Load-Based Fast Handoff Mechanism for Macro-femto Heterogeneous Networks

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Abstract. When mobile multimedia applications are considered in a femtocell and macrocell coexisted heterogeneous network, a fast handoff mechanism to select a target femtocell base station (FBS) for macrocell user equipment (MUE) to maintain the QoS turns out to be a major design issue. To address this problem, a fast Stochastic Election Process (SEP) is proposed to assign the initial counter value of each candidate FBS based on the load of the candidate FBS. Simulation results confirm that the proposed load-based handoff mechanism reduces the handoff time greatly.

Keywords: Fast handoff · Auction · Femtocell · Load balance

1 Introduction

In a macro-femto coexisted heterogeneous network, as an macrocell user equipment (MUE) moves from outdoor to indoor, due to the attenuation of the walls, the signal strength is greatly attenuated and, thus, the transmission rate is reduced accordingly. To address this issue, femtocells are developed to improve indoor signal quality. As depicted in Fig. 1(a), a femtocell is composed of a femto base station (FBS) and the UEs connected to this FBS. A FBS is a low-cost small-size base station [1] that is mainly designed to be installed indoor to boost the signal quality and increase the throughput of the mobile communication networks in indoor environment. Besides, in the macro-femto heterogeneous network, when FBSs can be accessed by any nearby MUE, i.e. FBSs are operated in the open subscriber group (OSG) access mode, they provide an important alternative to offload the traffic of macrocell base station (MBS). In the conventional handoff mechanisms, the signal quality, e.g., RSSI (received signal strength indicator), SINR (signal to interference plus noise ratio), or SNR (signal to noise ratio) is the main index used to select a new target base station to handoff. For example, to select a target FBS, the

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approaches proposed in [2, 3] are to maintain an optimal neighbor cell list (NCL). With such list, instead of scanning all neighboring FBSs, UE only needs to scan those listed FBSs when handoff is needed and, thus, conserves the limited battery power. The handoff mechanism proposed in [4] consisted of two phases. In the first phase, FBSs that within a predefined range were selected as the handoff candidate FBSs. In the second phase, a handoff candidate FBS with higher SINR was assigned higher probability to be selected as the target FBS for UE to handoff. Obviously, all the previous approaches selected the target FBS mainly based on the signal quality. In other words, load of each FBS was not considered. However, due to the increasing demand of mobile multimedia applications from the UEs, if the selection of target FBS only considers the signal quality, load unbalance may occur among FBSs.

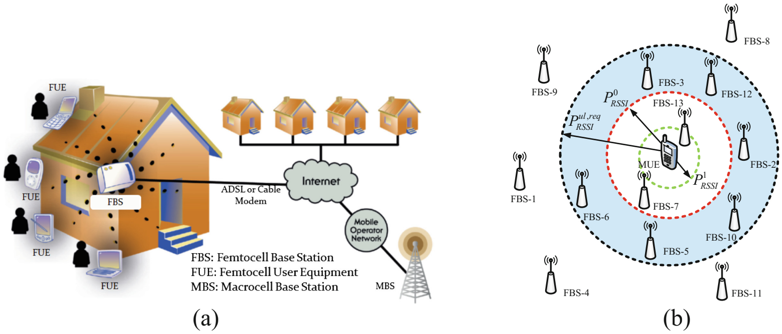


Fig. 1. (a) Illustration of femtocell [5] and (b) applying the MDA of the handoff mechanism. (Color figure online)

To address this problem, we have developed an auction-based handoff mechanism that jointly takes the signal quality and load balance into the selection of target FBS. It has been proved that better load balance among FBS is achieved by the auction-based handoff mechanism. However, in addition to selecting a light loaded FBS with satisfied signal quality, it is also important for the time elapsed in the target FBS selection to be short so that the QoS of the mobile multimedia applications can be maintained. Hence, the objective of this paper is to refine the handoff mechanism [6] to speed up the handoff time.

The rest of this paper is organized as follows. Introduction to the Dutch auction and descriptions of the system model are presented in Sect. 2. Section 3 summarizes the operations of the auction-based handoff mechanism with load balance in [6]. Detail descriptions of the refinements to speed up the handoff time are presented in Sect. 4. The performance results of the proposed refinements are presented in Sect. 5. Section 6 concludes this paper.

2 Preliminaries

2.1 Dutch Auction

Auction [7] is a special way to exchange merchandizes in human society. The Dutch auction [8] is named after the famous auctions of Dutch tulip bulbs in the 17th century.

