IEEE ICC '82*, 1982.
- [11] R. Jain, D. Chiu, and W. Hawe, "A quantitative measure of fairness and discrimination for resource allocation in shared computer systems," *DEC Research Report TR-301*, 1984.
- [12] D.J. Watts and S.H. Strogatz, "Collective dynamics of small-world networks," *Nature*, vol. 393, no. 6684, pp. 440–442, 1998.
- [13] "Reality mining project. <http://www.reality.media.mit.edu/>," .
- [14] M.S. Granovetter, "The strength of weak ties," *American Journal of Sociology*, vol. 78, no. 6, pp. 1360, 1973.
- [15] S.N. Dorogovtsev and J.F.F. Mendes, *Evolution of networks: from biological nets to the internet and WWW*, Oxford University Press, 2003.