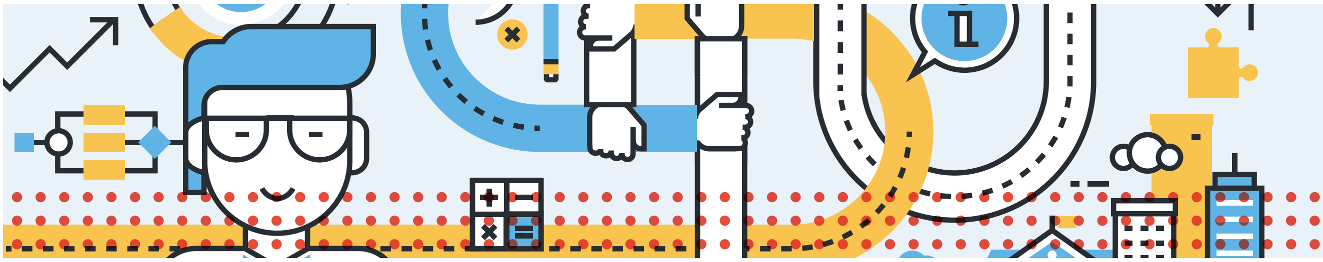

Social-Oriented Resource Management in Cloud-Based Mobile Networks

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This article presents enabling technologies for creating a blueprint for user experience-oriented resource management in cloud networks based on software-defined networking technology.

According to the 2015 *Ericsson Mobility Report*, the growth of mobile video traffic will reach a staggering 55 percent per year and will constitute around 60 percent of all mobile data traffic by the end of 2020, largely driven by shifting user preferences toward video streaming services.[1] The ever-increasing number of network terminals and the huge amount of data traffic create an urgent need for changing how we manage resources in wireless networks. Deploying clouds in mobile networks can mitigate the resource limitations of mobile facilities to some extent. However, existing cloud-based schemes increase network complexity and can't operate effectively without modifying current IP-based network elements[2] (see the "Current Work in Resource Management in Cloud Networks" sidebar).

Software-defined networking (SDN) separates the control plane from the data plane, further shielding network heterogeneity by abstracting the control plane. The study of wireless SDN has attracted significant attention. However, coupling the wireless environment with individual heterogeneity brings more challenges to cloud-based mobile networks.

Current cloud networks are mainly based on hybrid network structures, which have characteristics of both cellular and self-organizing networks. Traditional network resource management methods mostly focus on the network status of terminal nodes, such as link quality and quality of service (QoS). Quality of experience (QoE), however, aims to reduce the gap between perceived data and the real world by considering users' feelings.

Wireless terminals frequently reflect human consciousness, with social associations having similarities to user behaviors. Because individuals dynamically join and leave the network and are likely to forward packets to clients with whom they have

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CURRENT WORK IN RESOURCE MANAGEMENT IN CLOUD NETWORKS

As cloud-based self-organizing networks become widely utilized in metropolitan area networks, researchers are focusing on solutions that guarantee heterogeneous users network access and the ability to manage their network resources to improve performance.

Social-Associated Resource Management

The development of wireless communication technology has accelerated the combination of mobile and social networks. Users aren't merely terminals for acquiring information, they're also relays for message delivery. Therefore, social association is essential in resource distribution.

The social cloud paradigm exploits the cloud's computing ability.[1] Researchers have also combined real-world social graphs with structures of social traces to discover social relationship among clients. Some have advocated collaboration within the cloud community to allow clients to utilize spare resources in the cloud. For example, Fei Hao studied a multi-community cloud-based model for collaboration with multiple optimization objects, and designed a comprehensive scheme for selecting the best group in community clouds.[2] However, they ignored the dynamics of users joining and leaving the network, which would cause end-to-end information missing during packet routing.