The farmers pooled their tulips in a central market, while experienced sellers undertook their sale to traders from around the world. Sellers provided the starting price, the step of the auction and the time interval at which the price was to be reduced. The rule was simple: any time, any trader could buy any quantity of tulips in the auction at the prevailing price at that particular time interval. However, if the traders did not purchase, the price is reduced in the next time interval since the flowers would wither as time passed by. But, when some trader purchased, the remaining traders were in danger of being stuck without tulips. Thus, every trader was "waiting" or "competing" for the appropriate price, at the right time interval. In other words, in the Dutch auction, each bid is a winning bid, provided that there are still tulips (goods). When the flowers are sold out, the auction ends. Since participants never know if and when someone else will bid, they are under pressure, leading to prices and values that conform to market reality, in a short time period. For this reason, the Dutch auctions have become very popular. Thus, they are not limited to tulips. The Dutch auction, sometimes, is regarded as an open-outcry descending-price auction or a clock auction.

2.2 System Model

This paper considers a macro-femto coexisted heterogeneous network. We assumed the MUEs and FBSs are uniformly deployed inside the coverage area of an MBS. All FBSs are assumed operated in the OSG access mode. Examples of the considered environment can be found in our daily life, e.g., shopping malls, exhibitions, department stores, and offices. In practical, under the considered environment, FBSs are usually fixed and their location information is also known to the owner of the network. Besides, the location information of MUE can be provided by either the equipped GPS module or indoor positioning techniques. While the handoff probe message sent from the MUE is received by a nearby FBS, it calculates the received RSSI value based on the two equations below

$$RSSI = P - P_{(path\,loss)} \tag{1}$$

$$P_{(path\,loss)} = 127 + 30\log_{10}(d) + X_{\sigma}, \tag{2}$$

where P is the transmission power of the MUE in dBm, X_{σ} is the lognormal shadowing with zero mean and variance σ^2 in dB, d is the distance between MUE and FBS in Km and $P_{(path\ loss)}$ is the path loss in dB [9] and, respectively. With (1), the SNR can be calculated by $SNR = RSSI/N$ where N is the thermal noise.

3 Summary of the Auction-Based Handoff Mechanism with Load Balance

In [6], a two-stage auction-based handoff mechanism with load balance for macro-femto heterogeneous networks was proposed. The fundamental ideas of [6] are as follows. To find and identify the handoff candidate FBSs, a modified Dutch auction (MDA) is used in the first stage of the handoff mechanism in [6]. Next, a stochastic election process (SEP) is used in the second stage to select a light-loaded FBS among the candidate FBSs as the target FBS. Following, we summarize the operations of each stage.

3.1 Stage 1: Modified Dutch Auction (MDA)

Whenever a handoff is needed, MUE sends a handoff probe message that contains two parameter values, $P_{RSSI}^{ul,req}$ and P_{RSSI}^{0}. First, $P_{RSSI}^{ul,req}$ is the minimal required uplink RSSI value required to maintain the uplink QoS of the active mobile multimedia applications in the MUE. In addition, it is also used to define an area called potential handoff area. Then, the parameter P_{RSSI}^{0} is used to partition the potential handoff area into two priority zones. In the language of auction, $P_{RSSI}^{ul,req}$ is the upset price and P_{RSSI}^{0} is a price to partition all the bidding prices higher than the upset price into two groups. For example, as shown in Fig. 1(b), the entire area inside the dashed black line is the potential handoff area, while the region inside the red dashed line is named the high priority zone and the region between black and red dashed lines is called low priority zone. When receiving the handoff probe message, FBS calculates the uplink RSSI value based on (1) and (2). To maintain the QoS of active mobile multimedia applications, FBSs whose calculated uplink RSSI values less than $P_{RSSI}^{ul,req}$ are screened out. For example, in Fig. 1(b), the seven FBSs outside the potential handoff area (i.e., FBS-1, FBS-4, FBS-8, FBS-9, FBS-11, FBS-14, and FBS-15) are sifted out. In contrast, the rest of eight FBSs in the potential handoff area (i.e., FBS-2, FBS-3, FBS-5, FBS-6, FBS-7, FBS-10, FBS-12, and FBS-13) are called qualified FBSs. In the language of auction, this means that bidders with bidding prices higher than the upset price win the first round of bidding and called qualified bidders.

