

A Trust-based User Assignment Scheme in Ad hoc Social Networks

Zhaolong Ning^{1,2}, Zhikui Chen^{1,*}, and Xiangjie Kong¹

¹School of Software, Dalian University of Technology, Dalian, 116620, China

² State Key Laboratory for Novel Software Technology, Nanjing University, Nanjing, 210093, China

Abstract—Although cooperation among individuals plays a key factor in the commercial development of wireless networks, trust is an important factor due to the uncertainty and uncontrollability caused by the self-organizing character of different entities. In this paper, we present a trust-based user assignment scheme by considering node sociality, the reason behind is that effective user assignment should not only build a reliable system basing on the behavior of network individuals, but also encourage selfish nodes to forward packets for one another. At first, a model for trustworthiness management is built up by considering social relationship. Then, user assignment for each transmission is decided by a double auction-based mechanism. Simulation result demonstrates that our scheme is able to obtain better network performance than the existing method in link connectivity and social welfare.

Keywords—Social relationship; node trust; double auction

I. INTRODUCTION

Distributed cooperation and information interaction are viewed as essential solutions to acquire the deployment goals, such as bandwidth improvement and collision decrease. However, the cooperative only work well under the condition that all the participants perform in a trustworthy fashion. Since Ad hoc networks are frequently deployed in harsh or uncontrolled environments, it is impossible to utilize centralized intrusion detection system for node monitoring, thus the main objective of recommendation is to compensate for the lack of monitoring capabilities due to the distributed characters in Ad hoc networks. Therefore, describing and quantifying node trust is important to guarantee the operation of self-organizing network, especially where highly heterogeneous individuals participate and tight degree of collaborations are employed in large scale networks.

With the objective of enhancing network performance, the authors in [4] presented a social-oriented adaptive transmission scheme for Ad hoc networks. At first, a double auction-based social awareness mechanism was evaluated to determine the next-hop node for each transmission. Then, the optimal relaying method is selected by jointly considering various kinds of transmissions. In order to guarantee network robust to alleviate node selfishness and cheating, an integrated optimal relay assignment method for cooperative networks was studied in [7] to obtain high social system capacity. In [9], a novel semantic-based friend recommendation scheme for social networks was proposed, which is based on user life styles instead of social graphs. The presented method explores user life styles from user-centric sensor data, measures the similarity of life styles between individuals, and recommends friends to entities under the condition that their life styles are

similar. Since selecting the optimal community satisfying the efficiencies of both economy and communication is challenging, the authors in [10] firstly formulated a computational model for multi-community-cloud collaboration, then presented a comprehensive selection scheme to extract the best group of community clouds. Unfortunately, most references stressed on the formulations of social relationship, and node trust is not well studied.

In recent years, some studies focused on trust-based resource assignment. According to the human-based model, the authors in [1] built a trust relationship between nodes in an ad hoc network, which is based on previous entity experiences and the recommendations of other nodes. In [2], a trust-based intrusion detection method was studied by employing a scalable hierarchical trust management protocol for wireless sensor networks, and a trust metric considering both quality of service (QoS) trust and social trust for detecting malicious nodes was evaluated. In [3], a double-auction scenario was studied for user cooperation in cellular networks, where the asking and bidding prices are decided by their residual energy. Then this problem is transformed into maximum matching and maximum weighted matching problems respectively for solution. The authors in [5] defined a subjective model for trust management in P2P networks, where each node calculates the trustworthiness of its friends basing on node experience and the recommendation from potential service providers. Then, a feedback system is employed and node credibility together with centrality are combined to evaluate the trust level. In order to reduce node hazards and increase network security, the authors in [6] put forward a dynamic trust prediction model to assess node trustworthiness. The evaluation is based on node historical behaviors, together with the future behaviors predicted by fuzzy logic rules. In order to minimize trust bias while maximizing network application performances, the authors in [8] employed a probability model to describe node behavior, and derived the objective trust based on ground truth status of nodes. However, most of the related works mainly focused on node trust while ignoring its social characters.

The underlying idea of our work is to incorporate trust evaluation with node social relationship, so that the transmission can be performed effectively and network performance can be improved. At first, we evaluate node social relationship. Then, we define a novel model for node trust management. Finally, we present a trust-based user assignment scheme in social network, where source and potential relaying nodes are determined by the double auction mechanism. The remainder of this paper is organized as follows: Section II describes node social relationship

formulation. The model for node trust evaluation is introduced in Section III, and a trust-based user assignment scheme in social network is presented in Section IV. Simulation results are illustrated in Section V, and some concluding remarks are given in Section VI.

