A Joint Handoff and Offloading Decision Algorithm for Mobile Edge Computing (MEC)

Wahida Nasrin and Jiang Xie
The University of North Carolina at Charlotte
Email: {wnasrin, Linda.Xie}uncc.edu

Abstract*—The main feature of Mobile Edge Computing (MEC) is to push computational resources and storage to the network edges (e.g., cellular base stations (BSs)) in order to offload computation-intensive and latency-sensitive applications from mobile devices. However, the deployment of MEC with a BS adds extra traffic to the already crowded cellular network that may lead to a radio congestion. On the other hand, user mobility triggers handoffs (HOs) not only between two BSs but also between two MECs, which creates new unique challenges of performing HOs to a target BS with an MEC which must have sufficient computational resources. Unfortunately, existing HO decision algorithms for traditional cellular networks cannot address these challenges. In addition, the radio network congestion issue is being utterly ignored. In this paper, we propose a novel HO decision algorithm for MEC systems that cooperates both radio and computation offloading. The proposed HO decision algorithm cooperates with femtocells to reduce the effect of radio congestion by offloading static traffic. It also cooperates with the remote cloud to reduce the impact of congestion at the MEC by offloading delay-tolerant computation. Simulation results show that our proposed HO decision algorithm significantly improves the offloading success and the service failure rates. To the best of our knowledge, this is the first HO decision algorithm that addresses both radio and computation offloading issues and mobility together in MEC systems.

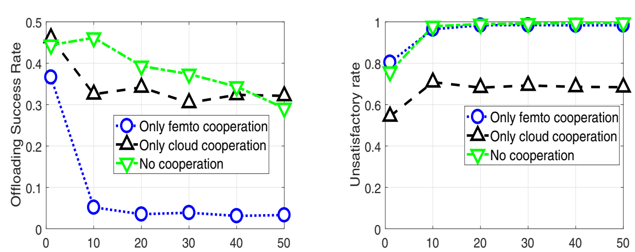
I. Introduction

As mobile devices are resource-constrained (limited computational resources and energy), offloading computational tasks to the cloud has become the most promising solution to support the resource-hungry mobile and rapidly-growing Internet of Things (IoT) applications. However, the remote execution of offloaded data in the cloud brings challenges to satisfy the delay requirement of end users because of the long transmission and offloading delay over the Internet. Recently, edge cloud technologies (e.g., Mobile Edge Computing (MEC) and cloudlet) are introduced to address these challenges of the remote cloud [1]. The concept of edge clouds is to bring the cloud closer to users to reduce the delay of offloading and to provide computational resources and storage closer to mobile users. For example, MEC enables end users to access cloud computing services within the range of Radio Access Networks (RAN), and each MEC is usually deployed with a cellular base station (BS) [1].

However, the deployment of an edge cloud with a BS introduces new research issues. First, though offloading computation tasks to the MEC solves the problem of limited resources for mobile devices and delay requirements for end users, this creates radio congestion by adding more traffic to the already crowded cellular network. Therefore, how to manage the excess traffic becomes an important issue. Second, unlike the remote cloud, the MEC has limited computational resources. How to efficiently assign these limited computational resources is another foremost issue. Third, if the allocation of radio resources and computational resources is not considered jointly, the congestion of computational resources may lead to the waste of radio resources and vice versa. Fourth, unlike in traditional cellular networks, the mobility of users triggers handoffs (HOs) not only between two BSs but also between two MECs. Therefore, how to migrate unfinished-computation due to user mobility is another critical issue.

This work was supported in part by the US National Science Foundation (NSF) under Grant No. 1718666, 1731675, 1910667, and 1910891.

Although extensive research has been conducted on resource allocation and offloading decisions in MEC systems, the mobility management issues along with the offloading issues have been utterly ignored. Most papers on joint resource allocation in MEC systems considered both radio and computational resources together [2], [3]. However, the available resources are assumed to be used by users only with computation traffic in these papers, which is not true for MEC because both communication and computation traffic need the radio resources to perform their operations, and delay-sensitive communication traffic should have a higher priority than the computation traffic. For example, a user with a voice call should be given a higher priority than a video game player. In addition, the mobility issue is ignored in existing papers when designing computation offloading decisions. An offloading decision without considering user mobility may cause an offloading failure. Similarly, an HO decision without considering offloading decisions may cause several unnecessary HOs. Moreover, existing HO decision algorithms for traditional cellular networks cannot be directly applied to MEC systems because, in MEC systems, the radio connection from a user to both the BS and the MEC changes when the user moves out of a cell. As a result, the user must perform an HO to a target BS with an MEC which has enough computational resources to perform the rest of the computation.



