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Vertical Handover Decision in Heterogeneous Wireless Networks with Femtocells

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***Abstract*—The implementation of small base stations, known as femtocells, can significantly improve network performance. Nevertheless, the inherent problem of the femtocells consists in significant amount of initiated handovers that could decrease a quality of service. This issue is further emphasized if the femtocells and the macrocells utilize different access technology, as vertical handover between them introduces longer interruption in the communication. Still, performing vertical handover can be profitable if other technology can offer higher quality of service. This paper contemplates three vertical handover decision strategies formerly considered for networks without femtocells and analyzes their performance if the femtocells are deployed. Since these strategies either introduce long interruption duration, high degradation of quality of service, or both, we also propose new vertical handover strategy considering femtocells features, such as small coverage and their vast deployment. Analytical evaluations and simulation results indicate that the proposed strategy can guarantee the highest quality of service for all considered performance metrics.**

***Index Terms*—Femtocells, vertical handover, handover decision, UMTS LTE-A.**

I. INTRODUCTION

In the next generation wireless networks, the users may move within heterogeneous networks and thus to perform Vertical Handover (VHO) [1]. The main difference between VHO and conventional Horizontal Handover (HHO) is that the purpose of HHO is to guarantee seamless transition between adjacent cells. If HHO would not be performed, the users would be disconnected from the network due to weak signal. On the other hand, the purpose of VHO is quite different and it is primarily executed if some network can offer higher Quality of Service (QoS), or if VHO is in some way more profitable for the user or the network.

The specific aspect of VHO is that VHO introduces much longer interruptions when compared to more common HHO. The HHO usually lasts tens of milliseconds whilst VHO can take hundredths of milliseconds and more, depending on involved technologies. The HHO interruption should be shorter than 27.5 ms [2] and VHO interruption for delay sensitive services should not exceed 300 ms [3]. This long service interruption temporarily decreases QoS experienced by users.

Significant amount of handovers may be generated if small base stations, known as femtocells [4], are introduced into a network. The reason is that the femtocells, represented by Femto Access Points (FAPs), cover only small areas. Moreover, a lot of FAPs are supposed to be deployed in the network [5]. Consequently, advanced handover decision strategies must be proposed taking into account FAPs' specifics (low coverage, high number of FAPs, limitations of FAP's backbone provided mainly by DSL).

So far, all existing studies focus either on HHO scenarios with/without the FAPs or on VHO scenarios without the FAPs (as described in more detail in the next section). There is no study dealing with appropriate VHO decision strategy in the networks with the FAPs. Nevertheless, this scenario is quite different and more challenging when compared to the conventional VHO without femtocells or to HHO with femtocells. The main reason why existing schemes proposed for VHO without the FAPs are not applicable here is that high amount of the FAPs is supposed to be deployed in near future and significant amount of VHOs can, thus, be generated. In addition, use of existing HHO strategies that take into account the FAPs is not sufficient as the purpose of HHO is different when compared to VHO, as already explained. Hence, this paper focuses on handover decision if the Macro Base Stations (MBSs) and the FAPs utilize different access technology. We consider two 3GPP technologies that are UMTS based on Release 7 and LTE-A based on Release 10. Still, the basic idea of the proposed decision strategy can be easily extended to different radio access technologies.

The basic idea of our proposal is to let outdoor users connected to the MBS if their QoS requirements can be met. Hence, VHO from the MBS to the FAP is not performed even if the latter can offer higher throughput since the user's demands are still satisfied. By this approach, the duration of the service interruption can be minimized (reduction of VHOs) whilst the QoS could be fulfilled.

The paper is organized as follows. The next section summarizes the related work dealing with handover decision strategies in the networks with and without the FAPs. The Section III describes individual VHO decision strategies contemplated in this paper. The next section is focused on analytical evaluations of individual handover decision schemes. Further, Section IV describes system model used for simulations and also demonstrates the results obtained by

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the simulations. The last section gives our conclusion and directions for future work.

II. Related Work

General overview on VHO decision strategies together with handover decision criteria is tackled in [6]. Further, VHO decision between 3G networks and WiFi hotspots is introduced in [7]. Three VHO decision mechanisms are suggested in [8]. While the first VHO decision is done only according to Received Signal Strength (RSS), the second decision strategy selects suitable network primarily according to the throughput that can be offered to the user. The best results are achieved by the last strategy combining both RSS and throughput metrics. In [9], the authors propose VHO algorithm taking hybrid networks based on IEEE 802.11 (WiFi) and IEEE 802.16 (WiMAX) into account. The authors in [10] also consider WiFi and WiMAX and propose an algorithm for selection of appropriate access technology based on analytic hierarchical process. The integration of mobile WiMAX and evolved 3GPP networks guarantying seamless handover mechanism between these two technologies is addressed in [11]. The VHO between 3GPP LTE and WLAN system is considered in [12]. Although the above mentioned studies deal primarily with VHO decision, the FAPs and their specifics are considered in none of above mentioned papers.

The handover decision with FAPs is considered, e.g., in [13]–[16]. In [13], the handover decision takes varying and limited FAP's backhaul capacity into account. Authors suggest performing handover to the FAP only if overall network throughput can be improved. The handover mechanism for the FAPs considering asymmetry of the transmitting power of the FAP and the MBS is introduced in [14] and further extended in [15]. These proposals increase the probability of handover to the FAP if the FAP's signal exceeds predefined threshold and if the FAP is deployed far from the MBS. The combination of additional parameters, such as user's speed and the type of the user's service (real time or non-real time) for improvement of the handover decision is presented in [16]. Nevertheless, [13]–[16] studies assume that the FAP and the MBS use the same technology and do not address the VHO decision.

Only two existing studies deal with VHO if the FAPs are included in the network. The VHO between WiFi and WiMAX with FAPs is addressed in [17]. The VHO's functionalities are deployed through the SIP protocol. The paper carries out the comprehensive measurements of the VHO delay. The results indicate that a significant delay is incurred by the DHCP mechanism, the authentication process in WiMAX, and the probing process in WiFi. Typical femtocell handover scenarios between UMTS and LTE/LTE-A are described by 3GPP TS 23.401 specification [18], where the handover completion procedure is described. Still, neither [17] nor [18] focus on VHO decision.