II. MICS SCHEME

Our presented social-aware metrics evaluate node relationship from network density, link quality and community character through analyzing the information interaction with their surrounding nodes. Three complementary metrics are presented, including friendship of neighboring nodes, friendship of associated nodes and friendship of community nodes. We utilize a directed graph $G=(V, E)$ to model network, where V is node set and E is a collection of links between nodes. Node pair $j-j'$ is defined as one session under the condition that the node pair can communicate with each other directly. With the objective of maximizing transmission rate, the authors in [11] proved that one relay node is enough for each source node. If there are packets to be transmitted from nodes j to j' with the help of an intermediate node i , we define node group $j-i-j'$ as one session.

A. Friendship of neighboring nodes

In order to assess node degree which influences its neighboring nodes during one scheduling period, the percentage of the packet number delivered from one source node to the total number of the packets obtained by its corresponding destination node is calculated. The Friendship of Neighboring nodes for node j , expressed by FN_j , is computed by:

$$FN_j = \frac{1}{|Q_j|} \sum_{j' \in V} \frac{b_{j,j'}}{\sum_{h \in V-j} b_{h,j'}} \quad (1)$$

where $b_{j,j'}$ is the number of packets to be delivered from nodes j to j' , and $\sum_{h \in V-j} b_{h,j'}$ is on behalf of the total number of packets from other nodes that are received by node j' . The number of neighboring nodes of node j is denoted by $|Q_j|$.

B. Friendship of associated nodes

With the objective of measuring the friendship between one node and its associated nodes, normalizing SINR value over associated links is utilized to evaluate link state. The Friendship of Associated nodes for node j is expressed by FA_j , and the normalization is employed to make sure the value of FA_j between 0 and 1, this metric is shown as:

$$FA_j = \frac{1}{|A_j|} \sum_{j' \in V} \frac{\gamma_{j,j'}}{1 + \gamma_{j,j'}} \quad (2)$$

where $|A_j|$ is the number of nodes that node j is connected. $\gamma_{j,j'}$ is the Signal to Interference and Noise Ratio (SINR) value at destination node j' , and can be worked out by:

$$\gamma_{j,j'} = \frac{P_{j,j'} G_{j,j'}}{\eta + \sum_{h \in V-\{j\}} P_{h,j'} G_{h,j'}} \geq \gamma \quad (3)$$

where $P_{j,j'}$ and $G_{j,j'}$ are the transmission power and channel gain from nodes j to j' respectively, and η is the thermal noise. The transmission on direct link is acceptable (in transmission rate and correctness) if the SINR value at the receiver is higher than a certain threshold. Otherwise, direct link transmission can be performed by multi-hop transmissions. Since not all the neighboring nodes can be associated, thus $|A_j| \leq |Q_j|$.

C. Friendship of community nodes

The quality of node friendship in the community is described by this metric. The Friendship of Community for node j , denoted as FC_j , is calculated by:

$$FC_j = \frac{|A_j|}{|V|} \quad (4)$$

where $|V|$ is the total number of network nodes. This metric is utilized to estimate node communication ability in the community.

The social relationship of node j , denoted by ϕ_j , is a weighting sum of these three complementary metrics stated above. The corresponding weights can be set up deterministically or by experimental combinations.

III. NODE TRUST EVALUATION

In this section, we evaluate the trust of network node. The trustworthiness of one node is evaluated by node behavior with the interaction of this node. Node reputation can be reflected by other nodes, which once have their past direct (direct interactions) or indirect (through relay nodes) experiences of this node. The trustworthiness level is calculated according to the feedback stored by other nodes. The reason behind is to avoid single point of failure.

Define T_{ij} as the trustworthiness of nodes i and j , it can be expressed as:

$$T_{ij} = \alpha Q_{ij} + \beta O_{ij}^{dir} + \chi O_{ij}^{ind} \quad (5)$$

where the summation of weighting factors in (5) equals to 1. Q_{ij} is node centrality, O_{ij}^{dir} together with O_{ij}^{ind} are the direct and indirect experiences of node j from its neighboring nodes.