Because of the numerous interconnections among wireless terminals, we need to study user behavior through information mining, so we can analyze and evaluate the deployed network effectively.[3] Most load-balance-based resource management strategies assume that users join or leave the network independently. However, data collection conducted on campus illustrates that this assumption doesn't hold.[4] Lei You and his colleagues studied a periodical time-aware movement model by extracting the movement pattern from node records and presented a movement pattern-aware routing scheme for social delay tolerant networks.[4]

Quality of Experience-Oriented Resource Management

As organizations increasingly migrate applications to the cloud, quality of service (QoS) has become a significant consideration among providers, especially for mobile operators. Beyond QoS, quality of experience (QoE) describes users' real experiences, and transmissions with high QoE can significantly shorten the gap between perception data and the real world. Miha Rugelj and his colleagues proposed a QoE-based scheme for resource allocation that aims to combine the variables in the application layer with human subjective perception, so users can access the network effectively.[5] Elsewhere, a survey of QoE-based studies in the cloud suggests directions for the development of future cloud services with QoE requirements.[6]

Since user experience contains many kinds of subjective and objective network information, data dimensions and network complexity rise sharply as network size scales. These features make the integrative description of QoE challenging. To improve user experience when network resources are constrained, Bruno Nunes and his colleagues studied a QoE-based routing mechanism using a reinforcement-learning mechanism.[7] Wu-Hsiao Hsu and Chi-Hsiang Lo investigated a model to map and adjust QoS to QoE by employing a simulated streaming video platform to represent the cloud-based multimedia infrastructure.[8] With the objective of responding to QoE variation

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a strong relationship (that is, *social selfishness*), the dynamic and selfish features would cause denial of service and link interruption, which degrade user experience in cloud-based networks. Furthermore, although wireless network architectures aim to provide seamless and ubiquitous network access, significant differences exist among network frameworks and access patterns, so a large amount of network resources can be wasted in the absence of cooperation and sharing.

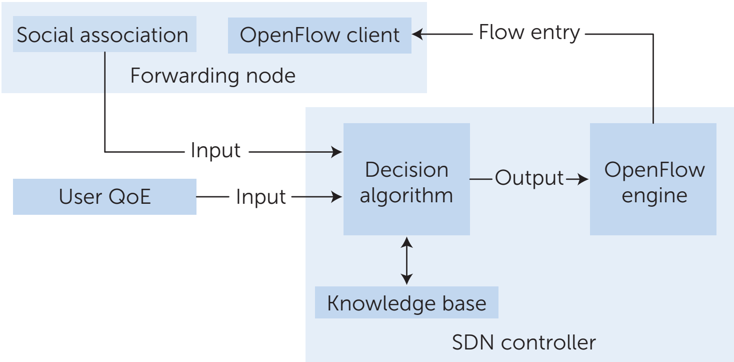

FIGURE 1. System architecture. The system takes nodes' social associations and user quality of experience (QoE) as input, and outputs the resource allocation scheme.

We present a blueprint for SDN-based resource management in cloud-based mobile networks for effective network resource management. To increase network connectivity, we use a social association-oriented forwarding scheme that considers the client's social relationship and trust in the cloud. We advocate use of a deep-learning-based mechanism for describing the user experience by uniformly integrating subjective and objective factors, letting us tightly combine the increasing data dimension and complexity as the number of clients in the cloud increases. To allow different clients to access the network effectively, we propose an SDN-based resource management method for cloud-based mobile networks that increases the node communication area.

Enabling Technologies

Figure 1 shows the system architecture of our user experience-oriented resource management model for SDN-based networks.

Packet Forwarding Based on Social Associations

Users' sociality and temporal-spatial complexity bring new challenges to network access and data transmission. Our opportunistic forwarding scheme considers clients' social relationships and trust.

Social-aware node cooperation. Because methods based on signal-to-interference and noise ratio (SINR) are inefficient for describing link state in complex networks, we evaluate node relationships from network density, link quality, and community characteristics, which correspond to neighborhood node friendship, associated node friendship, and community node friendship, respectively. The friendship of neighboring nodes for node j is the weighted average ratio between the number of packets to be conveyed from node j' to j and the total number of packets transmitting from other nodes received by node j, where j' is an arbitrary node in the network. The friendship of associated nodes for node j is the normalization of the SINR value. The friendship of community nodes for node j is the community's estimated node communication ability, which is the proportion of total nodes that are associated nodes. The social relationship of node $j(\varphi_j)$ is a weighted sum of these three complementary metrics.