All above mentioned papers solely consider either the VHO decision aspects without FAPs ([6]–[12]), HHO decision with FAPs ([13]–[16]) or VHO procedure with FAPs but criteria for VHO decision are out of scope ([17], [18]). Consequently, we propose a proper VHO decision strategy if the FAPs are assumed to be implemented in the network.

III. Vertical Handover Decision Strategies

This section describes three conventional handover decision strategies together with the proposed strategy and contemplates how these are affected by introduction of the FAPs. Before individual decision strategies are described in more detail, notations, basic assumptions, and terminology used in the rest of the paper is depicted.

A. Notations, Assumptions, and Terminology

The notations used in the rest of the paper are summarized in Table I. In addition, the following assumptions are taken into account: i) the MBSs use different radio access technology than the FAPs, ii) all FAPs use the same radio access technology, iii) the FAPs are utilizing the hybrid access, since it guarantees fair compromise both for users and the operators [19], iv) the MBS is supposed to be heavily loaded, since this case represents the worst case scenario for our proposal, v) handover decision is done primarily at the side of the network, as the decision done by the users only could significantly increase the amount of VHOs, and vi) only pedestrian users are allowed to connect to the FAPs due to its small radius.

The terminology used in this paper is as follows: i) serving station is a station to which the UE is currently attached, ii) target station is a station that can potentially become the UE's serving station after the handover execution, iii) hand-in is a handover from a MBS to a FAP (it is always VHO in our paper), iv) hand-out is a handover form a FAP to a MBS (it is always VHO in our paper), and v) inter-FAP is a handover between two adjacent FAPs (it is always HHO in our paper).

B. Conventional Strategy-I (CS-I)

The CS-I follows the same principle as the conventional HHO strategy [20], as simple comparison of RSS from the serving and target stations is done. In addition, HM and HDT are used to minimize ping-pong effect due to a fast fading or if the UE moves along boundaries of two or more cells. To that end, hand-in is performed if

$$s_t\left(t\right) > s_S\left(t\right) + \Delta_{HM}\ , \tag{1}$$

where $t \in \left\langle t, t + HDT \right\rangle$.

TABLE I. NOTATIONS USED IN DESCRIPTION OF VHO ALGORITHMS.

Symbol	Semantics
$s_s(t)$	RSS from a serving station (either a FAP or a MBS)
$s_t(t)$	RSS from a target station (either a FAP or a MBS)
Δ_{HM}	Hysteresis Margin (HM)
HDT	Handover Delay Timer (HDT)
$TH_{MBS}(t)$	Available capacity of the MBS in Mbps
$TH_{FAP}(t)$	Available capacity of the FAP in Mbps
$UE_{req}(t)$	UE requirements in Mbps
$TH_{UE}(t)$	UE current bitrate in Mbps
κ	Multiplier indicating how many available resources the MBS must have to perform hand-out

The hand-out is performed similarly as described in (1). However, the FAP is supposed to be the serving station while the MBS plays role of the target station. If the signal from an adjacent FAP is higher than the signal from the serving FAP by Δ_{HM} and if the conditions to perform hand-out are not satisfied at the same time, inter-FAP has to be initiated. Otherwise, the UE would be disconnected from the network since the target FAP causes a significant interference.

The example how the CS-I performs if the FAPs are considered is illustrated in Fig. 1(a) where the signal strength of the MBS and the FAPs is depicted. Furthermore, Fig. 1(a) shows available capacity of the MBS and the FAP together with the UE's requirements and UE's throughput currently served by the serving station. Note that $TH_{MBS}(t)$ and $TH_{FAP}(t)$ fluctuations is caused by their current loads. The $TH_{FAP}(t)$ takes both throughput achieved via a radio channel ($TH_{FAPr}(t)$) and a backbone throughput ($TH_{FAPb}(t)$) into account. Thus, the FAP's available capacity equals to

$$TH_{FAP}\left(t\right) = \min\left\{TH_{FAPf}\left(t\right), TH_{FAPb}\left(t\right)\right\}. \quad (2)$$

In the given example, the MBS is not able to serve requirements of the UE, which results in a QoS degradation, since handover to the FAP is performed only according to the current signal quality. VHO to the FAP is initiated (in Fig. 1 labeled as "*VHO init.*") if the condition (1) is fulfilled. After VHO is completed (in Fig. 1 labeled as "*VHO comp.*"), the FAP becomes the serving station. This approach may generate significant amount of VHOs and, thus, it is not suitable for the networks with the FAPs.

C. Conventional Strategy II (CS-II)

This approach is based on the VHO decision algorithm proposed in [8]. The handover decision is done not only according to the current signal quality but also according to the MBS and the FAP current offered throughputs. If the condition (1) is met, hand-in is executed only when

$$TH_{FAP}\left(t\right) > TH_{MBS}\left(t\right), \quad (3)$$

where $t \in \left\langle t, t+HDT\right\rangle$. Thus, hand-in is performed only if the FAP's current throughput is higher than the MBS's throughput. The hand-out is initiated according to similar rules as in the case of hand-in as indicated in the following expression

$$TH_{FAP}\left(t\right) < TH_{MBS}\left(t\right), \quad (4)$$

where $t \in \left\langle t, t+HDT\right\rangle$. Hence, hand-out is executed if the FAP's current available capacity is lower than the MBS's available capacity. The behavior of the CS-II for the networks utilizing the FAPs is depicted in Fig. 1(b). The CS-II is able to decrease the number of handovers in comparison to CS-I. Disadvantage of CS-II is that if the UE is located close to a congested MBS, QoS is decreased similar as in CS-I.

D. Conventional Strategy III (CS-III)

This strategy is based on one of the approaches described in [8] when the current stations throughput is the primary factor for the VHO decision. The main difference in the comparison to CS-II is that hand-in to the FAP is executed whenever the throughput that could be offered to the UE is higher than the throughput of the MBS as described in (3). Note that in the case of CS-II, the primary factor is the signal strength. Thus, the condition explained in (1) does not have to be necessarily met. Hand-out from the FAP to the MBS is performed similarly as soon as the MBS throughput exceeds the throughput offered by the FAP as described in (4).

The performance of the CS-III for the heterogeneous networks with the FAPs is shown in Fig. 1(c). It is demonstrated that the degradation of QoS could be significantly mitigated by this approach when compared to CS-I or to CS-II. The UE experiences QoS degradation only due to the handover interruptions. On the other hand, this approach is more susceptible to generate higher amount of VHOs. More than that, the implementation of the CS-III is quite a challenge, since actual available capacity of all involved stations has to be known.

