Connection Cost Based Handover Decision for Offloading Macrocells by Femtocells

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Abstract. Femtocells can offload macrocells and reduce a cost of transmitted data in wireless networks. If a connection via the femtocell is of a lower cost than via the macrocell, a time spent by users connected to the femtocells should be maximized. This leads to a reduction of the overall cost of user's connection. Besides, a prolongation of the time spent by users in the femtocells reduces load of the macrocells. Therefore, an extension of handover is presented in this paper. The extension consists in consideration of the connection cost together with user's requirements on a service quality. To that end, a conventional handover decision is modified to achieve higher efficiency in prolongation of the time spent by the users in the femtocells. As the results show, the user who does not require high quality of service spent more time connected to the femtocells and thus the macrocell can be offloaded.

Keywords: femtocell, handover, connection cost, macrocell offloading

1 Introduction

A concept of home base stations, so-called femtocells was developed to cope with increase in user's demands on throughput. The femtocell is represented by a Femto Access Point (FAP) deployed usually in areas with low level of signal from macrocell (e.g., indoor). The FAPs are typically connected to a network backbone via a wired connection such as xDSL or optical fiber. The FAP can provide three types of user's access: open, closed, and hybrid. All users in the coverage of a FAP can connect to this FAP if it operates in the open access mode. This way, the FAP can offload a Macro Base Station (MBS) by serving several outdoor users. Contrary, the FAP with closed access admits only users listed in so-called Closed Subscriber Group (CSG). This access increases interference to users connected to the MBSs. In the hybrid access mode, a part of capacity is dedicated for the CSG users and the rest of the bandwidth can be shared by other users.

The main purpose of the FAP is to improve indoor coverage for users in the FAP's vicinity or to offload macrocells by serving several outdoor users. Thereby significant increase in throughput is introduced. However, the implementation of the FAPs into the existing network brings several problems that need to be addressed. One of the main tasks is how to handle a handover procedure [1]. A conventional handover decision based on comparison of signals received from a serving and a target station does not take dense deployment and small serving radius of the FAPs into account. A large number of the FAPs in a network increases amount of initiated handovers and decreases Quality of Service (QoS) of users. This effect could be suppressed by common techniques for elimination of redundant handovers such as a hysteresis or a timer [2]. However, these techniques reduce not only amount of handovers, but also a gain in throughput introduced by the FAPs with open or hybrid access [3]. This is due to the small radius of the FAP together with the fact that the conventional techniques always postpone the handover decision. Consequently, the handover to/from the FAP is initiated too late to enable full exploitation of available capacity of the FAPs.

This paper proposes a way how to consider potential lower cost of the connection via the FAP than via the MBS in handover decision. This enables to prolong the time spent by User Equipments (UEs) in the FAP if the FAP provides connection for a lower cost than the MBS. Longer time spent by UEs connected to the FAPs shortens the time when the UE is connected to the MBS. Thus, this approach also offloads MBS and it increases amount of resources available for macrocell users out of femtocells' range. To efficient extension of the time in the FAPs, a modification of the conventional handover decision is described as well.

The rest of the paper is organized as follows. The next section presents related works on handovers in networks with FAPs. In Section III, modifications of the conventional handover to enable efficient considering of the cost of connection are introduced. In Section IV and Section V, the system model and simulation results are presented respectively. The last section gives our conclusions and future work plans.

2 Related Works

Several aspects such as low serving radius or limited backbone connection must be taken into account if the FAPs are deployed. These aspects can lead to an increase in amount of signaling overhead generated due to initiation of large amount of redundant handovers. Therefore, research papers dealing with mobility in a network with the FAPs are usually focused on a reduction of a number of unnecessary handovers.

The possibility of eliminating unnecessary handovers is described, for example, in [4]. The user's speed and a type of service are considered in handover decision algorithm. For users moving with the speed of up to 15 km/h, the handover to the FAP is executed if the signal level of the target FAP exceeds signal level of the serving cell. If the user's speed is in range of 15 km/h and 30 km/h, the type of service is additionally assessed. Handover is executed only if the user is using real-time service. When the user's speed is over 30 km/h, the handover to the FAP is denied.