After calculating the uplink RSSI value, each qualified FBS located within the high priority zone (i.e., FBS-7 and FBS-13 in Fig. 1(b)) replies a handoff probe response message to MUE. In the language of auction, this means qualified bidders that agree to pay higher bidding prices are given higher priority to win the bid. After broadcasting the handoff probe message, if MUE does not receive any handoff probe response message, the same handoff probe message is broadcast again. This time, each qualified FBS that receives the same handoff probe message twice and located within the low priority zone replies a handoff probe response message to the MUE. However, if MUE still receives nothing, MDA is ended. This is called as a handoff failure. However, if more than one qualified FBSs located in the same priority zone, as shown in Fig. 1(b), the handoff probe response messages sent by the qualified FBSs will collide to each other. In this case, MUE cannot identify which qualified FBS has sent the handoff probe response message. To this issue, after a collision is detected, MUE sends an updated handoff probe message in which an updated uplink RSSI value, P_{RSSI}^{1}, is included to further partition the corresponding priority zone into two priority sub-zones. For example, as shown by the green dashed line in Fig. 1(b), after detecting collision occurred in the high priority zone, P_{RSSI}^{1} is used to divide the high priority zone into two sub-zones. In our simulations, the above procedure to resolve the collision is ignored. In the language of auction, this means if some bidders offer similar bidding prices, in order to determine the winner, the auctioneer will separate them into two sub-groups based on their bidding prices.

Whenever MUE successfully receives a handoff probe response message, it calculates the received downlink SNR value. After all qualified FBSs in the selected priority zone have successfully sent back to MUE, those FBSs whose downlink SNR values greater than the required downlink SNR value SNR_{req}^{dl} will be selected by the MUE to maintain the downlink QoS of the active mobile multimedia applications as the candidate FBSs. If there is only one candidate FBS, it is the target FBS and MUE proceeds to handoff to it. However, if more than one candidate FBSs, a new handoff probe message will be sent to notify them to proceed to the second stage of the auction-based handoff mechanism. If no candidate FBS is found, MDA is ended and the handoff is regarded as failure.

3.2 Stage 2: Stochastic Election Process (SEP)

As mentioned in previous sub-section, the second stage of the auction-based handoff mechanism is executed only when more than one candidate FBSs are selected in the MDA. Hence, the objective of SEP is to determine the light-loaded target FBS so that the load among FBSs can be balanced. The operations of SEP are described below.

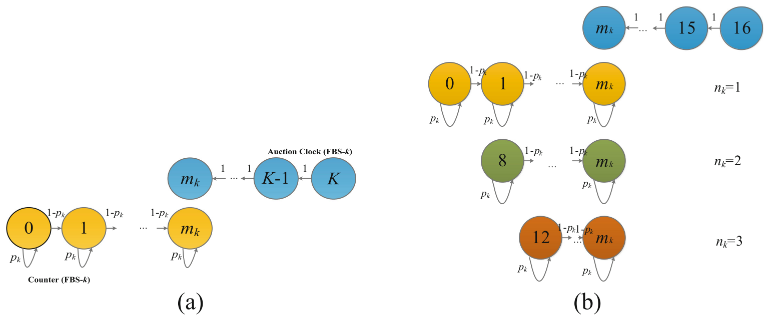


Fig. 2. The counter and auction clock of candidate FBS-k in the (a) SEP and (b) fast SEP.

Like the Dutch auction, a down-counted Auction Clock is maintained in each of the candidate FBSs and MUE. Initially, the Auction Clock is set to K. Besides, an up-counted Counter with initial value 0 is maintained in each candidate FBS as shown in Fig. 2(a). In each time unit of SEP, the values of Auction Clocks in candidate FBS-k and MUE are decreased by one with probability 1. However, the Counter value in each candidate FBS is unchanged with probability p_k or increased by one with probability $(1-p_k)$. The probability p_k is given by