The centrality of node j can be calculated by:

$$Q_{ij} = \frac{|K_{ij}|}{|N_i|} \quad (6)$$

where N_i is the number of friends of node i , and K_{ij} is the common number of friends between nodes i and j . The objective of this metric is to prevent malicious nodes obtaining high centrality value by constructing many relationships.

If two nodes have many friends in common, their evaluation parameters of constructing relationships are similar. When trustworthiness information is required from nodes i to j , node i checks the last direct transactions and determines its own opinion shown as:

$$O_{ij}^{dir} = \frac{\log(N_{ij}+1)}{1+\log(N_{ij}+1)} O_{ij}^{sho} + \frac{1}{1+\log(N_{ij}+1)} O_{ij}^{lon} \quad (7)$$

where O_{ij}^{sho} and O_{ij}^{lon} stand for the short and long term opinions. The reason for weighting factor setting is that the relationship factor starts to lose its importance and the feedback returned by the last transaction is stressed. The long and short term opinions in Eq. (7) are illustrated as:

$$O_{ij}^{sho} = \sum_{l=1}^{L^{sho}} f_{ij}^l \pi_{ij}^l / \sum_{l=1}^{L^{sho}} \pi_{ij}^l \quad (8)$$

$$O_{ij}^{lon} = \sum_{l=1}^{L^{lon}} f_{ij}^l \pi_{ij}^l / \sum_{l=1}^{L^{lon}} \pi_{ij}^l \quad (9)$$

where L^{sho} and L^{lon} stand for the windows of the short and long-term opinions, and l denoted as the latest transaction. The feedback is weighted by π_{ij}^l to distinguish important transactions from insignificance ones. It should be noted that when assessing node risk, the short-term opinion is useful. That is to reduce the possibility of node to act in a malicious method or oscillate around a regime value after building up its reputation. The indirect calculation is calculated by:

$$O_{ij}^{ind} = \sum_{k=1}^{|K_{ij}|} (C_{ik} O_{kj}^{dir}) / \sum_{k=1}^{|K_{ij}|} C_{ik} \quad (10)$$

where C_{ik} is the credibility from node i to node k , and can be calculated by:

$$C_{ik} = \eta O_{ik}^{dir} + \mu Q_{ik} \quad (11)$$

satisfying $\eta + \mu = 1$. It should be noted that C_{ik} depends on the direct experience between the two nodes. By Equations (6)-(11), we can work out trustworthiness T_{ij} in (5). The trust of node j can be calculated by:

$$T_j = \frac{1}{|N_j|} \sum_{i \in N_j} T_{ij} \quad (12)$$

IV. TRUST-BASED SOCIAL-AWARE USER ASSIGNMENT SCHEME

In wireless opportunistic networks, if we regard the relay service as commodity, the source and relay nodes as buyer and as seller respectively, the trust-based social-aware user assignment problem can be modeled by double auction mechanism.

On one hand, since the intermediate nodes are selfish, they are reluctant to serve as relays unless their resource expenditure (e.g. energy consumption) can be compensated. On the other hand, with the objective of obtaining high transmission rate, source nodes are prefer to purchase relay service from intermediate nodes. According to economic terminology, bidding and asking are the prices submitted by source and relay nodes, respectively. After the last auction terminates, the intermediate nodes start to obtain different bidding prices from the source nodes. Meanwhile, the source nodes receive different asking prices from potential relay nodes. The auction is conducted periodically, and one-round of the double auction is illustrated as follows.

According to *Shannon* formula, the data rate in one time slot for direct transmission is:

$$C_{j,j'} = W \log_2 \left(1 + \frac{P_{j,j'} G_{j,j'}}{\eta + \sum_{h \in V - \{j\}} P_{h,j'} G_{h,j'}} \right) \quad (13)$$

where W is the bandwidth. Without loss of generality, the bandwidth of each link is assumed to be the same. If node i is chosen as the relay between nodes j and j' , a relay based session is formed. Two links are included in the session, namely $j-i$ and $i-j'$, the acquired link rates are:

$$C_{j,i} = W \log_2 \left(1 + \frac{P_{j,i} G_{j,i}}{\eta + \sum_{h \in V - \{j\}} P_{h,i} G_{h,i}} \right) \quad (14)$$

$$C_{i,j'} = W \log_2 \left(1 + \frac{P_{i,j'} G_{i,j'}}{\eta + \sum_{h \in V - \{i\}} P_{h,j'} G_{h,j'}} \right) \quad (15)$$