The idea of the previous paper is further elaborated in [5]. The handover decision is based also on an available bandwidth of the FAP and a category of the user. The UEs are categorized according to their membership in the CSG. A user who is not included in the CSG is connected to the open/hybrid FAP only if three conditions are fulfilled: i) the FAP has available bandwidth, ii) the speed of user is lower than a threshold, and iii) the FAP interferes significantly to the UE connected to the MBS.

In [6], the authors also consider the speed of the user for the decision on handover. Unlike [4] and [5], the speed of users and the cell's configuration influence the setting of time-to-trigger (TTT) parameter.

Another proposal, presented in [7], targets the decrease of number of redundant handovers to the FAP by defining two thresholds, one related to the MBS signal level and the second one related to the FAP signal level. To perform the handover to the FAP, at least one of the following conditions must be fulfilled: i) signal level of the MBS must be lower than the first threshold; or ii) signal level of the FAP must exceed the second threshold. Last, the signal level of the FAP must be above than signal level of the MBS.

Handover for hierarchical macro/femto networks is presented also in [8] and further specified in [9]. The main idea of the proposed algorithm is to combine values of the received signal strength from the serving MBS and the target FAP while considering the large asymmetry in transmit power of both. This mechanism compares the level of signal received from the FAP with absolute threshold value of –72 dB. Besides, the signal of the MBS is compared with combination of signals from the MBS and the FAP. It increases the probability of handover to the FAP if this FAP provides signal above the threshold and if the FAP is deployed far from the MBS. Otherwise, if the threshold is not meet, the conventional handover is performed. The proposed scheme leads to elimination of the handovers if the FAP and MBS are close to each other.

All these proposals are trying to restrict connections of users to the FAPs. However, it leads to a reduction in utilization of the FAPs and the most of UEs stays connected to the MBS. This MBS can easily become overloaded since the FAPs interfere to the UEs connected to the MBS. Hence, those UEs must consume more radio resources to reach required throughput. None of before mentioned methods considers fact that the connection via the FAP can be of a lower cost than the connection through the MBS. Contrary to all above-mentioned proposals, the objective of this paper is to enhance handover decision by consideration of the cost of the connection via the FAPs and the MBSs. Therefore, modifications of the conventional handover with the purpose to increase the time spent connected to the FAPs are presented in this paper. More time spent at the FAP is profitable from an operator as well as from the user's point of view. From the operator side, the advantage is to relieve existing network infrastructure. From the user's perspective, it enables to attain higher transmission rate and/or lower cost of the connection.

3 Handover for maximization of the time spent in femtocells

The conventional handover decision is based on comparison of the signal level of the target ($\overline{s_t}[k]$) and serving ($\overline{s_s}[k]$) cells. Commonly, a hysteresis margin (Δ_{HM}) can be used in order to mitigate a ping-pong effect (i.e., continuous switching of two neighboring serving stations). The conventional handover is initiated if the next condition is fulfilled:

$$\overline{s_t}[k] > \overline{s_s}[k] + \Delta_{HM} \tag{1}$$

To additional elimination of redundant handovers, a timer (e.g. TTT [10]) can be implemented. The conventional handover algorithm is designed for networks with MBSs only and does not consider specifics of heterogeneous network composed of both MBSs and FAPs.

The conventional handover should be modified to maximize the time spent by users in the FAP and thus to either offload MBSs or reduce the connection cost if the FAP provides lower connection cost than the MBS. The handover decision in the proposed algorithm is based on absolute levels of the Carrier to Interference plus Noise Ratio (CINR), on a trend of the FAP's CINR level (as shown in Fig. 1), and on the acceptable outage for users. The modified algorithm compares the CINR values rather than Received Signal Strength Indicator (RSSI) since the interference significantly influence a quality of a radio channel. Due to consideration of the CINR, the FAP is accessed more effectively at a time when it is able to provide higher throughput.