$$p_k = \frac{l_k + q}{C_k}, \quad (3)$$

where l_k is the load of candidate FBS-k before handoff, q is the requested capacity of the MUE, and C_k is the maximal capacity of candidate FBS-k. For simplicity, we assume $C_k = C$ for every candidate FBS-k. Whenever a candidate FBS-k whose values of Auction Clock and Counter matched (e.g., their values are equal to m_k as shown in Fig. 2(a)), it will regard itself as the winner of the auction. Hence, it replies a handoff probe response message to grant the handoff request proposed by the MUE. But, if more than one candidate FBSs satisfy the above condition simultaneously, their handoff probe response messages to MUE will collide. This results in the failure of the first round of SEP. We define the failure of SEP due to the collision as "*collision failure.*" When a collision failure occurs, the value of Auction Clock of MUE and the values of Auction Clocks and Counters of the collided FBSs will be re-initialized and a new round of SEP is started. Before MUE successfully receives a handoff probe response message, the procedures will be repeated again and again. However, since the counter value is increased randomly, it is possible that no match occurs. In this case, MUE receives nothing from the candidate FBSs and the handoff will be regarded as failed when the value of Auction Clock of MUE equals to zero (i.e., $K = 0$). This is defined as "*miss failure.*" According to the calculation of p_k in (3), it can be easily found that a light-loaded candidate FBS-k, i.e. smaller l_k, will have a smaller p_k and, consequently, its counter value will have a higher probability to be advanced by one. In other words, a light-loaded candidate FBS is with higher probability to attain a match and become the first FBS to send the handoff probe response message to MUE. Thus, better load balance among FBSs can be obtained with the MDA and SEP.

4 Fast SEP

In the original design of SEP, named normal SEP in the following context, the initial value of each Counter is set to zero. With this initial value, the minimum clock time required for Counter and Auction Clock to match in each round of SEP will be $K/2$. In other words, the time before $K/2$ is wasted. Hence, it will be a feasible solution to speed up the handoff time if the SEP can be executed faster. Our improvement to speed up the time required in the SEP is as follows. Instead of assigning initial counter value of each candidate FBS to zero, it is assigned based on the load of candidate FBS. To do this, the maximum possible load among the candidate FBSs in the i^{th} round of SEP, X_i, is divided into W regions. Let $X_1 = C$ Mbps and n_k be the region number where candidate FBS-k is allocated. In this way, if a candidate FBS-k whose load l_k is 0 Mbps $\leq l_k \leq \lceil X_i/W \rceil$ Mbps, $n_k = W$. Similarly, if a candidate FBS-k whose load l_k is $\lceil X_i/W \rceil$ Mbps $< l_k \leq 2\lceil X_i/W \rceil$ Mbps, $n_k = (W\text{-}1)$, so on and so forth. Based on the obtained n_k, the initial counter value of candidate FBS-k is

$$\begin{cases} 0 & , n_k = 1 \\ \sum_{i=2}^{n_k} \frac{K}{2^{(i-1)}} & , n_k > 1. \end{cases} \tag{4}$$

Obviously, candidate FBS with light load will be allocated with a higher value of n_k, and thus, assigned with a higher initial counter value. In such a way, light loaded candidate FBS will achieve a match faster than those heavy loaded ones. In addition, the load balance is still maintained. For example, consider $K = 16$, $W = 3$, and $C = 50$

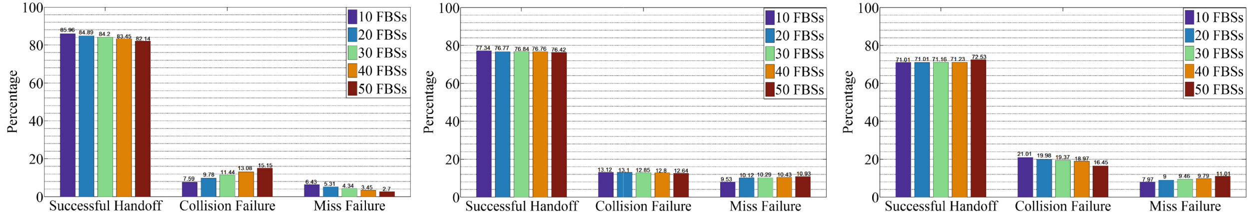
Mbps. In the first round of fast SEP, X_1 = 50 Mbps. As shown in Fig. 2(b), if the considered candidate FBS-k whose load l_k is 0 Mbps $\leq l_k \leq$ 17 Mbps, n_k = 3 and, based on (4), the initial counter value will be 12. On the contrary, if l_k is 17 Mbps < $l_k \leq$ 34 Mbps, n_k = 2 and the initial counter value will be 8. Otherwise, if l_k is 34 Mbps < $l_k \leq$ 50 Mbps, n_k = 1 and the initial counter value will be 0. If collision occurred in the first round of SEP, the value of X_2 in the second round of SEP will be 50 Mbps, 34 Mbps, or 17 Mbps if the initial counter value of the collided candidate FBSs is 0, 8, or 12, respectively. Since collided candidate FBSs are with the same initial counter value, with the above approach to assign X_i $i \geq 2$, we are trying to reallocate those collided candidate FBSs into different sub-regions so that they can be assigned with different initial counter values in the next round of fast SEP. For example, consider two candidate FBSs A and B with loads 20 Mbps and 30 Mbps and same initial counter value 8 collided in the first round of fast SEP. In the second of fast SEP, X_2 = 34 Mbps and the initial counter value will be 12 if the load l_k is 0 Mbps $\leq l_k \leq$ 12 Mbps, 8 if l_k is 12 Mbps < $l_k \leq$ 24 Mbps, and 0 if l_k is 24 Mbps < $l_k \leq$ 34 Mbps. Hence, the initial values for candidate FBSs A and B in the second round of fast SEP will be 8 and 0, respectively.