(a) Successful offloading (b) Unsatisfactory rate

Fig. 1. The rate of successful computation offloading and user's unsatisfactory rate.

In order to illustrate the effect of applying traditional HO

978-1-7281-0962-6/19/$31.00 ©2019 IEEE

decision algorithms to MEC systems, we have conducted simulations of an MEC system, and results are shown in Fig. 1 as the rate of successful computation offloading and user's unsatisfactory rate. Here, the first term represents the probability of successfully offloading a computation task and the later represents the probability of an offloaded task fails to meet the delay requirement (the details of the simulation setup are given in Section IV-A). From the figure, we observe that traditional HO decision algorithms, even with radio offloading to femtocells and computation offloading to the remote cloud, can only offload less than 50% of the requested computation traffic successfully and have a high unsatisfactory rate that indicates a large number of offloading failures. Therefore, we need a new HO decision algorithm along with proper offloading decisions to address the issues causing these offloading failures.

In this paper, we propose a new HO decision algorithm for MEC systems. The proposed algorithm is designed in a way that it can improve the Quality-of-Service (QoS) for both radio access networks and MEC systems. We incorporate both *radio offloading* and *computation offloading* decisions in our proposed HO decision algorithm. The *radio offloading* is incorporated to reduce the effect of increased traffic in cellular networks due to the addition of computation traffic. This offloading allows users to perform HOs to a proper small-cell network, e.g., femtocells, to avoid traffic congestion [4]. In addition, in our proposed HO decision algorithm, different priorities for users are considered to better serve the delay requirement and user mobility. Similarly, the cooperation with the remote cloud is also considered to reduce the computation offloading failure rate. Our proposed HO decision algorithm can increase the rate of successful computation offloading, reduce the rate of HO failure, and reduce the computational migration costs.

The rest of the paper is organized as follows. System model and contributions of the paper are described in Section II. The proposed HO decision algorithm is presented in Section III. In Section IV, the performance evaluation is given, followed by the conclusions in Section V.

II. System Model and Contributions

A. System Model

We consider a computation offloading system that includes multiple MECs deployed with macro BSs, multiple femtocells, multiple users, and a remote cloud. The system model is shown in Fig. 2. In the system, all macro BSs, MECs, and the remote cloud are deployed by the same service provider [1]. Each MEC is co-located with a macro BS. Each macrocell contains multiple femtocells within it. The coverage area of each femtocell is much smaller than the coverage area of a macrocell. Femtocells can serve less number of users and they share the same spectrum band with the macrocell.

In the system, each MEC can be accessed via cellular channels from the macrocell, while the remote cloud can be accessed over the Internet. Mobile users are connected either to a macro BS or to a femto BS based on their priorities and resource availabilities at the BS. The details of the priority selection are given in Section III-A. Each user can offload its computation tasks to the remote cloud while connected to a femto BS. On the other hand, whether to offload to the MEC or to the remote cloud is decided based on the resource availability while users are connected to the macro BS.

B. Contributions

In this paper, we propose a novel HO decision algorithm for MEC systems considering both radio and computation offloading issues for mobile users. The contributions of this paper are summarized as follows:

- We propose a joint HO and offloading decision algorithm for MEC systems for the first time. In our proposed algorithm, we assigned priorities to different users based on their speeds, delay requirements, and traffic conditions of both the radio network and the MEC system.
- We propose to cooperate with femtocells to reduce the effect of radio congestion and with the remote cloud to reduce the impact of congestion at the MEC.
- We use a realistic simulation scenario to evaluate the performance of our proposed algorithms in terms of the rate of MEC offloading success, the rate of HO failure, and service migration cost. We also compare our proposed algorithm with three HO and offloading decision algorithms.

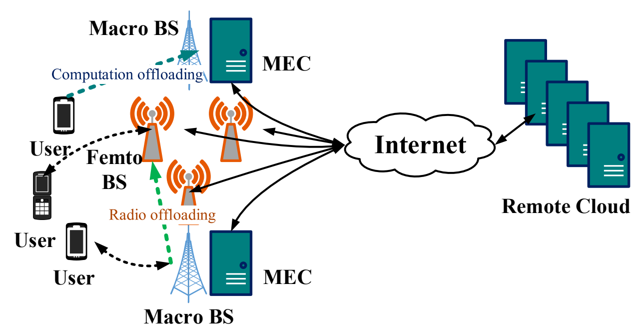


Fig. 2. A femtocell-deployed cellular network with MECs and the remote cloud.