The proposed handover to the FAP is performed immediately when the CINR level of the FAP (denoted $\overline{s_{FAP}}[k]$) exceeds a threshold $CINR_{T,in}$ as expressed in (2). The $CINR_{T,in}$ is set as a fixed value equal to the minimum level of CINR when the UE can be served by the FAP. In addition to (2), the level of the signal received from the FAP must be rising as well (see (3)). The requirements on the rising signal level provides a certain level of a prediction. Thus, we can assume that the user is moving in a direction to become closer to the FAP. This way, the ping-pong effect is suppressed, the time spent by users in the FAP is maximized, and the UE's outage is not increased.

$$\overline{s_{FAP}}[k] > CINR_{T,in} \tag{2}$$

$$\overline{s_{FAP}}[k-1] < \overline{s_{FAP}}[k] \tag{3}$$

When the UE is leaving the FAP, the handover is initiated according to the absolute CINR level of the FAP as well. Moreover, the trend of the FAP's CINR level and the actual level of the MBS's CINR are also taken into account. The handover from the FAP to the MBS is performed only if the following conditions are fulfilled: i) the CINR level from the FAP is lower than the level $CINR_{T,out}$ as defined in (4); ii) the CINR level of the MBS ($\overline{s_{MBS}}[k]$) exceeds the CINR level of the FAP (see (5)); and iii) the trend of the signal received from the FAP is declining, as expressed in (6).

$$\overline{s_{FAP}}[k] < CINR_{T,out} \tag{4}$$

$$\overline{s_{FAP}}[k] < \overline{s_{MBS}}[k] \tag{5}$$

$$\overline{s_{FAP}}[k-1] > \overline{s_{FAP}}[k] \tag{6}$$

The handover between two FAPs is performed based on the same conditions as in the conventional algorithm (defined in (1)).

To avoid an immediate handover back to the MBS a short timer is considered. During this timer no backward handover can be performed. The imminent handover might occur if the value of $CINR_{T,in}$ is set lower than the value of a threshold for handover from the FAP ($CINR_{T,out}$).

As depicted in Fig. 1, the proposed approach leads to earlier initiation of the handover to the FAP comparing to the conventional handover. Contrary, the connection to the

FAP remains for a longer time then in the conventional approach if the user is leaving the FAP. This is since the UE performs the handover only if the FAP is no longer able to satisfy QoS requirements of the UE. Therefore, the threshold $CINR_{T,out}$ must be related to the QoS required by individual UEs. In this paper, the QoS requirements are represented by an outage probability. The outage probability is expressed as the probability of being in a state when the user cannot transmit data. However, other metrics can be implemented and considered in the same way.

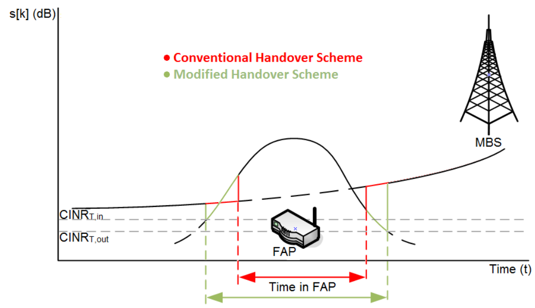

Fig. 1. The principle of the modified handover schemes.

An optimum $CINR_{T,out}$ should be determine with respect to the user's preferences in either cost of the connection or the quality of the connection. The variable threshold $CINR_{T,out}$ enables a consideration of different cost of the connection via the MBS and the FAP. If a user can tolerate lower quality of the connection, it can spent more time connected to the FAPs. Then, an operator benefits from lower load of the MBS. Therefore, the operator can give a benefit, such as discount on cost of services, if the user would accept to stay connected to the FAP for a longer time even if it would lead to minor drop in quality.