5 Simulation Results

The performance of the proposed load-based fast handoff mechanism for macro-femto heterogeneous networks is evaluated by the MATLAB and all the parameter values used in our simulations are in Table 1. In the simulations, 10, 20, 30, 40, and 50 FBSs are uniformly deployed inside the considered area, respectively. The requested capacity of the MUE, i.e., q, for each corresponding number of FBSs are 0.5, 1, 1.5, 2, and 2.5 Mbps, respectively. The initial load of each FBS is assumed uniformly between 0 and 50 Mbps. Besides, the procedures to resolve the collision as mentioned in Sect. 3 are ignored. To investigate the performances of the proposed fast SEP, the percentages of "successful handoff", "collision failure", and "miss failure" in each round of normal SEP and fast SEP are collected and compared. They are defined as the ratios of the number of candidate FBSs "that successfully send MUE the handoff probe response message", "whose handoff probe response messages are collided", and "whose values of Auction Clock and Counter are mis-matched" to the number of candidate FBSs in that round, respectively.

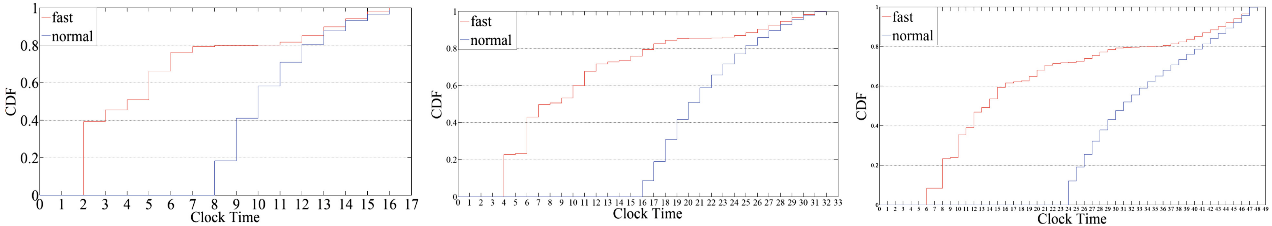
Table 1. The parameter values used in simulation.

Parameter	Value	Parameter	Value
Network side-length	70 m	Min. req. uplink RSSI value ($P_{RSSI}^{ul,req}$)	−56 dBm
FBS transmit power	23 dBm	P_{RSSI}^{0}	−47 dBm
MUE transmit power	20 dBm	Downlink threshold (SNR_{req}^{dl})	50 dB
Frequency band	2 GHz	Capacity of candidate FBS (C)	50 Mbps
System bandwidth	10 MHz	Shadowing standard deviation	4 dB
Thermal noise (N)	−104 dBm	Initial auction clock value (K)	16



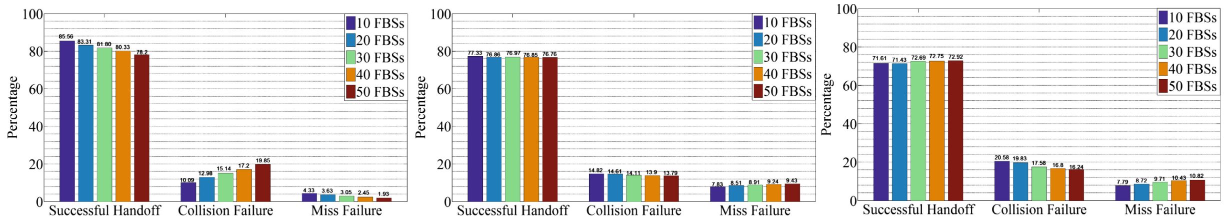
(a) first round (b) second round (c) third round

Fig. 3. Percentages of successful handoff, collision failure, and miss failure in the (a) 1st round, (b) 2nd round, and (c) 3rd round of normal SEP.



(a) first round (b) second round (c) third round

Fig. 4. CDF of the clock time required for a successful handoff with fast SEP and normal SEP under 30 FBS.