III. Proposed HO Decision Algorithm

In this section, we present our proposed HO decision algorithm which incorporates the radio and the computation offloading decision algorithms. These algorithms are executed at the serving BS [5]. Now, a BS can only get the information of available computational resources at the MEC which is deployed with it during the offloading and HO decision phase. However, additional information of the target MECs is required to perform an offloading during an HO. Moreover, the BSs (or MECs) do not have a direct connection with each other. Therefore, coming up with a single solution to address both HO and offloading problems is challenging.

Here, we first propose a solution to assign priorities to users based on their speeds, delay requirements, and traffic conditions of the network. Then, we propose a joint HO and offloading decision algorithm for mobile users which incorporates the radio and computation offloading decision algorithm.

A. Users' Priority Assignment

Users' priority is assigned based on three parameters: user speed, delay requirement of the computation task, and resource availability at the BS and at the MEC. Our main goal is to avoid three crucial issues in the MEC deployed cellular networks, which are (a) to meet delay requirements of the offloaded computation task; (b) to pay attention to radio network congestion; and (c) to reduce unnecessary HOs, therefore, unnecessary service migration.

We consider that there are N users, each has a computation task with different delay requirements and different speeds. Users with task i and speed j arrive at the BS in a Poisson process with the average arrival rate of λ_i. Now, each of these users has a task with a delay requirement $T_i (i = 1, 2, \ldots, N)$ and the user speed is $S_j (j = 1, 2, \ldots, N)$. To rank these users according to their delay requirements, we need to get the delay requirement vector as $T = (T_1, T_2, \ldots, T_N)$, where the ranking is $T_1 < T_2 < \cdots < T_N$. We consider the user with a computation task that has the lowest delay requirement as the highest priority user to offload to the MEC. Therefore, the computation priority of the user is given as:

$$P_{comp} \in \{P_{T1}, P_{T2}, \ldots, P_{TN}\}, \tag{1}$$

where $P_{Ti} \propto \frac{1}{T_i}$ and $P_{T1} > P_{T2} > \cdots > P_{TN}$.

Similarly, to rank the user according to their speed, we first get the speed vector as $S_j = (S_1, S_2, \ldots, S_N)$, where $S_1 < S_2 < \ldots S_N$. Now, to assign the radio priority, we consider the user with the lowest speed has the highest priority to perform HO to the femto BS. Therefore, unnecessary HOs caused by the connection of high-speed users to the femto BS can be avoided. Since femto users can only offload computational tasks to the remote cloud, the user with the lowest speed has the lowest priority to offload computational tasks to the MEC. The priority for a speed j can be assigned as $P_{Sj} \propto S_j$. The radio priority is:

$$P_{radio} \in \{P_{S1}, P_{S2}, \ldots, P_{SN}\}, \tag{2}$$

where $P_{S1} < P_{S2} < \cdots < P_{SN}$.

Besides the issues of delay requirements and unnecessary HOs, we address another important issue of resource unavailability in designing HO and offloading decisions. As the serving BS makes a decision based on the measurement report from the UE, the information of available resources at the target cell is unknown to the serving BS during the decision phase. Without this information, the serving BS might need to select a different target cell when an HO or an offloading is not succeeded in the HO execution phase, which will cause a delay in the HO or offloading process. To avoid this issue, we assign weight values to both radio and computational resources based on the communication traffic at the serving BS. Thus, the weight values of the radio and the computational resources can be obtained as $W_r = \frac{Ch_{used}}{Ch_{total}}$ and $W_c = 1 - W_r$, where Ch_{total} represents the total available radio channels at the serving BS and Ch_{used} represents the total channels occupied by the communication traffic. Then, the BS can determine the overall priority (P_u) for a user following the formula given below where a low value of P_u represents a low priority to access the MEC via a femto BS:

$$P_u = P_{radio} \cdot w_r + P_{comp} \cdot w_c. \tag{3}$$

B. Joint Handoff and Offloading Decision Algorithm

In this section, the proposed joint HO and offloading decision algorithm is presented. The block diagram of the proposed algorithm is shown in Fig. 3. It is observed in the figure that when a user moves out of a cellular coverage area, it sends a measurement report to the serving BS which contains RSSIs from the serving macro BS, neighboring macro BSs, and femto BSs, their cell IDs, and user speed. The HO decision block at the serving BS in the figure decides whether to perform an HO to a macro BS or to perform a radio offloading to a femto BS. The target BS makes the decision whether to migrate the computation to the MEC or to the remote cloud based on the resource availability. The notations used in our algorithms are given in Table I.