The required time for completing one-unit data transmission in the relay based session is:

$$\tau = \frac{1}{C_{j,i}} + \frac{1}{C_{i,j'}} \quad (16)$$

and the average transmission rate under this situation is:

$$C_{j,i,j'} = \frac{1}{\tau} = \frac{C_{j,i} C_{i,j'}}{C_{j,i} + C_{i,j'}} \quad (17)$$

From the view of source nodes (buyers), the enhanced rate gained by the relay based transmission is: $C_j^i = C_{j,i,j'} - C_{j,j'}$, where C_j^i is the benefit that buyer (source) j gains from seller (relay) i . It is a fact that no buyer would purchase the commodity only if the transmission rate obtained by the relay based transmission is higher than that achieved by direct transmission.

From the aspect of relay nodes (sellers), they are reluctant to offer relay service to the source nodes unless the gained reward can satisfy their resource consumption. Similar with [13], we employ the utility function to evaluate the relationship between transmission rate and the gained network utility. For any $C \geq 0$, the utility function is:

$$F(C) = \rho(1 - e^{-\theta C}), \quad C \geq 0 \quad (18)$$

where ρ is the upper limitation of the utility function, and θ determines the curve shape of the function.

If relay node i transmit packets for source node j to destination node j' , compared with the direct transmission, the increased utility I_j is:

$$I_j = F(C_{j,i,j'}) - F(C_{j,j'}) \quad (19)$$

where $F(C_{j,i,j'})$ and $F(C_{j,j'})$ are the utilities achieved by relay based and direct transmissions, respectively.

For relay node i , after affording relay service, its lost ability L_i in contributing utility improvement is calculated by:

$$L_i = F(C_{i,j'}(P_{i,j'})) - F(C_{i,j'}(P_{i,j'} - P_{i,j'}^{con})) \quad (20)$$

where $P_{i,j'}$ and $(P_{i,j'} - P_{i,j'}^{con})$ are the usable transmission powers of relay node i before and after relaying packets to node j' respectively, and $P_{i,j'}^{con}$ is the consumed power for packet transmission. $C_{i,j'}(P_{i,j'})$ and $C_{i,j'}(P_{i,j'} - P_{i,j'}^{con})$ illustrate the achievable data rates before and after providing relay service respectively. $F(C_{i,j'}(P_{i,j'}))$ and $F(C_{i,j'}(P_{i,j'} - P_{i,j'}^{con}))$

demonstrate the utilities that node i is able to contribute before and after providing relay service respectively.

Driven by economic profit, traders in real market are not willing to announce the actual value (cost) of the commodity. As a result, buyer j would bid a lower price than the actual value of the commodity, and seller i will ask a higher value than its actual cost. This extra part deviated from the real value is named mark-up in economic terminology. Due to the greedy characters of traders in the double auction based market, the source node j would bid as:

$$I_j^{bid} = I_j e^{-m_j} \quad (21)$$

where $m_j \in [0,1]$ is the mark-up of the buyer, and the relay node i would ask as:

$$L_i^{ask} = L_i e^{m_i} \quad (22)$$

where $m_i \in [0,1]$ is the mark-up of the seller.

Our mark-up selection takes node trust, social relationship and energy into consideration. This is because trust is a key factor for cooperative transmission, and malicious node would mislead other nodes. Furthermore, network individuals in the real world are often socially selfish, namely they prefer to forward packets for others with strong social relationship. Furthermore, if the source node has plenty of energy, it would not be so eager to purchase the relay service. The mark-up of the source node can be defined as:

$$m_j = A_1 \phi_j + A_2 \frac{AE_j}{TE_j} + A_3 T_j \quad (23)$$

Herein, AE_j and TE_j are the available (residual) and total energies of node j respectively, ϕ_j is the social relationship of node j , and T_j is the trust value of node j .