E. Proposed Strategy (PS)

The objective of the proposed scheme is to eliminate drawbacks introduced by all above mentioned decision strategies. The idea is to keep the UEs attached to the MBS as long as UEs' QoS requirements can be satisfied. Similarly as in the case of the CS-III, the PS primarily make the VHO decision according to the MBS's and the FAP's current available throughput. However, the PS also considers throughput requirements of the UEs. Consequently, hand-in to the FAP is performed only if:

$$TH_{MBS}(t) < UE_{req}(t), \quad (5)$$

$$TH_{FAP}(t) > TH_{MBS}(t), \quad (6)$$

where $t \in < t, t+HDT >$. Still, a condition that must be fulfilled is that the FAP must be able to serve the UE. In other words, CINR (Carrier to Interference and Noise Ratio) between the FAP and the UE is higher than a minimum value of CINR ($CINR_{min}$) and the UE is still able to receive data. This way, the PS can eliminate unnecessary VHO. Furthermore, the amount of HHOs is reduced since inter-FAPs between small adjacent cells could be avoided.

The hand-out from the FAP to the MBS is performed similarly as in the case of hand-in. That is if the load of the MBS is decreased to a sufficient level to serve the UE. Nonetheless, if hand-out would be executed immediately as the MBS's throughput is higher than UE's requirements, the PS could generate high number of VHOs (especially if the load of the stations changes frequently). Thus, the hand-out decision mechanism is enhanced by two additional features. First, a new parameter is introduced as indicates the next formula:

$$TH_{MBS}(t) > \left(1+\copyright\right) \times UE_{req}(t), \quad (7)$$

$$TH_{FAP}(t) < TH_{MBS}(t), \tag{8}$$

where $t \in < t, t + HDT >$, the amount of MBS's free resources necessary to allow hand-out can be controlled by means of parameter κ. Low value of κ leads to high number of VHOs while high value of κ results in high number of HHO. If the MBS has temporarily free resources that are barely sufficient to serve the UE (i.e., if $TH_{MBS}(t)$ is only slightly higher than $UE_{req}(t)$), no handover is performed thanks to κ.

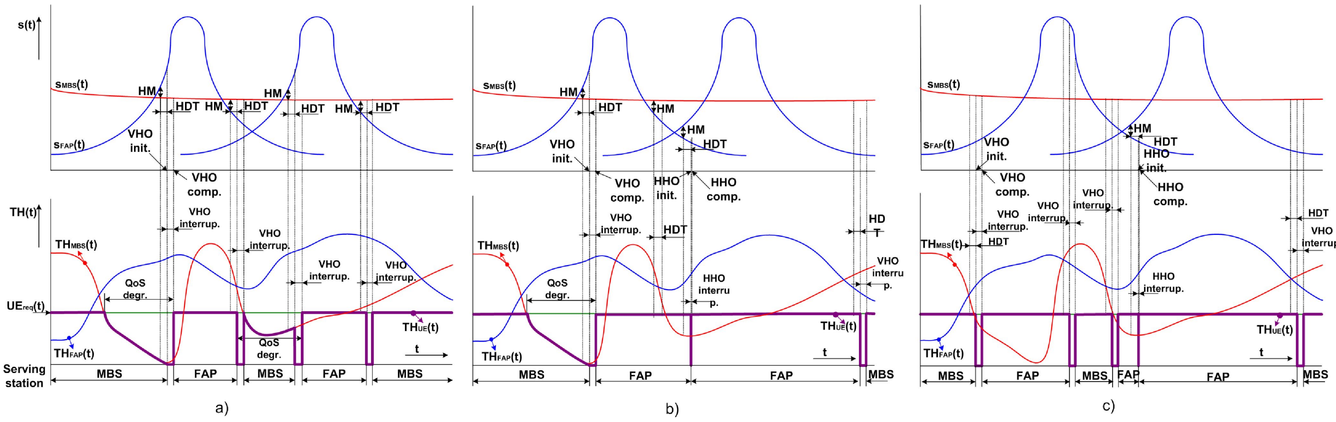


Fig. 1. VHO decision according to conventional strategies; a) CS-I, b) CS-II, c) CS-III.

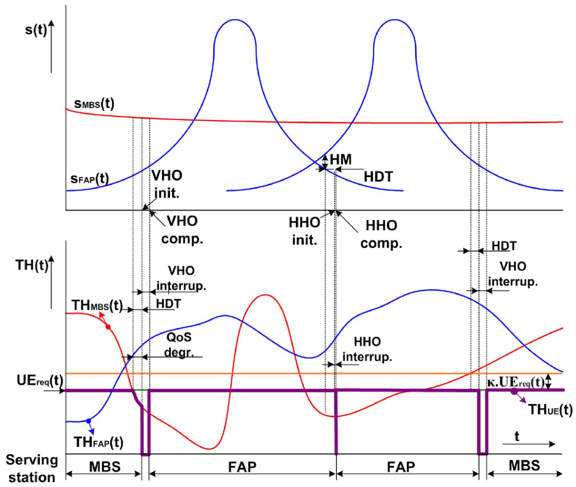


Fig. 2. VHO decision according to proposed strategy.

Second, the hand-out decision is done only when the UE is leaving the FAP's coverage. In other words, as long as the UE is connected to the FAP and its QoS requirements are fulfilled, it is redundant to perform hand-out. The moment when the UE is moving out of the FAPs coverage, either hand-out or inter-FAP handover is initiated.

A behavior of the PS is illustrated in Fig. 2. The advantage of the PS is that the amount of VHOs could be significantly mitigated as only two VHOs and one HHO is performed. Further, the QoS degradation is notably reduced since only small QoS degradation is observed before hand-in depending on the HDT duration.

IV. NUMERICAL ANALYSIS

This section analyses the factors that influence the probability of hand-in ($\Pr(HO_{IN})$), presents the model for analytical evaluations and shows numerical results.