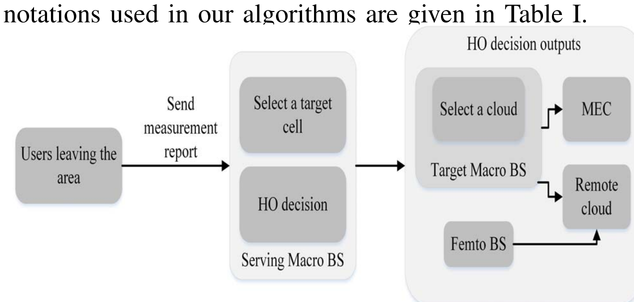


Fig. 3. A model for HO and offloading decision.

When the RSSI of the serving BS goes below a threshold, the HO is triggered. Then, after getting the measurement report from the user, the serving BS selects a target macro or femto BS. The maximum $RSSI$ of the target macrocell is used to select a target macro BS along with the priority of a user. The target cell list for macrocells is assumed to be $list_m$, and it can be obtained as:

$$list_m = \{(q, RSSI_{targ}(q)) : RSSI_{targ}(q) > RSSI_{min}\}, \tag{4}$$

where q is the cell ID for the target macro BS and $q \in \{1, 2, \ldots, n_m\}$. Then, the target macrocell (q') can be attained as:

$$RSSI(q') = \arg\max_q (RSSI_{targ}(q)). \tag{5}$$

TABLE I
NOTATIONS USED IN THE ALGORITHMS

$RSSI_{serv}$	RSSI in the serving macrocell
$RSSI_{targ}$	RSSI in the target macrocell
$RSSI_{femto}$	RSSI in a femtocell
$RSSI_{femtoMin}$	Minimum acceptable RSSI in a femtocell
Th_{RSSI}	Threshold for the macrocell network
Th_{femto}	Threshold for the femtocell network
HM	Hysteresis margin
Th_{pr}	Priority threshold
Ch_{avM}	Available channels in a macrocell
Ch_{avF}	Available channels in a femtocell
$compRes_{avl}$	Available computational resources at the target MEC
$compRes_{req}$	Required computational resources
ϕ	Null set

During the HO decision phase, the HO decision is made based on the user priority, available channels, and RSSIs. The proposed HO decision algorithm is shown in Algorithm 1. In our proposed joint offloading and HO decision algorithm, if the target macro BS does not have enough radio resources, the serving BS requests a user to perform a radio offloading to the target femtocell, which is presented in Algorithm 2. To determine the target femtocell, the serving macrocell generates a target femtocell list, $list_f$, after getting the measurement report. The target femtocell list can be presented as:

$$list_f = \{(r, RSSI_{femto}(r)) : RSSI_{femto}(r) > RSSI_{femtoMin}\}, \quad (6)$$

where $r \in \{1, 2, \ldots, n_f\}$ represents femtocell IDs. Finally, the target femtocell (r') is selected from this list by the highest value of the RSSI as:

$$RSSI(r') = \arg\max_r (RSSI_{femto}(r)). \quad (7)$$

Algorithm 1: Joint HO and offloading decision

if $RSSI_{serv} < Th_{RSSI}$ **then**
  Select $list_m$ using (4);
  if $list_m = \phi$ *or* $P_u > Th_{pr}$ **then**
    HO to femtocell (radio offloading **Algorithm** 2);
  else
    Select a target macrocell, q', using (5);
    if $RSSI_{targ} \geq Th_{RSSI} + HM$ *and* $Ch_{avM} > 0$ **then**
      Perform HO to the target macrocell;
      Call computation offloading **Algorithm** 3;
      $RSSI_{serv} \leftarrow RSSI_{targ}$;
      $Ch_{avM} \leftarrow Ch_{avM} - 1$;
    else
      HO to femtocell (radio offloading **Algorithm** 2);
  End;
else
  Call computation offloading **Algorithm** 3;
End;