The mark-up selection of the relay node is quite different. If the energy of the potential relay node is insufficient, it would not like to provide service for other nodes, since its own communication requirement should be satisfied before earning extra profit. Furthermore, if the social relationship and trust value of this relay node is strong, many source nodes will bid to purchase the relay service from this node. Therefore, it will ask higher price than the actual value. Otherwise, a relatively reasonable price would be given to fulfill the transaction to gain economic profit. The mark-up of the relay node can be illustrated as:

$$m_i = A_1 \phi_i + A_2 (1 - \frac{AE_i}{TE_i}) + A_3 T_i \quad (24)$$

where the variables in (24) are defined similarly as those in Eq. (23).

Similar with the concept introduced in [10], we consider a central bank-based model which keeps an account of each node in our Time division multiple access-based system. The source node pays a sum of virtual money to the relaying node through the central bank when its packets are forwarded, and the relaying node receives a sum of virtual money via the central bank if this node wins out during the double auction. The virtual money of each node recorded in the central bank can be used to purchase relay service from other nodes. If source node j wins out, the PayOff (PO) can be expressed as:

$$PO_j = I_j - I_j^{bid} \quad (25)$$

If relaying node i wins out, the payoff will be:

$$PO_i = L_i^{ask} - L_i \quad (26)$$

The virtual money of each node in the central bank will be updated according to (25) and (26).

From an economic point of view, a market will be prosperous if the participants are able to gain satisfying income and then are more eager to engage into the trades. Therefore, the objective of the Trust-based Social-aware Relay Assignment (TSRA) scheme is to maximize the value of Social Welfare (SW), which can be calculated by:

$$SW = \sum_{i \in V} \sum_{j \in V} (PO_i + PO_j) \quad (27)$$

After finishing conducting the TSRA scheme, the next-hop node for packet delivery can be determined. If the next-hop node is not the final destination, the packet forwarding will continue by the selected node, until the packet is transmitted into the destination node.

V. SIMULATION RESULTS

In our simulation, two different network topologies, including the linear topology with 30 nodes and the random topology with 50 nodes, are considered. Some nodes are randomly selected to generate sessions to different destinations. The distance in the linear network topology between any two neighboring nodes is 100 meters. In the random network topology, 50 nodes are arbitrarily distributed in a square region, and each side equals to 333 meters. A simple path loss channel model is considered. The channel gain is expressed as $G_{i,j} = \beta_{i,j}^S \beta_{i,j}^F d_{i,j}^{-\nu}$ [12], where $d_{i,j}$ is the Euclidean distance between nodes i and j , and ν is the path loss factor set to 4. $\beta_{i,j}^S$ and $\beta_{i,j}^F$ are the gains that correspond to channel fluctuations caused by large-time-scale shadowing and small-time-scale channel fading, respectively. Without loss of generality, the shadowing gain is assumed to be a constant value, and the small-scale fading gain is normalized to a random value with unit mean. The SINR threshold γ is set to 2.5, and bandwidth W equals to 6 MHz. The residual energy (in Joule) of each node is randomly selected during (0, 1], and the total energy of each node equals to 1 Joule. According to [13], we set $\rho = 1$, $\theta = \ln 0.1 / 12.5$, and the thermal noise is 10^{-6} mW. The weights of the three complementary social based metrics are equal and all set to 1/3, and define $\alpha = 0.4$, $\beta = \chi = 0.3$.

Double Auction for Relay Assignment (DARA), presented in [3], is utilized to compare with our TSRA scheme. It can be observed in Fig. 1 and that our presented method can achieve high percent of link connection. The reason behind is that our scheme takes not only social relationship but also node trust into consideration, while the DARA scheme merely considers node energy.

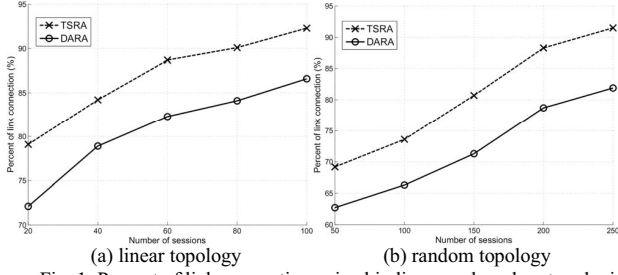


Fig. 1. Percent of link connection gained in linear and random topologies respectively.