A. *Probability of Hand-in*

The hand-in in the case of CS-I is influenced by the distance of the UE from the MBS ($d_{UE\text{-}MBS}$), by the distance of the UE from the FAP ($d_{UE\text{-}FAP}$) and by the value of hysteresis margin (Δ_{HM}). Impact of $d_{UE\text{-}MBS}$ on hand-in probability can be formulated as follows

$$d^1_{UE-MBS} > d^2_{UE-MBS} \Rightarrow \Pr\left(HO_{IN} \mid d^1_{UE-MBS}\right) > \Pr\left(HO_{IN} \mid d^2_{UE-MBS}\right). \tag{9}$$

It is evident that with an increase in the distance between the UE and the MBS, the probability of hand-in is getting higher. On the other hand, the probability of hand-in is increased with lower $d_{UE\text{-}FAP}$ since $s_t(t)$ in (1) is higher as

$$d^1_{UE-FAP} < d^2_{UE-FAP} \Rightarrow \Pr\left(HO_{IN} \mid d^1_{UE-FAP}\right) > \Pr\left(HO_{IN} \mid d^2_{UE-FAP}\right). \tag{10}$$

Finally, the value of Δ_{HM} is indirectly proportional to the probability of hand-in as explicitly shown in (1). Thus, the probability of hand-in for the different value of Δ_{HM} is

$$\Delta^1_{HM} > \Delta^2_{HM} \Rightarrow \Pr\left(HO_{IN} \mid \Delta^1_{HM}\right) < \Pr\left(HO_{IN} \mid \Delta^2_{HM}\right). \tag{11}$$

Besides the factors influencing CS-I, available capacity of the MBS (TH_{MBS}) and the FAP (TH_{FAP}) are taken into account in the case of CS-II. According to (3), the probability of hand-in with respect to the stations capacity can be formulated as:

$$TH^1_{MBS} > TH^2_{MBS} \Rightarrow \Pr\left(HO_{IN} \mid TH^1_{MBS}\right) < \Pr\left(HO_{IN} \mid TH^2_{MBS}\right), \tag{12}$$

$$TH^1_{FAP} > TH^2_{FAP} \Rightarrow \Pr\left(HO_{IN} \mid TH^1_{FAP}\right) > \Pr\left(HO_{IN} \mid TH^2_{FAP}\right). \tag{13}$$

In the case of CS-III, the probability of hand-in is solely dependent on the available capacity of the stations while the signal quality is not considered here. Thus, only (12) and (13) are assumed. Logically, the probability of hand-in is increased with the FAP's available capacity and with decrease of the MBS's available capacity.

Finally, the decision of hand-in in PS considers also the current requirements of the UE (*UEreq*) that is about to perform handover to the FAP. Obviously, the higher UE's requirement increase the probability of hand-in on the assumption that the FAP is able to offer higher throughput as suggested in the next formula:

$$\left(UE_{req}^{1} > UE_{req}^{2}\right), \tag{14}$$

$$TH_{FAP} > TH_{MBS} \Rightarrow \Pr\left(HO_{IN} \mid UE_{req}^{1}\right) > \\ > \Pr\left(HO_{IN} \mid UE_{req}^{2}\right). \tag{15}$$

B. Model for Analytical Evaluations

The model used for analytical evaluation is illustrated in Fig. 3. Independently on technology used, TDD duplex mode is assumed. To keep reasonable length of the paper, only the influence of Δ_{HM} on CS-I/CS-II and the impact of the MBS' load (i.e., TH_{MBS}) on CS-II/CS-III/PS are evaluated. To that end, three different values of Δ_{HM} are assumed (see Table II). The load of the MBS is varying between 50 % and 95 %. The FAP is utilizing hybrid access and 50 % of the radio resources could be dedicated to the outdoor UE if requested. Still, other parameters, such as different MBS-UE distance or varying FAP-UE distance, are taken into account in our estimation. At the end, results are averaged out over all those parameters. To be more specific, three different locations of the FAP with respect to the MBS are considered (near, in the middle, and at the edge of the MBS cell). Also the position of the FAP within the house is varying as indicated in Fig. 5. Finally, the position of the UE is generated randomly 1000 times within the square as shown in Fig. 3.

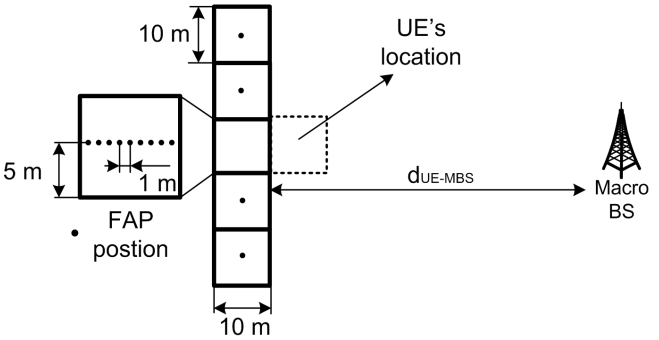


Fig. 3. Scenario for analytical evaluations.

To compare the available capacity that could be offered to outdoor UEs, we calculate the throughput for both technologies as follows. In the case of LTE-A system, the throughput is derived according to CINR, which is observed by the UE, as indicated by following formula

$$Th_{LTE-A}[Mbit/s] = \frac{n_{RE} \times \Gamma}{t_f \times 10^6}, \tag{16}$$

where n_{RE} represents the amount of the resource elements available for data transmission, Γ corresponds to the transmission efficiency based on CINR (see [21]), and t_f stands for the physical layer frame duration.

The throughput offered by UMTS for one cell is up roughly 21.1 Mbps on the assumption that 15 HS-PDSCH codes and 64QAM are used [22]. The available throughput depends on the load of the stations, that is, how often the scheduler assigns transmission time intervals (TTI) to the UE. Further, the available capacity depends on a Transport Block Size (TBS) transmitted per every TTI. Subsequently the available capacity can be derived as

$$TH_{UMTS}[Mbit/s] = \frac{TBS}{10^6} \times \frac{10^3}{TTI} = \frac{TBS}{TTI \times 10^3}. \tag{17}$$

The parameters for the analytical evaluations are summarized in Table II.

TABLE II. PARAMETERS FOR ANALYTICAL EVALUATIONS.