Algorithm 2: Radio offloading decision

Find $list_f$ using (6);
if $list_f = \phi$ **then**
  HO failure;
else
  Select a target femtocell, r', using (7);
  if $RSSI_{femto}(r') \geq Th_{femto}$ *and* $Ch_{avF} > 0$ **then**
    Perform HO to femtocell;
    Computation offload to remote cloud;
    $Ch_{avF} \leftarrow Ch_{avF} - 1$;
  else
    HO failure;
End;

Now, the computation offloading decision algorithm (presented in Algorithm 3) is incorporated into the HO decision algorithm. In the computation offloading decision algorithm, we migrate the rest of the computation tasks to the new MEC if resources are available, otherwise, complete the computation at the old MEC and send the result via the remote cloud. The reason behind this is that the migration of the remaining computation tasks to the remote cloud may cause more migration costs and more delay at the user's end than the transmission cost of the result via the remote cloud. As users using femtocells to offload their computation tasks only to the remote cloud, the computation offloading or the computation task migration is not an issue in this case. As a result, we can use a traditional femto-to-macro HO decision algorithm when a femtocell user moves out of the cell coverage area.

C. Determining Handoff Decision Parameters

Selecting a proper threshold while designing an appropriate HO decision algorithm is a very important issue. In our algorithms, we use multiple thresholds. How these thresholds are determined is discussed in this section.

To select the minimum RSSI for the macrocell and the femtocell networks, we use the RSSI at the cell boundary. RSSIs at different distances from the macro BS is shown in Fig. 4(a), which are calculated using Okumura-Hata propagation model [6]. The $RSSI_{min}$ is considered as the RSSI (-75dB) at 1.1km. The hysteresis margin (HM) as $5dB$ and the Th_{RSSI} as -70dB can be taken from [7]. Next, to determine the value of Th_{femto}, the ITU-R P.1238-7 indoor path-loss model is used to calculate the RSSI at the femtocell boundary (15m) in Fig. 4(b) [8]. The $RSSI$ calculation and the path-loss model for femtocells are:

$$RSSI = P_{tx} + G_f + G_u - PL, \quad (8)$$

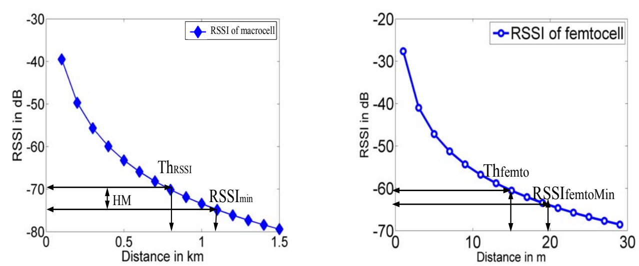
and

$$PL = 20log_{10}(f) + Nlog_{10}(r_f) + L_f(n) - a(n), \quad (9)$$

where the carrier frequency $f = 1700$ MHz assuming that the femtocell operates on the LTE radio spectrum, r_f is the radius of a femtocell, N is the distance power coefficient, L_f is the floor/wall penetration loss, $a(n)$ is the shadow fading, and n is the number of floors/walls. The minimum RSSI is taken at a 20m distance from the femto BS so that the target femtocell is selected by the time the user enters the femto coverage area.

Algorithm 3: Computation offloading decision

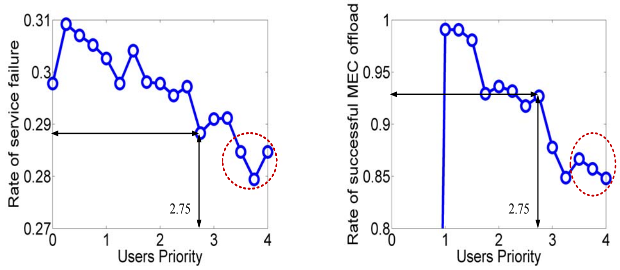
if $compRes_{req} \leq compRes_{avl}$ **then**
  Offload to the MEC;
  $compRes_{avl} \leftarrow compRes_{avl} - compRes_{req}$;
else if $P_u \leq Th_{pr}$ **then**
  Compute at the serving MEC;
  Migrate result via the remote cloud;
else
  Offload to the remote cloud;
End;



(a) $RSSI$ for a macrocell (b) $RSSI$ for a femtocell

Fig. 4. Selection of $RSSI_{min}$, Th_{RSSI}, and HM for macrocell networks, and $RSSI_{femtoMin}$ and Th_{femto} for femtocell networks.