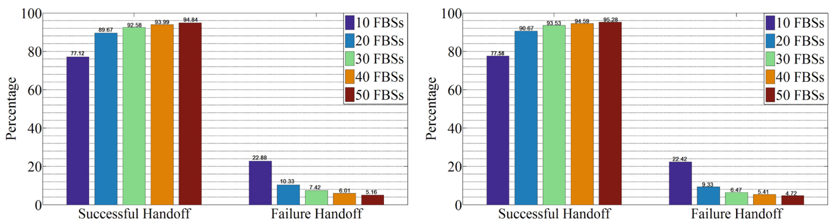


(a) first round (b) second round (c) third round

Fig. 5. Percentages of successful handoff, collision failure, and miss failure in the (a) 1st round, (b) 2nd round, and (c) 3rd round of fast SEP.

First, we show the percentages of successful handoff, collision failure, and miss failure for the normal SEP in Fig. 3. Since the percentages of more than two candidate FBSs observed in the first round of normal SEP are increased as the number of FBSs increases, as shown in Fig. 3(a), more collision failures, fewer successful handoffs, and fewer miss failure occur in the normal SEP as the number of FBSs increased. Next, the simulation results for the second and third rounds of normal SEP show that more than 90% of the number of candidate FBSs is two. In addition, according to (3) and the operations of normal SEP, we find collisions are most likely generated by candidate FBSs with similar loads. Furthermore, based on our observations, if candidate FBSs with similar load collided in the i^{th} round of normal SEP, they are likely to collide again in the $(i + 1)^{th}$ round of normal SEP. As a consequence, as shown in Fig. 3(b) and (c), the percentage of successful handoff is reduced. However, different from Fig. 3(a), we can see that the percentages of collision failure in Fig. 3(b) and Fig. 3(c) slightly decrease as the number of FBSs increases. This is mainly because the percentage of more than two candidate FBSs is slightly increased as the number of FBSs increases. Hence, the differences between values of p_x are getting larger, which reduces the possibility of collision. On the contrary, due to the decreases of collision failure, the percentage of miss failure increases as the number of FBSs increases.

Next, we verify the handoff time improved by the fast SEP. Figure 4 shows the CDF of the clock time elapsed for a successful handoff with fast SEP and normal SEP when the number of FBS is 30. First, in Fig. 4(a), as we mentioned earlier, the minimum clock time required to have a successful handoff in the first round of normal SEP is 8 (for $K = 16$). On the contrary, by assigning different initial counter values, the minimum clock time required for fast SEP is reduced to 2. Similarly, the minimum clock time required to have a successful handoff in the second and third rounds of normal SEP are 16 and 24 in Fig. 4(b) and (c), respectively. However, as shown in Fig. 4(b) and (c), they are 4 and 6 if fast SEP is applied. In addition, with the fast SEP, we can also find that nearly 80% of successful handoff occurred before the first successful handoff occurred in the normal SEP. In other words, the overall handoff time is greatly improved by the proposed fast SEP.



(a) MDA+normal SEP (b) MDA+fast SEP

Fig. 6. The percentages of successful handoff and failure handoff.

Next, we need to verify if the fast SEP deteriorates the other performance of handoff. Figure 5 shows the percentages of successful handoff, collision failure, and miss failure in the different rounds of fast SEP. Comparing with the results shown in

Fig. 3, we find that fast SEP induces very limited negative effects on the performances of the successful handoff, collision failure, and miss failure. Hence, we conclude that the fast SEP greatly reduces the handoff time with limited side effect on the performances of the normal SEP.

Finally, the overall percentages of successful handoff and failure handoff with respect to normal SEP and fast SEP are shown in Fig. 6. As expected, since fast SEP is mainly focus on speeding up the time to a successful handoff, it only slightly improves the percentages of successful handoff and failure handoff obtained by normal SEP.

6 Conclusions

In the macro-femto heterogeneous networks, if the service from the serving MBS deteriorates, an auction-based handoff mechanism with load balance is needed for MUE to quickly select a light-loaded FBS to perform a handoff so that the load among each FBS can be balanced. To achieve this goal, a modified Dutch auction (MDA) is used to sift out candidate FBSs. After that, a normal stochastic election process (SEP) is employed to decide the target FBS to perform handoff. However, it is found that normal SEP is not quick enough since $K/2$ clock time is wasted in each round of normal SEP. Thus, by assigning light-loaded candidate FBS with higher initial counter value, simulation results confirms that the handoff time is greatly improved by proposed load-based fast handoff mechanism.

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