Parameter	Value
LTE-A/UMTS frequency band [GHz]	2/2.1
LTE-A/UMTS channel bandwidth [MHz]	20/5
LTE-A/UMTS Frame duration t_f [ms]	10
MBS/FAP/UE transmit power [dBm]	46 / 15 / 21
Number of FAPs	5
Noise spectral density [dBm/Hz]	- 174
Loss ext. wall/window [dB]	10/3
Physical layer overhead [%]	25
Δ_{HM} between the MBS and the FAP [dB]	2, 6, 10
Outdoor path loss model	ITU-RP.1238 model [20]
Indoor path loss mode	COST 231 model [20]
UE_{req} [Mbit/s]	2

C. Numerical Results

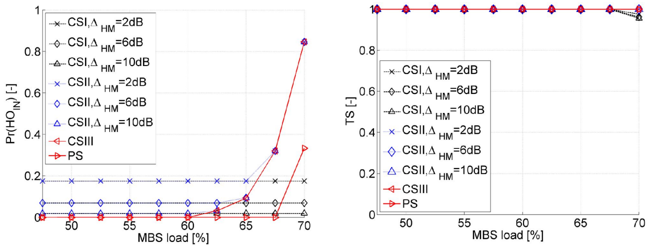
Two scenarios are considered in the analytical evaluations. The first scenario (Scenario I) represents the case when the MBS uses LTE-A while UMTS technology is implemented at the side of the FAPs. The second scenario (Scenario II) corresponds to the situation when the technologies between the MBS and the FAPs are exchanged.

Figure 4 illustrates the performance for Scenario I. In the case of CS-I the probability of hand-in Pr(HO_{IN}) is the same for all load of the MBS since this scheme is not influenced by this factor. As indicated in (9), higher value of hysteresis decreases Pr(HO_{IN}). The performance of CS-II is similar to CS-I as long as the load of the MBS is not high. In Scenario I, the MBS available capacity is higher than the capacity of the FAP. Nonetheless, if the MBS is loaded heavily (80 % and higher), the probability of hand-in is increased substantially. This is in compliance with (12). If CS-III or PS are considered, no hand-ins occur at low or middle loads of the MBS. However, the performance of CS-III is similar to CS-II at heavy loads. The PS demonstrates that it is able to significantly reduce the amount of hand-ins. Only at 95 % of the MBS's load CS-I performs better than PS but it is at the cost of lower amount of served traffic. All other decision strategies are able to serve 100 % of UE's traffic (TS).

TABLE III. PARAMETERS FOR SIMULATIONS.

Parameter	Value
$CINR_{min}$ [dB]	-3
Number of FAPs	50
HDT value [s]	0.5
Δ_{HM} between the MBS and the FAP / between the FAPs [dB]	2, 4, 6, 8, 10 / 2
κ [-]	0 - 1,2
HHO interruption HHO_{int} [ms]	25
VHO interruption VHO_{int} [ms]	300
Real-time duration of one simulation cycle [s]	10 000
Standard deviation of shadowing for MBS/FAP [dB]	8 / 4

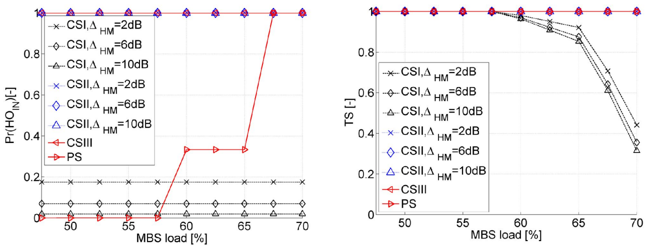
Since the MBS, in general, can offer lower capacity, the probability of hand-in is increased in the case of CS-II, CS-III and PS. The probability of hand-in for CS-II and CS-III is high as the FAP is always able to offer higher throughput than the MBS (see (3)).



a) b)

Fig. 4. Probability of hand-in (left figure) and served traffic (right figure) for Scenario I.

The performance for Scenario II is demonstrated in Fig. 5.



a) b)

Fig. 5. The probability of hand-in (left figure) and served traffic (right figure) for Scenario II.

Only PS is able to distinctively decrease Pr(HO_{IN}) as long as the load of the MBS does not exceed 70 %. The results for CS-I are the same as in Fig. 4 as this decision strategy does not consider capacity of individual stations. Although the performance of CS-I is the highest for the load of the MBS above 70 % in terms of Pr(HO_{IN}), the served traffic is notably decreased.

V. SIMULATIONS

This section focuses on the description of the simulation model and presentation of the simulation results.

A. Simulation Model

The simulations performed in MATLAB use similar parameters as depicted in Table II. Nevertheless, several additional aspects are taken into account as suggested in Table III.

The system model contains one hundred square structured houses and corresponds to simplified version of the corporate scenario according to Small cell forum [23]. The disposition of the houses is depicted in Fig. 6. The FAPs are deployed uniformly in a half of the houses. The position of the FAP within the house is the same as in the analytical evaluations. The simulation is run separately for every position of the FAP and then the results are averaged out.

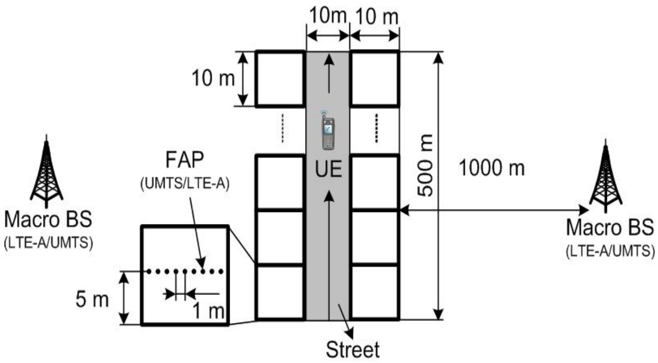


Fig. 6. System model and MBSs/FAPs deployment.

The outdoor users are moving within the streets boundaries from the south to the north with speed equal to 1 m/s along straight trajectories. Their distance from the house is selected randomly with uniform distribution. The indoor users are fixed and always connected to the FAPs.

Since we study handover decision strategies, the pedestrian outdoor users are always active with either voice emulated by VoIP traffic model or DL data emulated by FTP traffic model (the UE utilizing FTP generates 2 Mbps). Whether the former or latter traffic is used is selected randomly with equal probability. The purpose why we use also FTP model is that this scenario is more challenging for our proposal as our objective is to let attach the UE to the MBS.

The MBS traffic load is not fixed during the simulation and varies in time. The mean traffic load of the MBS is set to 85 %. Again, this heavy load is worse case for our proposal as at the light traffic load of the MBS, the UE stays connected to the MBS according to the PS. Available capacity of individual stations is calculated according to (13) and (14) depending on selected technology.