As the priority threshold, Th_{pr}, decides the radio connection and cloud for a user, optimizing the value of the priority threshold is another important task. However, selecting a proper priority threshold is challenging because of the randomness of user mobility and the necessity of additional information of computational resources availabilities. In this section, we use two metrics to select a proper priority threshold: the rate of service failure and the rate of MEC offloading success (the definitions of these metrics are given in Section IV-A). The performance of these two metrics is presented based on the simulation results with respect to different user priorities (0 to 4) in Fig. 5. From the figures, we can observe that when the priority value is 3.75, the rate of service failure is the lowest, however, the rate of successful MEC offload presents one of the lowest values. As a result, we choose 2.75 as the priority threshold which represents the next lowest value for the rate of service failure, and the rate of successful MEC offload is above 90% for this threshold.



(a) Service failure (b) MEC offloading success

Fig. 5. Rate of Service failure and MEC offloading success.

D. MEC Service Migration Cost

In MEC systems, when a user moves out of the coverage area before the computation is completed, the computation task needs to be migrated to a new MEC. This migration adds a delay in the HO process of mobile users. We use the technique from [9], [10] to calculate the service migration cost of the MEC system, where the probability of service migration can be calculated as:

$$P_{Mig} = P(A_1 < t_1 < A_1 + T_A) \cdot P(T_{AH} > T_H) + P(A_1 < t_1 < A_1 + T_A) \cdot P(T_{AH} \leq T_A) + P(t_1 < A_1 < t_1 + T_H) \cdot P(T_H \geq T_{Ha}), \quad (10)$$

where the descriptions of the parameters are given in Table II. T_A and T_H are independent random variables, where T_A is exponentially distributed with mean $1/\eta$ and the probability density function $f_{TA}(t) = \eta e^{-\eta t}$. Similarly, T_H is exponentially distributed with mean $1/\mu$ and the probability density function $f_{TF}(t) = \mu e^{-\mu t}$. In addition, T_{AH} and T_{Ha} follow the memoryless property of the residence times, T_A and T_H, respectively. In addition, the probability density function of T_{AH} and T_{Ha} is f_{AH} with mean $1/\eta$ and f_{Ha} with mean $1/\mu$, respectively. Finally, applying the Laplace transform and solving the equation, we obtain $P_{Mig} = \frac{\lambda(\eta+\mu+\mu^2)}{(\lambda+\eta)^2(\mu+\eta)}$. Later, the migration cost can be calculated as:

$$C_{Mig} = P_{Mig} \cdot (\sum T_j^i + \sum P_i + \sum M_j^i), \quad (11)$$

where T_j^i and M_j^i are the transmission cost of a migration signaling and the migration cost between node i and j, respectively. P_i represents the processing cost of the migration signaling at node i. The value of $\sum T_j^i + \sum P_i$ are considered from [9], [10]. We calculated an average value of $\sum M_j^i$ from the simulation and results are shown in Section IV-D.

TABLE II
NOTATIONS USED IN THE SERVICE MIGRATION COST

A_1	Moment a computation task is offloaded
A_2	Moment a computation task is completed
t_1	Moment a user moves into a target cell
t_2	Moment a user moves out of a target cell
T_A	Duration of a computation at an MEC
T_{AH}	Time required to complete a computation after an HO
T_{Ha}	Time to stay at the MEC before performing an HO
T_H	Duration of staying connected to the target cell

IV. Performance Evaluation

In this section, the performance of our proposed HO decision algorithm is presented in terms of the rate of MEC offloading success, the rate of HO failure, and service migration cost. First, we introduce the settings of the scenarios in the simulation. Then, the performance of the proposed HO decision algorithm is evaluated.

A. Simulation Setup

To simulate our proposed HO decision algorithm, we use our system model shown in Fig. 2. We consider three macro BSs (each with an MEC), sixteen femto BSs placed randomly within the macrocell coverage areas, and a remote cloud. The number of users varies from 0 to 30. They are placed randomly within the macrocell and follow the Random WayPoint mobility model. We use Net Logo 6.0.1 to simulate our proposed algorithm [11]. To reduce the randomness of the scenario, we use the average of 100 simulations for each case. The values of the parameters used in the simulation are listed in Table III [7], [8], [12]–[15].