4 System Model

First, a model of consideration of the connection cost is introduced. Then, the simulation models are presented.

4.1 Model for Connection Cost

For determining appropriate trade-off between the connection quality and cost, we define three illustrative types of users. Each type represents an example of user's preferences on the outage probability over the connection cost. The first type, *User A*, is aimed primarily on the quality (i.e., low outage) regardless of the connection cost. An example of the *User A* is someone who requires high quality of voice calls. The second type, *User B*, is willing to compromise on the quality requirements for cheaper services. The third type of the user, *User C*, is focused on saving money and does not stress the quality of connection. This user can be seen as someone who uses mainly the services with low requirements on delay, such as e-mail, FTP, or HTTP.

An example of acceptable increase in outage probability over the connection cost ratio for all illustrative types of users is depicted in Fig. 2. The "Cost Ratio" can be expressed as the ratio of the cost of the FAP's connection to the cost of the connection to the MBS. For example, the ratio 1/1 means the same price of the connection via the FAP and the MBS. In this case, the user has preferences for neither FAP nor MBS in term of the cost. On the other hand, the ratio 0/1 corresponds to the situation when the connection via the FAP is for free.

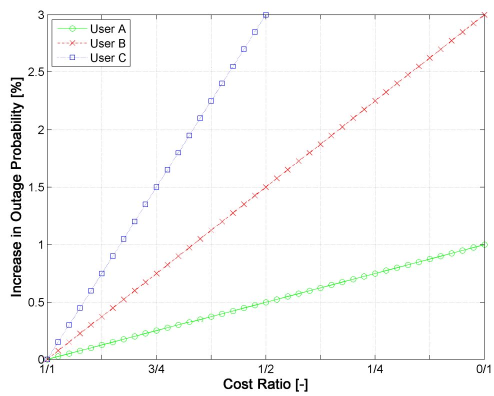

Fig. 2. Acceptable increase in outage for different types of users over ratio of connection cost to FAP and MBS.

4.2 Simulation models

In simulations, twenty-five blocks of flats with the square shape are arranged in a matrix with size of 5 x 5 blocks (see Fig. 3). The size of each block is 100 x 100 meters. Blocks are separated by streets with the width of 10 meters. Each block contains 64 apartments with the size of 10 x 10 meters. The apartments are arranged in two rows around the perimeter.

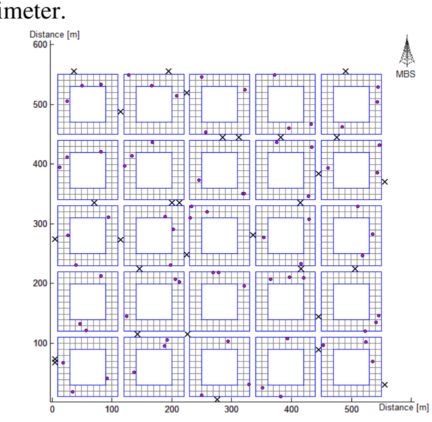

Fig. 3. Example of a random simulation deployment.

Three FAPs per a block of flats are randomly placed in random apartments for each drop. All FAPs operate in the open access mode. The MBS is located in the top right corner of the simulation area in distance of approximately 50 meters from the closest flat. Thirty users are randomly deployed in this simulation area. The users are moving along the streets with speed of 1 m/s. Each user covers the distance of 3000 m per a simulation drop, i.e., the duration of each drop is 3000 s of the real time. Indoor users are not considered in the simulation since the FAP provides signal of sufficient quality to serve the user inside the flat and these users are not supposed to perform handover within the flat.

The quality of signal received by the UE from the FAP is determined according to the ITU-R P.1238 path loss model including wall losses [11]. The Okumura-Hata path loss model for outdoor to outdoor communication [12] is used for derivation of the MBS's signal propagation. For the evaluation of the handover outage probability and the overall outage probability, a CINR Outage Limit ($CINR_{OL}$) is defined. It is the level of the CINR, under which the QoS is not fully guaranteed. It means, the transmission speed and quality of the user's channel are very low. According to [13] and [14], the $CINR_{OL}$ is set to -3 *dB*. The major simulation parameters are summarized in Table 1.