Several performance metrics are taken into consideration. Firstly, the number of handovers depending on Δ_{HM} (for CS-I and CS-II) and depending on κ (for CS-III and PS) is monitored. We distinguish the amount of both HHOs and VHOs. All the values are normalized to the maximal VHOs generated by the CS-I ($N_{VHO\max}^{CS-I}$), since this approach introduces the highest amount of handovers. Thus, the amount of handovers is expressed as:

$$n_{HHO}[-] = \frac{N_{HHO}}{N_{VHO\max}^{CS-I}}, \tag{18}$$

$$n_{VHO}[-] = \frac{N_{VHO}}{N_{VHO\max}^{CS-I}}. \tag{19}$$

Secondly, the duration of the service interruption due to the execution of all handovers is calculated as

$$HO\_\text{interr}\ [\%] = \frac{n_{HHO} \times HHO_{\text{int}} + n_{VHO} \times VHO_{\text{int}}}{T} \times \times 100, \quad (20)$$

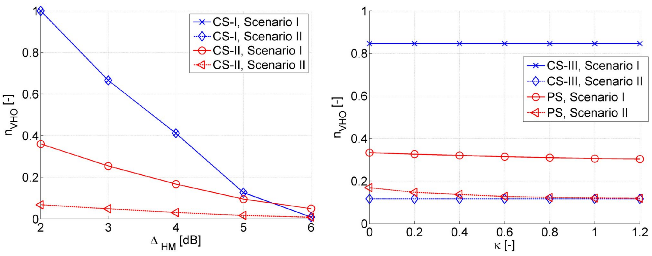
where T represents the overall simulation time. Thirdly, we measure the overall time when the QoS requirements are not fulfilled for the outdoor UEs as

$$QoS\_decreased\ [\%] = \frac{t_d}{T} \times 100, \quad (21)$$

where t_d is the summation of the times when the throughput of the current serving station ($TH_{MBS}(t)$ or $TH_{FAP}(t)$) is lower than $UE_{req}(t)$. The QoS requirements are not fulfilled if not all data can be transmitted at the moment. The last evaluation criterion is the amount of the traffic served *(TS)* during the whole simulation time T

$$TS^T\,[\%] = \frac{TG^T - TL^T}{TG^T} \times 100, \quad (22)$$

where TL stands for the lost traffic that cannot be served during the simulation cycle by the system and TG is the amount of the traffic generated within the simulation cycle.



a) b)

Fig. 7. Normalized number of VHOs for individual decision strategies.

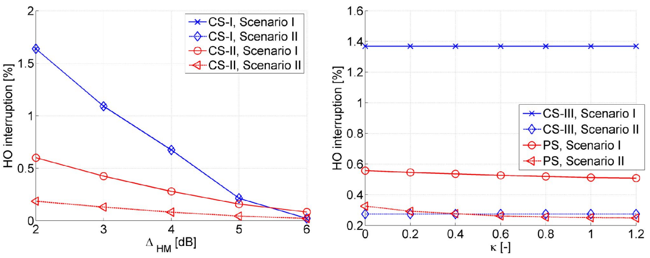


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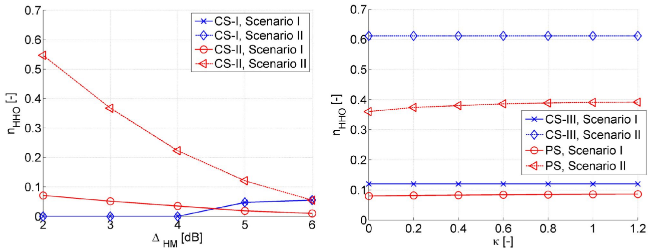
Fig. 8. Handover interruption time for individual decision strategies.

B. *Simulation Results*

Figure 7 and Fig. 8 depict the normalized amount of handovers generated during the simulations. Figure 7 demonstrates that in Scenario I, the decision according to the CS-I generates the lowest amount of HHOs if Δ_{HM} is up to 6 dB. Still, for all other VHO decision strategies, the amount of HHOs is negligible. The number of HHOs is slightly increased for Δ_{HM} equal to 8 dB and 10 dB for the CS-I. This is due to the fact that with higher Δ_{HM}, VHO is postponed long enough to perform HHO to an adjacent FAP rather than to initiate VHO to the MBS.

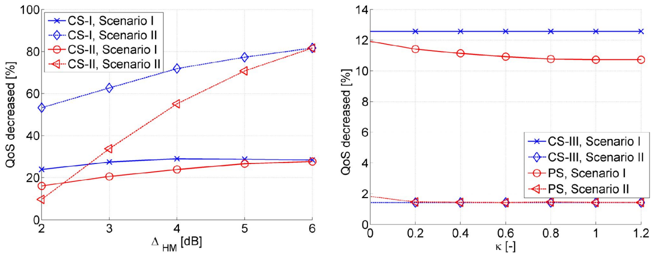
The lowest amount of HHOs for Scenario II is again generated by the CS-I independently on Δ_{HM}. The amount of handovers (both HHOs and VHOs) is the same for the CS-I for both scenarios since handover decision is done only according to the signal strength. On the contrary, the amount of HHOs is notably increased for the CS-II, the CS-III and the PS. The worst affected is the CS-II for lower Δ_{HM} values and the CS-III. The reason for this phenomenon is that the FAPs utilizing the LTE-A have higher capacity than the MBS using UMTS for the most of the time. Hence, the UE rather performs HHO between FAPs instead of VHO to the MBS. Regarding our proposal, the amount of HHOs is slightly increased for higher values of κ. Nonetheless, the amount of HHOs is significantly lower than in the case of CS-III.



a) b)

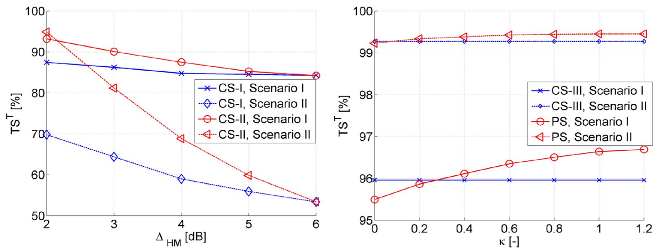
Fig. 9. Normalized number of HHOs for individual decision strategies.