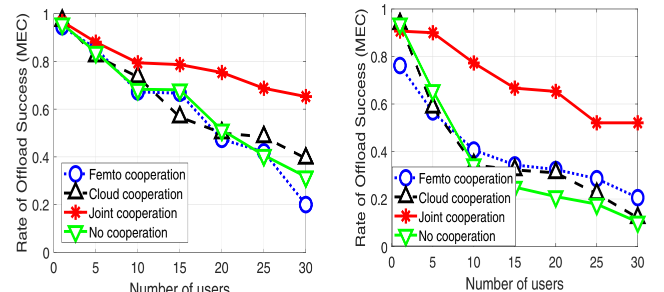
TABLE III
SIMULATION PARAMETERS

Transmission power of macro & femto BSs	45 & 15 dBm
Available channels for macro & femto BSs	100 & 10
Radius of macrocell & femtocell	1100 m & 15 m
Minimum Macro RSSI, $RSSI_{min}$	-75 dB
RSSI threshold for macrocell, Th_{RSSI}	-70 dB
RSSI threshold for femtocell, Th_{femto}	-60 dB
Priority threshold, P_u	2.75
Minimum femto RSSI, $RSSI_{femtoMin}$	-68 dB
User speed	0 to 20 km/hr

To evaluate the performance of our proposed HO decision algorithm, we investigate the following three performance metrics: 1) *Rate of MEC offloading success*: the probability of a computation task successfully offloaded to the MEC; 2) *Rate of HO failure*: the probability of service drop when a user fails to connect to the target cell; 3) *Service migration cost*: the cost of migrating a computation task from a serving MEC to a target MEC during an HO. In addition, we compare our proposed HO decision algorithm with three algorithms: *Femto cooperation*: only considers the radio offloading from the macrocell to a femtocell, *Cloud cooperation*: only considers the computation offloading that cooperates a remote cloud with the MEC, and *No cooperation*: has no cooperation of femtocells or the remote cloud. Since there is no HO decision paper available in MEC systems, we implement our proposed HO decision algorithm with these three algorithms. Moreover, we consider two worse network conditions: low availability of radio resources and low availability of computational resources.

B. Rate of MEC Offloading Success

Fig. 6 shows the results of the rate of MEC offloading success for the two worse scenarios. A low availability of radio resources and computational resources are presented in Fig. 6(a) and Fig. 6(b), respectively. In both cases, MEC offloading success rate decreases with the increment of users in the network because of the limited radio and computational resources. However, we can observe from these figures that though the availability of radio resource is low, the success rate is high in case of the high computational resource availability when the number of users is high. This is because the MEC can allocate more computational resources to each user and finish each computation task with a low computation time, therefore, support more users.



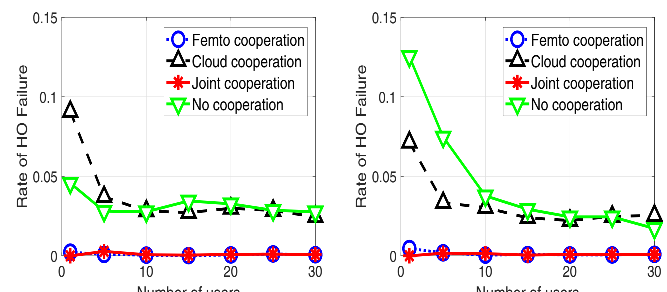
(a) Radio resource 30% and computational resource 70% available

(b) Radio resource 70% and computational resource 30% available

Fig. 6. The rate of MEC offloading success.

C. Rate of HO Failure

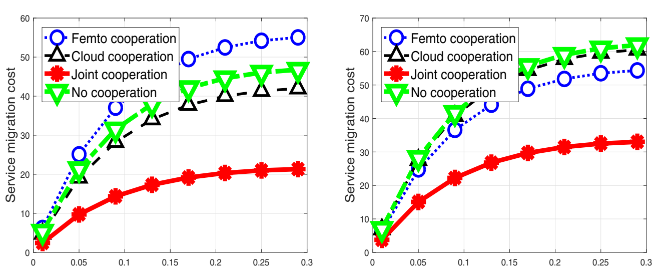
The rate of HO failure for all four algorithms is shown in Fig. 7. From the HO failure rate, we can observe that both our proposed algorithm and the algorithm with the femtocell cooperation have the lowest rate of HO failure as femtocells can offload radio traffic from the macrocell network. The algorithms without the cooperation of femtocells have a high HO failure rate. As a result, we can conclude that only cooperating the remote cloud cannot address the issue of HO failure in MEC-deployed macrocell networks.



(a) Radio resource 30% and computational resource 70% available

(b) Radio resource 70% and computational resource 30% available

Fig. 7. The rate of HO failure.