Table 1. Parameters of simulation

Parameters	**Value**
Frequency / Channel bandwidth	2 GHz / 20 MHz
Transmiting power of MBS / FAP	46 / 15 dBm
Height of macro MBS / FAP / UE	32 / 1 / 1.5 m
External / internal wall loss	10 / 5 dBm
$CINR_{OL}$	–3 dB
$CINR_{T,in}$	–3 dB
Simulation real-time	3 000 s

Three competitive handover algorithms are evaluated for the same movement of users: i) the conventional algorithm based on comparison of RSSI, ii) the conventional algorithm based on comparison of CINR, iii) the Moon's algorithm according to [9] (described in Section 2). These three algorithms are simulated for two levels of hysteresis, i.e., $\Delta_{HM} = 1\ dB$ and $\Delta_{HM} = 4\ dB$. In addition, the modified handover decision proposed in this paper is evaluated and compared with three before mentioned algorithms.

5 Results

The results are split into two subsections. In the first one, the comparison of slightly modified handover decision with the competitive handovers is performed. The second subsection focuses on determination of an optimum threshold for consideration of the connection cost based on the requirements of users.

5.1 Evaluation of the handover decision algorithms

Three parameters are observed and compared: time in the FAP, outage probability, and handover outage probability.
The time spent in the FAP (t_{FAP}) is understood as the average duration of the connection of the UE to the FAP. In other words, it is an average time interval between the handover to the FAP and the handover back to the MBS.
The results of evaluation of t_{FAP} over $CINR_{T,out}$, presented in Fig. 4, show that t_{FAP} is rising with decreasing level of $CINR_{T,out}$ for the proposed handover. Comparing to the other competitive algorithms, our modification of handover outperforms the Moon's algorithm for all levels of $CINR_{T,out}$. Note that t_{FAP} reached by the Moon's algorithm is nearly independent on hysteresis. Performing handover based on the CINR levels leads to a prolongation of t_{FAP} with increasing hysteresis. However, even for the hysteresis of 4 dB, the proposed scheme achieves higher t_{FAP} if $CINR_{T,out} < -3.4\ dB$. The improvement in t_{FAP} can be reached by the replacement of the conventional CINR based handover decision by the RSSI based one. In this case, the results of the RSSI based handover with hysteresis of 4 dB are the same as results of the proposed algorithm for $CINR_{T,out} = -5.7\ dB$.

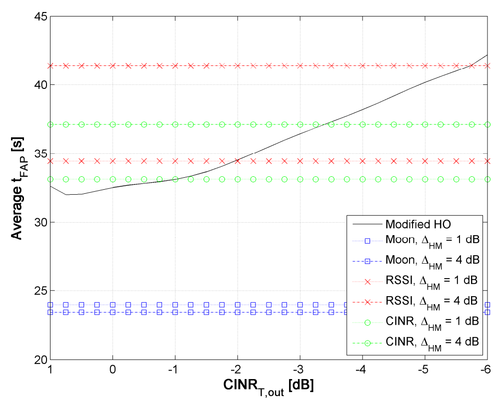

Fig. 4. Average time spent by UEs in connected to the FAP.

According to the results in Fig. 4, it is profitable to either increase the hysteresis for the conventional algorithms or lower $CINR_{T,out}$ for the proposed scheme to increase t_{FAP}. However, higher hysteresis as well as lower threshold $CINR_{T,out}$ can negatively influence the handover outage probability.
The handover outage probability is the ratio of unsuccessful handovers to the overall number of the performed handovers during the simulations. As an unsuccessful handover is understood the handover during which the CINR level drops under the $CINR_{OL}$. According to Fig. 5, the handover outage probability is constant up to $CINR_{T,out} = -2.3\ dB$ for our proposal. Then it rises rapidly and get steady at approximately 50 % of handover outage. This steep increase is caused by the fact that channel quality is not sufficient if the CINR level drops close to the $CINR_{OL}$.