We also evaluate node trust, which we calculate according to feedback stored by other nodes to reflect node reputation. This is because trust is a critical element of cooperative transmission, since malicious nodes would misdirect other nodes and degrade network performance. The trustworthiness of node j evaluated by node j' is $T_{jj'}$, denoted as

$$T_{jj'} = \alpha Q_{jj'} + \beta O^{dir}_{jj'} + \chi O^{ind}_{jj'},$$

where the summation of weighting factors equals 1. Node centrality is represented by $Q_{jj'}$, and $O^{dir}_{jj'}$ $O^{ind}_{jj'}$ are the direct and indirect experiences of node j from neighboring node j', respectively.

Node centrality measurement aims to prevent malicious nodes from obtaining high centrality values by constantly constructing relationships. We define the centrality of node j as the percentage difference between the common number of friends of nodes j and j' and the number of friends of node j only. To determine the direct experience of trustworthiness, node j forms an opinion according to the combination of short- and long-term opinions. We stress the effectiveness of short-term opinion. Thus, the corresponding weighting factors are $\log(W_{jj'} + 1)/1 + \log(W_{jj'} + 1)$ and $1/1 + \log(W_{jj'} + 1)$ for short- and long-term opinions, respectively, where $W_{jj'}$ is the total number of transactions between nodes j and j'. The long- and short-term opinions consider node feedback and the corresponding priorities to distinguish important transactions from insignificant ones. The indirect experience contains user credibility and the interactions between node j and other nodes (except node j').

Because terminal nodes are socially selfish, the incentive mechanism for link connection is important. If we regard the relay service as a commodity, and the source and relay nodes as buyer and seller, respectively, we can formulate the social-aware user assignment problem using a double auction mechanism. Our mark-up selection considers nodes' social relationships and trust. Driven by economic profit,

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in a timely manner, they proposed a genetic-based scheme to regulate the diffserv-aware multicast tree. However, because these works mainly focused on network characteristics (such as routing or handoff control), studies on social association and QoE integrative description are insufficient.

SDN-Based Resource Management

One of the key challenges in cloud networks is guaranteeing that different clients obtain satisfactory network services. However, users' requirements, preferences, and social attributes vary a lot, highlighting the urgent need for changing resource management patterns in cloud-based mobile networks.

SDN and network function virtualization (NFV) are viewed as key technologies for resource management in cloud-based networks. Robert Szabo and his colleagues demonstrated that SDN- and NFV-based architectures can support elastic resource services from the cloud.[9] Under current network architectures, cloud differences require various kinds of software protocol stacks, and they're generally not compatible. Ricardo Matos and his colleagues presented an SDN-based scheme to control node cooperation and studied the sharing mechanism in user-centric networks by considering network load and QoS.[10] Wei-Cheng Liao and his colleagues studied a software-defined radio access technology for resource allocation, which aims to maximize the minimum transmission rate.[11] Chenchen Yang and his colleagues describe the development of information-centric networks, cloud computing, and SDN.[12] However, research comprehensively studying user QoE and social association in SDN-based cloud networks is far from enough.

Possible Solutions for Future Challenges

As this discussion suggests, many theoretical vacancies in user-centric wireless resource management in cloud-based mobile networks still exist. Furthermore, current studies don't harmonize well with each other. We therefore suggest some possible solutions to future challenges. First, to increase link connections, we advocate an opportunistic forwarding scheme by considering the social relationship and trust of clients in the cloud. In addition to QoS, user subjective and objective QoE information should also be acquired and refined. The deep learning-based method is promising for describing this information comprehensively. Finally, by considering users' social associations and QoE requirements, SDN-based resource management could satisfy the requirements of user access and resource sharing in the cloud with timeliness and high efficiency.