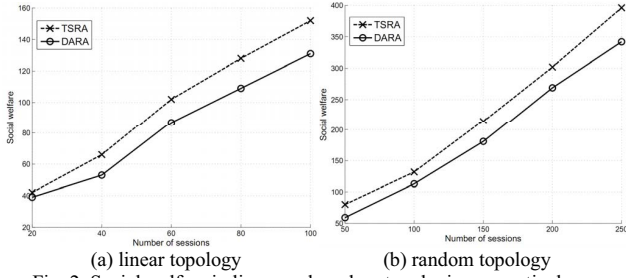


Fig. 2. Social welfare in linear and random topologies respectively.

From Fig. 2, we can see that social welfare gained by our method is higher than that by DARA. This is because comprehensive factors are jointly considered in our method, and malicious nodes, which would cause link disconnection are kicked out of our double auction scheme. Since our method is social-oriented, nodes with high relationship are encourage to exchange information, thus the obtained social welfare of our scheme is higher than DARA.

VI. CONCLUSIONS

Social relationship, node trust, energy are important factors for user assignment in Ad hoc social networks. In order to increase link connectivity and social welfare, in this paper, we jointly consider these elements and present a social-aware trust-based user assignment scheme. We first evaluate the social relationship of each node, then construct a trustworthiness management model. Furthermore, we present a double auction-based user assignment scheme basing on node social relationship and trust. Simulation results have shown that our presented scheme outperforms other methods in link connectivity and social welfare, the reason behind is that our method takes comprehensive factors into consideration instead of node energy only.

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REFERENCES

- [1] P. Velloso, R. Laufer, D. Cunha, O. Carlos, M. Duarte, and G. Pujolle, Trust Management in Mobile Ad Hoc Networks Using a Scalable Maturity-Based Model, *IEEE Transactions on Network and Service Management*, 7(3): 172-185, 2010.
- [2] F. Bao, I. Chen, M. Chang, and J. Cho, Trust-Based Intrusion Detection in Wireless Sensor Networks, *IEEE ICC*, pp. 1-6, 2011.
- [3] Y. Wang, Y. Li, C. Liao, C. Wang and X. Yang, Double Auction-based Optimal User Assignment for Multi-Source Multi-Relay Cellular Networks, *IEEE Transactions on Vehicular Technology*, 99(1): 1-10, 2013.
- [4] Z. Ning, Q. Song, L. Guo and K. Okamura, Social-Oriented Adaptive Transmission in Wireless Ad Hoc Networks, *IEEE ICC*, pp. 490-495, 2014.
- [5] M. Nitti, R. Girau, L. Atzori, A. Iera and G. Morabito, A Subjective Model for Trustworthiness Evaluation in the Social Internet of Things, *IEEE PIMRC*, pp. 18-23, 2012.
- [6] H. Xia, Z. Jia, X. Li, L. Ju and E. Sha, Trust prediction and trust-based source routing in mobile ad hoc networks, *Ad Hoc Networks*, 11(7): 2096-2114, 2013.
- [7] D. Yang, X. Fang, and G. Xue, HERA: An Optimal Relay Assignment Scheme for Cooperative Networks, *IEEE Journal on Selected Areas in Communications*, 30(2): 245-253, 2012.
- [8] I. Chen, J. Guo, F. Bao, and J. Cho, Trust management in mobile ad hoc networks for bias minimization and application performance maximization, *Ad Hoc Networks*, 19: 59-74, 2014.
- [9] Z. Wang, J. Liao, Q. Cao, H. Qi and Z. Wang, Friendbook: A Semantic-Based Friend Recommendation System for Social Networks, *IEEE Transactions on Mobile Computing*, 14(3): 538-551, 2015.
- [10] F. Hao, G. Min, J. Chen, F. Wang, M. Lin, C. Luo, and L. Yang, An Optimized Computational Model for Multi-Community-Cloud Social Collaboration, *IEEE Transactions on Service Computing*, 7(3): 346-358, 2014.
- [11] Y. Zhao, R. Adve, and T. Kim, "Improving amplify-and-forward relay networks: Optimal power allocation versus selection," *IEEE Transactions on Wireless Communications*, vol. 6, no. 8, pp. 3114-3123, 2007.
- [12] J. Zhang, S. Liew, L. Fu. On fast optimal STDMA scheduling over fading wireless channels, *IEEE INFOCOM*, 2009, pp. 1710-1718.
- [13] C.-Y. Ng and W. Yu, "Joint optimization of relay strategies and resource allocations in cooperative cellular networks," *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 2, pp. 328-339, 2007.