The handover outage probability comparable with the proposed scheme can be obtained only by the conventional handover based on the CINR with very low hysteresis. Nevertheless, the proposal reaches nearly twice lower handover outage (8 % instead of 15 %). Simultaneously, t_{FAP} is prolonged by 9 % by the proposal as can be observed in Fig. 4. If $CINR_{T,out}$ is above $-2.5\ dB$, a half of handover fails by our proposed procedure. The similar level of handover outage is reached either by the CINR based and the Moon's algorithm with hysteresis of 4 dB. However, in this case, the proposed procedure prolongs t_{FAP} by 14 % and 85 % comparing to the conventional CINR based and the Moon's algorithm respectively for $CINR_{T,out} = -6\ dB$ (see Fig. 4). Although the RSSI based algorithm shows good results in term of t_{FAP}, the outage is very high even for low hysteresis. It is due to not efficiently chosen times of the handover decision. It means the handover to the FAP and back to the MBS is performed too late comparing to an optimum time instant.

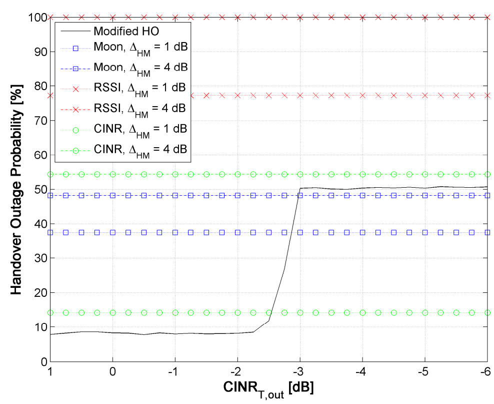

Fig. 5. Handover Outage Probability over the threshold for handover to the MBS.

The results for t_{FAP} and handover outage probability can be summarized in two points. First, the proposal can significantly reduce the handover outage probability simultaneously with slight prolongation of t_{FAP}. This is the case when users do not accept high level of the handover outage (outage is reduced from 15 % to 8 % by our proposal). Second, the modified handover algorithm significantly prolongs t_{FAP} and keeps roughly the same handover outage probability if users are willing to tolerate higher level (roughly 50 %) of the handover outage. Therefore, our proposal is profitable for the user who prefers quality as well as for the user who aims low connection cost.

The number of handovers initiated by our modified algorithm is kept at nearly the same level as in case of the conventional handover. The simulation shows only 3 % and 5 % rise in the overall amount of initiated handovers comparing to the CINR and the RSSI based procedure respectively. Comparing to the Moon's procedure, our proposal reduces amount of handovers for approximately 4 %.

Fig. 6 shows the percentage of overall simulation time spent by the UEs in a state of outage. The outage probability is the ratio of the time when the user's requirements are not fulfilled due to the CINR level under the $CINR_{OL}$ to the overall duration of the simulation.

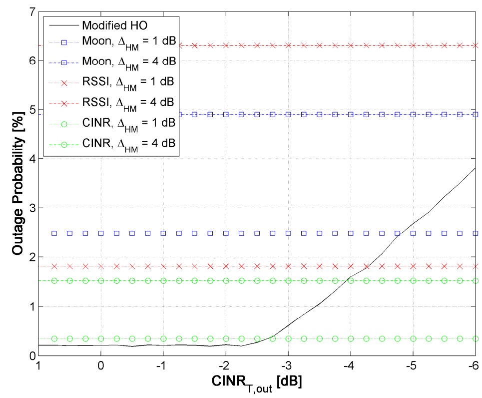

Fig. 6. Outage Probability over the threshold for handover to the MBS.