References

1. A. Mohaisen et al., "Trustworthy Distributed Computing on Social Networks," *IEEE Trans. Services Computing*, vol. 7, no. 3, 2014, pp. 333–345.
2. F. Hao et al., "An Optimized Computational Model for Multi-Community-Cloud Social Collaboration," *IEEE Trans. Services Computing*, vol. 7, no. 3, 2014, pp. 346–358.
3. Y. Wang et al., "Double Auction-Based Optimal User Assignment for Multi-Source Multi-Relay Cellular Networks," *IEEE Trans. Vehicular Technology*, vol. 99, no. 1, 2013, pp. 1–10.
4. L. You et al., "MPAR: A Movement Pattern-Aware Optimal Routing for Social Delay Tolerant Networks," *Ad Hoc Networks*, vol. 24, part A, 2014, pp. 228–249.
5. M. Rugelj et al., "Novel Cross-Layer QoE-Aware Radio Resource Allocation Algorithms in Multiuser OFDMA Systems," *IEEE Trans. Comm.*, vol. 62, no. 9, 2014, pp. 3196–3208.
6. P. Casas and R. Schatz, "Quality of Experience in Cloud Services: Survey and Measurements," *Computer Networks*, vol. 68, no. 11, 2014, pp. 149–165.
7. B. Nunes et al., "Software Defined Networking Enabled Capacity Sharing in User-Centric Networks," *IEEE Comm. Magazine*, vol. 52, no. 9, 2014, pp. 28–36.
8. W. Hsu and C. Lo, "QoS/QoE Mapping and Adjustment Model in the Cloud-based Multimedia Infrastructure," *IEEE Systems J.*, vol. 8, no. 1, 2014, pp. 247–255.
9. R. Szabo et al., "Elastic Network Functions: Opportunities and Challenges," *IEEE Network*, vol. 29, no. 3, 2015, pp. 15–21.
10. R. Matos et al., "Quality of Experience-Based Routing in Multi-Service Wireless Mesh Networks," *IEEE Int'l Conf. Comm.* (ICC 12), 2012, pp. 7060–7065.
11. W. Liao et al., "Min Flow Rate Maximization for Software Defined Radio Access Networks," *IEEE J. Selected Areas in Comm.*, vol. 32, no. 6, 2014, pp. 1282–1294.
12. C. Yang et al., "When ICN Meets C-RAN for HetNets: An SDN Approach," *IEEE Comm. Magazine*, vol. 53, no. 11, 2015, pp. 118–125.

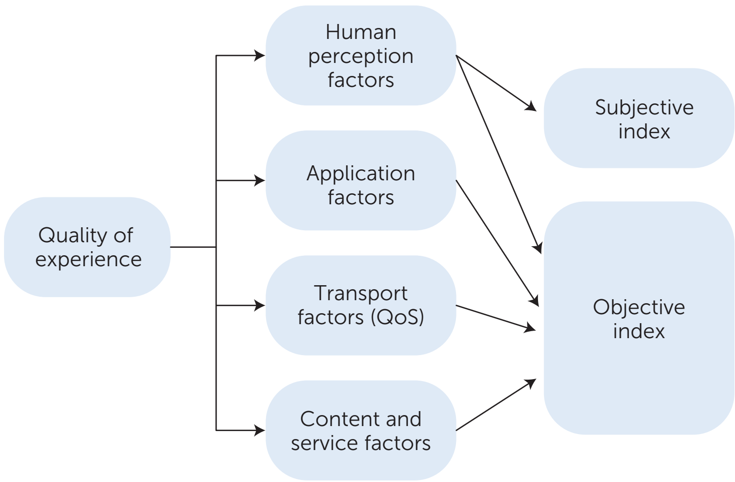

FIGURE 2. Schematic of the QoE model. The model defines four types of factors, which correspond to subjective and objective indexes.

buyer j will bid a lower price than the commodity's actual value, and seller i will ask a higher price than its real cost. Because the traders in the market possess a greedy nature, the source node j would bid as $I_j^{bid} = I_j e^{-m_j}$. The buyer's markup, m_j, combines social relationship, residue energy ratio, and node trustworthiness factors.

If the potential relay node has insufficient energy, it might refuse to provide service to other nodes, since its own communication is the primary task. Otherwise, if the relay node has a strong social relationship and high trustworthiness, many source nodes would bid to purchase its relay service. Therefore, it could ask a higher price than the actual value. The relay markup is $L_i^{ask} = L_i e^{m_i}$, and m_i is defined similarly to m_j.

If source node j wins the double auction, its payoff (PO_j) is the difference between I_j and I_j^{bid}. Otherwise, PO_j is the gap between L_i^{ask} and L_i. We define the social welfare (SW) value as

$$SW = \sum_{i \in V} \sum_{j \in V} \left(PO_i + PO_j \right).$$

Thus, node selection in social-association-based cooperation involves maximizing the total social welfare value.