More important indicator is the amount of VHOs instead of HHOs since the negative effect of VHO is more prominent due to longer duration of the interruption. Figure 8 reveals that in the case of Scenario I, the best results are observed for CS-II and the PS. The CS-I is able to outperform CS-II only for Δ_{HM} value equal to 10 dB. Otherwise, the performance of CS-I is highly unsatisfactory similar as in the case of CS-III). Other interesting observation derived from Fig. 8 is that the amount of VHOs for all strategies except CS-I is lower for Scenario II. This occurrence confirms the fact that if the MBS is utilizing UMTS, the UEs prefer to be connected to the FAPs. On the other hand, this result in an increase of HHOs for Scenario II as illustrated in Fig. 7.



a) b)

Fig. 10. Decrease of QoS for individual decision strategies.



a) b)

Fig. 11. The amount of traffic served for individual decision strategies.

Figure 9 depicts the length of the service interruption caused by both HHOs and VHOs. Since the interruption incurred by VHO is more significant than HHO interruption, the results are similar to Fig. 8. Consequently, the worst performance is observed for CS-I as the interruption of the service lasts approximately up to 1.6 % cases (this is true for both scenarios). Similarly if Scenario I is considered, CS-III introduces service interruption in up to 1.4 % of the simulation time. On the other hand, the best performance in the case of Scenario I is accomplished by PS as the service interruption lasts only up to 0.51 % of the simulation time. If Scenario II is implemented, the best results are achieved by CS-II since service interruption is only up to 0.2 %. Nevertheless, CS-III and PS perform only slightly worse than CS-II.

Figure 10 shows QoS degradation caused either due to the handover interruption or if the serving station is not able to serve all data generated by the outdoor UEs. The PS outperforms all other VHO decision strategies for both scenarios except for Scenario II where the results of PS are comparable with CS-III. Moreover, while the performance of CS-III and PS is notable improved for Scenario II, the results achieved by CS-I and CS-II are significantly worsened for higher values of Δ_{HM}.

Figure 11 depicts the amount of traffic that could be served by individual handover decision strategies. The results are analogical to those observed in Fig. 10. The first two strategies (CS-I and CS-II) still perform worse than the strategies taking the available capacity of the stations and requirements of the UEs into consideration. Further, it is demonstrated that although higher Δ_{HM} mitigates the redundant handovers more efficiently, this is at the cost of notable decrease in UE’s throughput.

In the following tables, the values of Δ_{HM} and κ that should be considered to obtain the best results are depicted. It is demonstrated that higher values of Δ_{HM} leads to significant drop in QoS and throughput in the case of CS-I and CS-II strategies. Hence, the lowest value of Δ_{HM} = 2 dB is considered to be the best option. In the case of PS, the best performance is always achieved for κ = 1.2. Note that the results for CS-III are dependent neither on Δ_{HM} nor on κ as only load of individual stations is the only decision factor.

If we analyse suitability of individual VHO decision strategies for the networks with the FAPs, following key findings could be observed.

As indicated in Table IV and Table V, CS-I generates the highest amount of VHOs and thus longest service interruption (1.64 % for both scenarios). The worst performance is achieved also in terms of QoS degradation and throughput. The performance gap is observed especially in Scenario II. Consequently, CS-I is not suitable for the heterogeneous networks with the FAPs.

TABLE IV. COMPARISON OF DECISION STRATEGIES – SCENARIO I.

	n_{HHO} [-]	n_{VHO} [-]	HO int. [%]	QoS deg. [%]	TS^T [%]
CS-I (Δ_{HM}=2 dB)	0	1	1.64	23.94	87.47
CS-II (Δ_{HM}=2 dB)	0.07	0.36	0.6	16.09	93.2
CS-III	0.12	0.83	1.37	12.57	95.96
PS (κ=1.2)	0.09	0.30	0.51	10.72	96.7

TABLE V. COMPARISON OF DECISION STRATEGIES – SCENARIO II.

	n_{HHO} [-]	n_{VHO} [-]	HO int. [%]	QoS deg. [%]	TS^T [%]
CS-I (Δ_{HM}=2 dB)	0	1	1.64	53.25	69.82
CS-II (Δ_{HM}=2 dB)	0.55	0.07	0.19	9.69	94.9
CS-III	0.61	0.12	0.27	1.44	99.27
PS (κ=1.2)	0.39	0.12	0.25	1.43	99.45

The results accomplished by CS-II are significantly improved for all observed performance metrics in comparison to CS-I. Above all, the handover interruption time is significantly minimized to 0.6 % (Scenario I) and to 0.19 % (Scenario II). Still, the QoS degradation is distinctive and the served traffic is notably lower than in the case of CS-III or PS. The additional drawback of CS-II is that if the received signal from the MBS is significantly higher than the received signal from the FAPs, the UE would be connected still to the MBS regardless its current capacity. Hence, neither CS-II is appropriate to be implemented to the networks with the FAPs.

Regarding CS-III, the results are favourable in terms of QoS degradation and served traffic. Mainly for Scenario II where QoS degradation lasts only 1.44 % of whole simulation time and 99.27 % of generated traffic is served. The disadvantage of CS-III is that it generates high service interruption equal to 1.37 %). Other drawback is that the status of current traffic loads has to be reported all the time. Thus, the utilization of CS-III is not really suitable.

The results achieved by PS are rather encouraging. Especially, if we consider the worst case scenario is assumed in the simulations and PS’s merits cannot be fully exploited. Despite of this fact, the PS outperforms all VHO decision strategies in all considered aspects if Scenario I is assumed. Only the CS-II presents slightly better results in terms of service interruption when Scenario II is considered. In addition, PS introduces negligible additional overhead in comparison to CS-III.

VI. CONCLUSIONS

This paper has been focused on VHO decision strategies in the heterogeneous networks with femtocells. We have demonstrated that existing VHO decision methods are not suitable for networks with FAPs. Thus, we have proposed new VHO decision strategy that considers FAPs specifics.