The proposed scheme shows again a constant outage, of roughly 0.2 %, for $CINR_{T,out}$ up to *–2.5 dB*. This outage is the lowest of all evaluated algorithms. Then, the outage probability rises linearly with slope of 1 % per 1 dB for $CINR_{T,out}$ lower than *–2.5 dB*. The handover performed based on the comparison of the CINR reaches very low outage if the hysteresis is set to low value. Nevertheless, the outage is still nearly twice higher than the outage obtained by the proposed handover decision with $CINR_{T,out}$ up to *–2.5 dB*. All other algorithms are outperformed significantly by the proposed one.

Comparing to all three competitive algorithms, the proposed one provides highest extension of the t_{FAP} with lowest rise in the outage probability. In the proposed handover, the t_{FAP} can be adapted more significantly according to user's requirements on outage probability while the outage rises slowly comparing to other competitive techniques. Therefore, the modified handover algorithm proposed in this paper is more suitable for consideration of the connection cost.

5.2 Optimum CINR threshold over Connection Cost ratio

As it is shown in the previous subsection, t_{FAP} rises with lowering $CINR_{T,out}$. However, the outage is also rising with decreasing $CINR_{T,out}$. Therefore, a sort of compromise between t_{FAP} and the outage probability must be found.

Based on the user's requirements and on the connection cost ratio (depicted in Fig. 2), optimum $CINR_{T,out}$ can be determined for each type of users. Fig. 7 shows that the *User C* whose demands on the quality are the lowest can use lower level of $CINR_{T,out}$ (more negative numbers) than other users. The lower threshold results in higher probability of the outage as shown in Fig. 6. However, the *User C* is willing to tolerate an increase in the outage as it prolongs t_{FAP} (see Fig. 4) and thus it reduces the cost of connection.

In contrary, the *User A* prefers high quality regardless of higher connection cost. Therefore, higher threshold must be set to maintain an adequate quality of the connection.

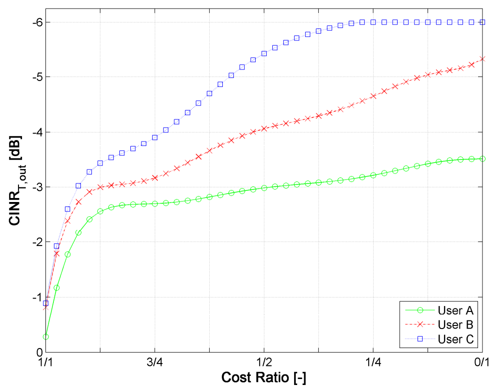

Fig. 7. Threshold for handover to MBS according user's requirements.

In real networks, the threshold can be derived by an operator from Fig. 7 as a fix value for all users, according to the quality the operator wants to provide. Another option is to let individual users choose their preferences on the quality and cost (as presented in Fig. 2). Then the billing is performed according to the user's selection. It means the operator gives a benefit, e.g., in form of a lower price, to *User C* over *User A* since *User C* consumes fewer resources of MBSs.

6 Conclusions

This paper proposes an enhancement of the conventional handover by a consideration of user's requirements on the quality of the connection with respect to the cost of the connection. This way, an operator can give a benefit to the users that are willing to offload its network at the cost of higher outage. The offloading is reached by prolonging the time spend by the UEs connected to the FAPs instead of staying connected to the MBS. To maximize the time spent by UEs connected to the FAP, the conventional handover algorithm is slightly modified. Extension of the time in the FAP is achieved primarily by decreasing the CINR threshold for disconnection from a FAP. This modification kept the number of handovers at nearly the same level as in the case of conventional handovers.

In the future work, we aim on the extension of the metrics to efficiently evaluate users requirements. It means, for example, the throughput, the MBS offloading requirements and other parameters will be taken into account. Simultaneously, the possibility of prediction of the FAP's CINR level will be investigated. This could further prolong the time in FAPs with minimized negative impact on the outage probability.

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