Opportunistic forwarding. Because the movements of wireless terminals are largely influenced by their social relationships, some correlations exist in the disciplines of spatial information and moving. To avoid load imbalance and link connection failures caused by nodes massively entering or leaving the network, we assign nodes with high social relationship to different access networks. Given n users to connect with m access nodes, with each user having a corresponding throughput requirement, the problem becomes one of maximizing social welfare while guaranteeing load balance in bandwidth-constrained networks. The objective is to promote social welfare by stimulating relay node forwarding packets, and thus enhance link connectivity and user QoE. Because this problem is known as NP-complete, we could use bionic algorithms, such as the ant colony algorithm and firefly algorithm, to solve it through approximation.

QoE Integrative Description

Because of network heterogeneity and complexity, QoS-based studies can't accurately describe the quality of the received information and users' feeling. Thus, the integration of user subjective perception and objective description has important research significance.

As Figure 2 shows, human perception factors include both objective indexes (information, service, and content factors) and subjective indexes (expression factor) for individual experience description. Objective QoE depicts the corresponding indexes that can be described explicitly, for example, human objective cognitive factors (QoE expectation, user priority, and so on), and terminal evaluation (service effectiveness, comfort level, and so on). Only this layer contains subjective factors for user QoE. Content and service factors refer to the construction of communication requests and network condition predictions. This layer mainly includes service depictions (such as transmission type and service level) and standard QoS parameters (such as throughput and bandwidth). The transport layer's core objective is to ensure transmission quality. The relevant network parameters can be classified into three types:

- basic network parameters, such as access technology, bandwidth, and transmission time;
- other parameter types, such as factors affecting communication progress (transmission delay, buffer queue, and so on), the node-level strategy, and other operations; and
- complex parameters, which denote the network factors to be codetermined by basic and other types.

User QoE factors generally include structured and semistructured data, and both data dimension and network complexity increase as the network expands, complicating the integrative presentation of QoE. Although researchers have successfully ap-

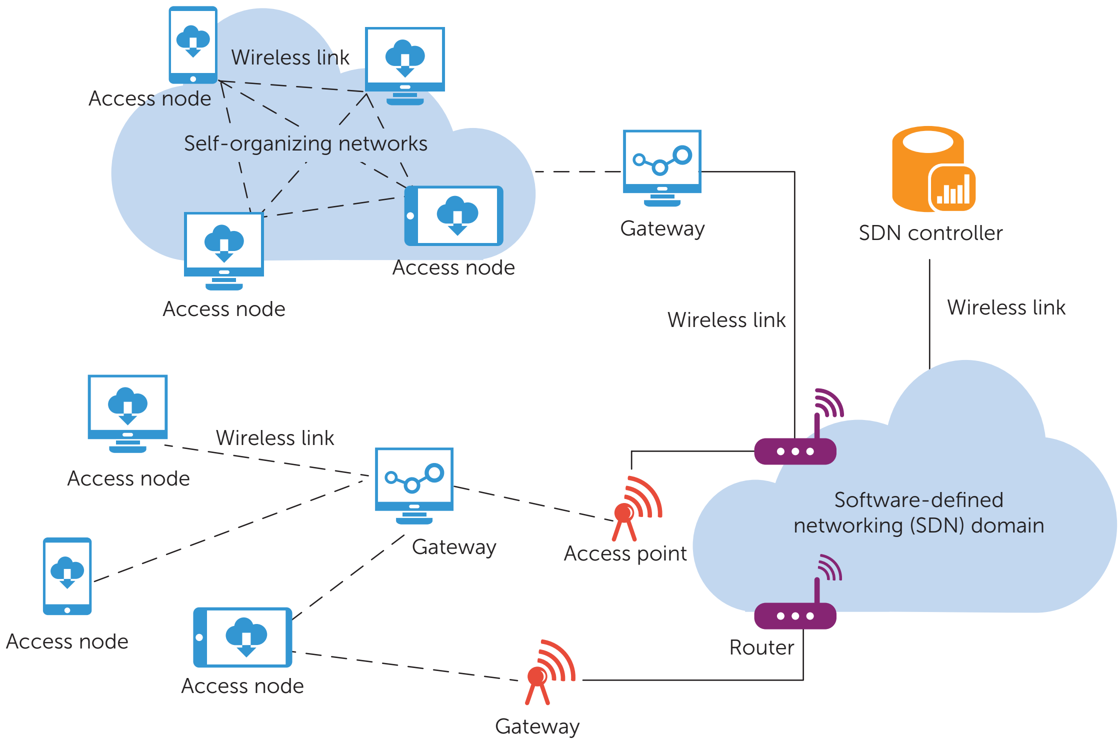

FIGURE 3. The software defined networking (SDN)-based resource-sharing model. This model can increase the communication coverage from infrastructure-supported networks to other networks without strong link connectivity.