The proposed decision strategy is the most suitable out of all evaluated strategies for heterogeneous femtocells network. Mainly in the case of Scenario I, PS outperforms each existing strategies in most of the considered aspects such as the amount of vertical handovers, the service interruption time, QoS degradation and the amount of served traffic. In case of the Scenario II, the PS is the most sufficient in terms of QoS degradation and served traffic. However, also other performance metrics are only marginally worse than other existing schemes. The other advantage of PS is its uncomplicated implementation that could be easily accomplished by introduction of simple messages transmitted via the backbone of the FAPs. In addition, the signalling overhead introduced by the PS is insignificant.

As the future work, we intend to extend the work presented in this paper by considering different technologies at the side of individual FAPs, which make the decision process even more challenging.

REFERENCES

[1] K. L. Chiu, Y. S. Chen, R. H. Hwang, “Seamless session mobility scheme in heterogeneous wireless networks”, *Int. Journal of Communication Systems*, vol. 24, no. 6, pp. 789–809, 2011. [Online]. Available: http://dx.doi.org/10.1002/dac.1189

[2] *Guidelines for evaluation of radio interface technologies for IMT-Advanced*, ITU-R M.2135 Recommendation, 2008.

[3] 3GPP TR 25.913 V9.0.0., Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN), 2009.

[4] Z. Bharucha, H. Hass, A. Saul, G. Auer, “Throughput Enhancement Through Femto-Cell Deployment”, *European Trans. Telecommunications*, vol. 21, no. 5, pp. 469–477, 2010. [Online]. Available: http://dx.doi.org/10.1002/ett.1428

[5] M. Z. Chowdhury, J. M. Jang, Z. J. Haas, “Cost-Effective Frequency Planning for Capacity Enhancement of Femtocellular Network”, *Personal Wireless Communications*, vol. 60, no. 1, pp. 83–104, 2011. [Online]. Available: http://dx.doi.org/10.1007/s11277-011-0258-y

[6] X. Jan, A. Sekercioglu, S. Narayanan, “A survey of vertical handover decision algorithms in Fourth Generation heterogeneous wireless networks”, *Computer Network*, vol. 54, no 11, pp. 1848–1863, 2010. [Online]. Available: http://dx.doi.org/10.1016/j.comnet.2010.02.006

[7] W. I. Kim, B. J. Lee, J. S. Song, Y. S. Shin, Y. J. Kim, “Ping-Pong Avoidance Algorithm for Vertical Handover in Wireless Overlay Networks”, in *IEEE Vehicular Technology Conf.-Fall (VTC-Fall* 2007*)*, 2007, pp. 1509–1512,.

[8] A. M. Wengi, G. Tamea, T. Inzerilli, R. Cusani, “A Combined Vertical Handover Decision Metric for QoS Enhancement in Next Generation Networks”, in *IEEE Int. Conf. on Wireless and Mobile Computing, Networking and Communications (WIMOB)*, 2009, pp. 233-238.

[9] Z. Dai, R. Fracchia, J. Goesteau, P. Pellati, G. Vivier, “Vertical Handover Criteria and Algorithm in IEEE802.11 and 802.16 Hybrid Networks”, in *IEEE Int. Conf. Communications (ICC)*, 2008, pp. 2480–2484.

[10] S. M. Matinkhah, S. Khorsandi, S. Yarahmadian, “A new handoff management system for heterogeneous wireless access networks”, *Int. Journal of Communication Systems*, 2012.

[11] W. J. Song, J. M. Chung, D. Lee, “Handover between Mobile WiMAX and 3GPP UTRAN through the Evolved Packet Core”, *IEEE Communication Magazine*, vol. 47, no. 4, pp. 66–73, 2009. [Online]. Available: http://dx.doi.org/10.1109/MCOM.2009.4907409

[12] T. S. Kim et al. “Vertical Handover between LTE and Wireless LAN System based on Common Resource Management (CRRM) and Generic Link Layer (GLL)”, in *Int. Conf. Interaction Sciences: Information Technology, Culture and Human (ICIS)*, 2009.

[13] Z. Becvar, P. Mach, “On Enhancement of Handover Decision in Femtocells”, *IFIP Wireless Days (WD)*, pp. 1–3, 2011.

[14] J. M. Moon, D. H. Cho, “Efficient Handoff Algorithm for Inbound Mobility in Hierarchical Macro/Femto Cell Networks”, *IEEE Communication. Letters*; vol. 13, no. 10, pp. 755–757, 2009. [Online]. Available: http://dx.doi.org/10.1109/LCOMM.2009.090823

[15] J. M. Moon, D. H. Cho, “Novel Handoff Decision Algorithm in Hierarchical Macro/Femto-Cell Networks”, in *IEEE Wireless Communications and Networking Conf. (WCNC)*, 2010, pp. 1–6.

[16] H. Zhang, X. Wen, B. Wang, W. Zheng, Y. A. Sun, “Novel Handover Mechanism between Femtocell and Macrocell for LTE based Networks”, in *Int. Conf. Communication Software and Networks (ICCSN)*, 2010, pp. 228–231.

[17] Y. Im et al. “Vertical handovers in Multiple Heteregeneous Wireless Networks: A Measurement Study for the Future Internet”, in *Int. Conf. on Future Internet Technologies* (CFI), 2010. [Online]. Available: http://dx.doi.org/10.1145/1853079.1853083

[18] 3GPP: LTS 23.401 v10.0.0. Services and System Aspects; General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access, 2011.

[19] A. Golaup, M. Mustapha, L. B. Patanapongpibul, “Femtocell Access Control Strategy in UMTS and LTE”, *IEEE Communication Magazine*, vol. 49, no. 7, pp. 117–123, 2009. [Online]. Available: http://dx.doi.org/10.1109/MCOM.2009.5277464

[20] G. P. Pollini, “Trends in Handover Design”, *IEEE Communication Magazine*, vol. 34, no. 3, pp. 82–90, 1996. [Online]. Available: http://dx.doi.org/10.1109/35.486807

[21] Ch. Yu, W. Xiangming, L. Xinqi, Z. Wei, “Research on the Modulation Coding Scheme in LTE TDD Wireless Network”, in *Int. Conf. on Industrial Mechanotrics and Automation (ICIMA)*, 2009, pp. 468–471.

[22] S. H. Wu, Y. L. Chung, Z. Tsai, “A study of dynamic network selection for HSPA dual-network users”, in *Int. Conf. Information Networking (ICOIN)*, 2011, pp. 329–334.

[23] SmallCellForum, *Interference management in OFDMA Femtocells*, white paper, 2011.