(a) Radio resource 30% and computational resource 70% available

(b) Radio resource 70% and computational resource 30% available

Fig. 8. Service migration cost.

D. Service Migration Cost

To show how much migration cost is needed for each algorithm, we present the cost of service migration in Fig. 8. It is observed in the figures that our proposed HO decision algorithm with the joint cooperation has the lowest service migration cost as compared to other algorithms. The service migration cost is calculated for an exponential offloading duration (mean $1/\eta = 3$), a residence time (mean $1/\mu = 10$), and a computation task arrival rate λ (0.1 to 0.34).

V. Conclusion

In this paper, a handoff decision algorithm that incorporates both radio and computation offloading is proposed for MEC systems. We addressed the issue of mobility management along with the issue of radio congestions. A user's priority is added to address these issues during designing the handoff and the offloading decision algorithms. Simulation results show that our proposed handoff decision algorithm increases the success rate of MEC offloading, at the same time, reduces the handoff failure rate and the migration cost as compared to other handoff and offloading decision algorithms.

References

[1] Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, "A survey on mobile edge computing: The communication perspective," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 4, pp. 2322–2358, 2017.

[2] S. Barbarossa, S. Sardellitti, and P. Di Lorenzo, "Joint allocation of computation and communication resources in multiuser mobile cloud computing," in *Proc. of IEEE Signal Processing Advances in Wireless Communications (SPAWC)*, 2013, pp. 26–30.

[3] S. Sardellitti, G. Scutari, and S. Barbarossa, "Joint optimization of radio and computational resources for multicell mobile-edge computing," *IEEE Transactions on Signal and Information Processing over Networks*, vol. 1, no. 2, pp. 89–103, 2015.

[4] D. Calin, H. Claussen, and H. Uzunalioglu, "On femto deployment architectures and macrocell offloading benefits in joint macro-femto deployments," *IEEE Communications Magazine*, vol. 48, no. 1, 2010.

[5] T. Zhao, S. Zhou, X. Guo, Y. Zhao, and Z. Niu, "A cooperative scheduling scheme of local cloud and Internet cloud for delay-aware mobile cloud computing," in *Proc. of IEEE Globecom Workshops (GC Wkshps)*, 2015, pp. 1–6.

[6] V. Erceg, L. J. Greenstein, S. Y. Tjandra, S. R. Parkoff, A. Gupta, B. Kulic, A. A. Julius, and R. Bianchi, "An empirically based path loss model for wireless channels in suburban environments," *IEEE Journal on Selected Aeas in Communications*, vol. 17, no. 7, pp. 1205–1211, 1999.

[7] W. Nasrin and J. Xie, "A self-adaptive handoff decision algorithm for densely deployed closed-group femtocell networks," in *Proc. of IEEE International Conferance on Sensing, Communication, and Networking (SECON)*, 2015.

[8] "Propagation data and prediction methods for the planning of indoor radio communication systems and radio local area networks in the frequency range 900 MHz to 100 GHz," Recommendation ITU-R P.1238-7, 2012.

[9] W. Nasrin and J. Xie, "SharedMEC: Sharing Clouds to Support User Mobility in Mobile Edge Computing," in *Proc. of IEEE International Conference on Communications (ICC)*, 2018.

[10] ——, "Signaling cost analysis for handoff decision algorithms in femtocell networks," in *Proc. of IEEE International Conference on Communications (ICC)*, 2017, pp. 1–6.

[11] S. Tisue and U. Wilensky, "Netlogo: A simple environment for modeling complexity," in *Proc. International Conference on Complex Systems*, 2004, pp. 16–21.

[12] W. Nasrin and J. Xie, "An effective target cell selection scheme for next-generation open-access femtocell networks," in *Proc. of IEEE Global Communications Conference*, 2017, pp. 1–6.

[13] ——, "A mobility management scheme to reduce the impact of channel heterogeneity in cognitive radio femtocell networks," in *Proc. of IEEE International Conference on Sensing, Communication, and Networking (SECON)*, 2016, pp. 1–9.

[14] ——, "Effects of heterogeneous frequency changes in cognitive radio femtocell networks," in *Proc. of IEEE Global Communications Conference (GLOBECOM)*, 2016, pp. 1–6.

[15] U. Narayanan and J. Xie, "Signaling cost analysis of handoffs in a mixed IPv4/IPv6 mobile environment," in *Proc. of IEEE GLOBECOM*, 2007, pp. 1792–1796.