plied the deep learning method in natural language processing, this method can't effectively extract the characteristics of heterogeneous data. We intend to associate heterogeneous data through tensor and its operation in the data layer, utilize unsupervised patterns to learn user QoE features, and construct a tensor-based high-order automatic coding machine model to integrate user QoE information.

To do so, we use a tensor-based representation method to model the nonlinear correlations of the heterogeneous data from multiple sources. Next, we devise a deep computation model based on data integration to learn the hierarchical features of QoE information. In the proposed model, we design a high-order back-propagation algorithm for parameter training. To efficiently learn the obtained data's features in the dynamic environment, we investigate an incremental deep computation model by devising some novel incremental learning algorithms, such as parameter-based and structure-based incremental learning algorithms.

SDN-Based Resource Management in the Cloud

Based on the studies described earlier, we use SDN-based technology to manage resources in the cloud. Our main idea is to extend the communication coverage from current infrastructure-supported networks (for example, wireless LANs and cellular networks) to terminals in other access networks, whose capacity might not be strong enough to provide high link connectivity.

SDN-based node access. SDN controllers collect network state information periodically, determine the appropriate access network, and select the corresponding resource-distribution method. Since network information is crucial for user judgment, current SDN standards (such as OpenFlow) mainly use port and queue statistics to estimate available bandwidth. By transmitting statistics to controllers via a gateway, the network can perform access and handoff decisions, and controllers can support periodic information queries from SDN-based devices. Therefore, we set network measurement factors (such as throughput and retransmission time) as system input, combining the knowledge acquired by SDN controllers (such as topology and social association). The output is conveyed to the OpenFlow engine, and the information is fed back to data-forwarding devices. We intend to employ an access

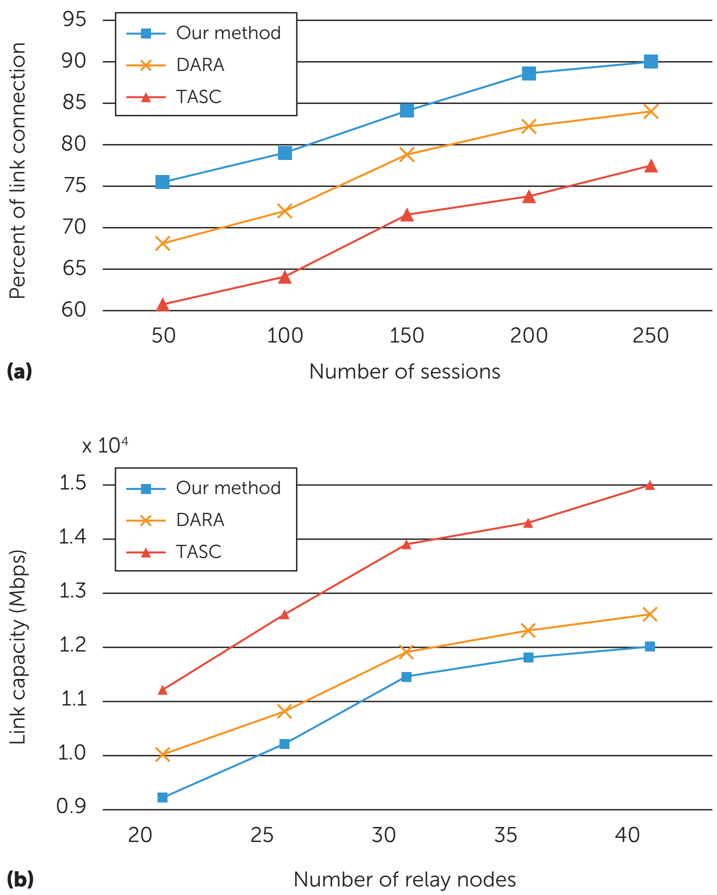

FIGURE 4. Results of the performance evaluation: (a) percent of link connection gained in the network; and (b) comparison of link capacity with varying numbers of relay node.

node to perform rapid and transparent handoff using SDN technology. By instantiating the SDN switches of access nodes, connecting the virtual interfaces, and mapping these interfaces to the gateways, we formulate the interaction between virtual interfaces and gateways as a two-way selection problem.

Resource sharing in SDN-enabled networks. Users access the network through gateways, which can be either user terminals or an access node equipped with an SDN controller. Figure 3 shows the corresponding network resource-sharing model.

Gateway nodes can be divided into three layers: node characteristic description model, SDN-enabled converter, and network interface. Node characteristics include its social association and QoE features, which can support packet forwarding decisions. The SDN-enabled converter includes an OpenFlow user instance and SDN-based equipment. Access nodes in the network interface are terminals that provide service and maintain link connectivity. Access nodes don't contain SDN-enabled converters since data forwarding is unnecessary.

The resource-sharing network model aims to increase communication coverage, guaranteeing network connectivity and user QoE with a scalable and high-efficiency pattern. To exploit existing network infrastructures, access nodes can join the network in the form of a gateway via the SDN-enabled user terminal equipment. If the access node is in the self-organizing network, the node can deliver information to the gateway through multihop transmission and receive notifications through the transmission route defined by the network controller.

We believe two schemes are promising for analyzing performance in the SDN-based resource-management scheme. In the first, we integrate mobile and distributed self-organizing networks with the centralized SDN control model. Cluster nodes then select a head node according to the network topology, load, and computational capacity. In the second scheme, we use the centralized control in the SDN control plane, where the controller informs node channel state and transmission pattern, and the data plane adopts a distributed control strategy.

Performance Evaluation

We conducted preliminary simulations to guide future work. We consider a random topology with 50 nodes, where some nodes generate sessions to random destinations. These nodes are distributed arbitrarily in a 333 meter × 333 meter-square region, and move randomly at rates between 0 and 10 meters per second. We can view the considered network as part of the campus environment, and assume the path loss channel model. The weights of the social association-based metrics are equal and all set to 1/3, and we define the weights of node centrality and direct and indirect experiences as 0.4, 0.3, and 0.3, respectively.

We chose double auction for relay assignment (DARA)[3] and truthful auction scheme for cooperative (TASC) communication[4] for comparison, since they're the two main representative schemes for resource management introduced in recent years. As Figure 4a demonstrates, our method obtains the highest percentage of link connection. This is because it comprehensively considers social relationship, node energy, and trust. Furthermore, it stimulates node cooperation, and the commodity value dynamically fluctuates according to the supply-demand relationship. However, DARA merely considers node energy, and TASC sacrifices many potential trades for fear of market manipulation.

Figure 4b compares link capacity among different algorithms. As the figure shows, link capacity increases as the number of relay nodes increases. More opportunities exist as more relay nodes are dedicated to packet forwarding, so source nodes don't need to compete with each other for relay nodes. By allocating network resources to different clients according to their characteristics (such as social relationship, user requirement, and trust), we can ameliorate overall network performance.

Our future will have two areas of focus. First, we intend to investigate a framework to jointly optimize network resources in the domains of time, frequency, and space using SDN-based technology. In addition, we'll attempt to construct a real network platform under practical circumstances following the scheme presented in this article. Furthermore, how to describe network heterogeneity more accurately requires further study.

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References

1. Ericsson Mobility Report: *On the Pulse of the Networked Society,* Ericsson, June 2015; www.slideshare.net/Ericsson/ericsson-mobilityreportjune2015.
2. J. Wan et al., "Context-Aware Vehicular Cyber-Physical Systems with Cloud Support: Architecture, Challenges, and Solutions," *IEEE Comm. Magazine*, vol. 52, no. 8, 2014, pp. 106–113.
3. Y. Wang et al., "Double Auction-Based Optimal User Assignment for Multi-Source Multi-Relay Cellular Networks," *IEEE Trans. Vehicular Technology*, vol. 99, no. 1, 2013, pp. 1–10.
4. D. Yang, X. Wang, and G. Xue, "Truthful Auction for Cooperative Communications," *Proc. 12th ACM Int'l Symp. Mobile Ad Hoc Networking and Computing* (MobiHoc), 2011, pp. 89–98.

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