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Enhanced Matching Game for Decoupled Uplink Downlink Context-Aware Handover

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Abstract: In this paper, we address the problem of cell association during a handover performed in a dense heterogeneous network, where the preference of a mobile user's equipment in terms of uplink traffic is not the same as for the downlink traffic. Therefore, since mobility is an intrinsic element of cellular networks, designing a handover from the perspective of the uplink and downlink is mandatory in the context of 5G cellular networks. Based on this arena, we propose a decoupled uplink-downlink handover scheme while making use of femtocells in order to maximize the overall network entity utilities and avoid overloading macrocells. However, the fact that the handover process is performed in a dense heterogeneous network makes the issue NP-hard. Therefore, taking into account the need for self-organizing solutions, we modeled the handover process as a matching game with externalities. Thus, we will provide an aspect of intelligence for the execution of the handover process to mobile user's equipment (UE). To make the proposition more efficient, we integrate an assignment step to assist the matching game. Hence, the base stations will be investigated and filtered, keeping only the helpful base stations as the players in terms of the quality of service for the uplink and downlink. The numerical results verify the superiority of the proposed context-aware algorithm over traditional downlink handover and traditional decoupled uplink and downlink handover schemes, by improving the load balancing, increasing rates and reducing delays.

Keywords: 5G; heterogeneous wireless networks; small cells; decoupled uplink and downlink association; network selection; matching game; handover process; cell association

1. Introduction

In recent years, the requirements of mobile data traffic have radically changed, whereby the beneficial base station (BS) for the downlink traffic (video streaming, downloading) is not the same as for the uplink traffic (video chatting, gaming) [1,2]. More specifically, applications with intensive consumption of uplink traffic have emerged in the realm of mobile communication. In addition, since the progress of 5G is tending towards a capability enhancement of 1000-fold even to users with high mobility, the idea of the developmental heterogeneous densification of the network [3] will be the essential key to fulfilling the purpose of 5G's development. Thus, the expanding level of heterogeneity over past and up coming years is a primordial truth that contributes to meeting the demands of the paradigm shift in uplink and downlink requirements, by offering a promising arrangement that utilizes an ultra-dense network to affiliate users suitably. More precisely, this heterogeneity lies in deploying multi-level cellular networks, such as femtocells [4], which are generally portrayed by the transmission power, coverage area, ease of deployment and the cost. However, even with a reasonable arrangement, such as setting these femtocells in high activity territories, most of the user's equipment (UE) will, in any case, receive a most grounded downlink signal from the macrocell station. In the context of this environment, the need for a cost-effective way of managing the uplink and downlink requirements separately for cell association while executing the handover process arises. At the time of writing, a separate association for uplink and downlink in HetNet has been demonstrated such that they can offer higher throughput to static UE. Nevertheless, the situation with mobile UE is quite a complicated issue, since mobile UE will frequently leave base stations and will cross an extensive number of new cells.

In this respect, the proposed handover approach will take the femtocells into consideration to exploit the gain revealed by femtocells to the next-generation wireless network [5]. However, it is quite possible that mobile UE captures the higher downlink rate from macro BS, while for the same mobile UE, it will obtain a beneficial uplink rate if it is associated with the nearby femto BS. For this reason, the proposed handover scheme will embrace a new concept to choose the BS to deal with, among macro BSs and femto BSs.

In such a context, we consider an uplink execution during the association step for the handover procedure to meet the service requirements. Therefore, along these lines, unlike a conventional handover, we handle the case where the selected BS for the downlink handover may not be valuable for the uplink handover [6]. Using the decoupled uplink-downlink (DUDe) approach [5] for a mobile UE association, we give the possibility to a mobile UE to deal with two BSs in the downlink and uplink independently. Otherwise, while adopting this approach for the handover process, the positive effects are two-fold by improving uplink emission control, and as an obvious consequence, we will enhance the uplink interference state and promote transmit power reduction for UE. In this context, to resolve the problem of the applicability of the centralized optimization approach in a heterogeneous context, we adjust the handover process to a matching game with externalities adapted to a mobile UE. Thus, we give a distributed solution to maximize the gain of all the components of a heterogeneous network while preserving a load balancing that guarantees a required quality of service (QoS). The integration of the matching game will provide a robust mathematical tool to model and to analyze distributed interactions between entities with opposing interests, as well as to ensure equity since BSs cannot individually try to maximize their sucess due to their restricted rationality.

In this way, our commitment will be arranged towards a mobile UE association. The association will offer fulfillment to the mobile UE in terms of QoS to the downlink as much as the uplink while favoring a specific load adjustment utilizing a self-organization process for faster convergence. Thus, our current contribution extends the DUDe association schemes-based matching game and covers some novel aspects, as follows:

- We defined association issues as a utility function (see Section 3.1) that guarantees that each UE will meet the stringent data throughput prerequisites for uplink and downlink.
- We define the QoS as a context-aware constraint to the above optimization problem. To do this, we go through the assignment step (see Section 4.2) to filter the candidate BSs for the selective handover process.
- So as to enhance the network throughput and to consider a reasonable resource allocation for the UE, the proposed handover solution will boost the defined utility function (see Equation (7) in Section 3.1), which is the logarithm sum of the UE long-term rates served by the BS, to support a strategic distance from the overload circumstance and offer proportional equity. As a result, our proposed utility function encourages mobile UE association with the least loaded cells, even if they offer an instantaneous signal-to-interference-plus-noise ratio (SINR) less than the macro BS.
- At that point, we formulate the handover process as a matching game with externalities (see Section 4). In the proposed scheme, we support the decrease of the algorithm's convergence time by introducing a stable dismissing-matching concept and assignment steps. During the defined assignment step, we investigate and filter the BS to keep just the helpful agent BS in terms of QoS for uplink and downlink. Along these lines, we propose a suitable cellular association calculation that achieves a local optimum with a faster convergence since the assignment step will further reduce the calculation time.

- To study the performance of the proposed scheme, we elaborate a simulation scenario in network simulator-3 [7] for a two-tier heterogeneous network. The numerical results verify their potentials on utility increase and equity in comparison with the traditional cell association for the coupling and decoupling technique.

The rest of this paper is arranged as follows: a prologue to the matching-game theory application for the system choice will be presented in Section 2. In Section 3, we depict the system model and frame the issue as the maximization of the utility function. Afterwards, our proposed model will be presented in Section 4, where we characterize the decoupled handover process as an assignment QoS-based technique in the primary stage and a matching-game in the second step. Then, Section 5 portrays the execution assessment scheme where the reproduction details and results are examined for the exposed schemes. Finally, we complete with the conclusion in Section 6.

2. Related Work

In order to keep pace with network evolution, redesigning the handover scheme is a pivotal strategy to accomplish the best QoS in a heterogeneous environment for mobile UE. This settlement of how to make stalwart network selection for the mobile user association requires us to investigate UE preferences in terms of uplink (UL) and downlink (DL) while taking the mobility into account.

2.1. Handover Schemes in Ultra-Dense Networks

Introducing more advanced handover plans for ultra-dense networks where UL preference is not the same as DL preference is necessary. However, related work for smart handover at the time of writing is limited, and the vast majority of the proposed handover plans neglect the UL preference. For example, Taha et al. [8] propose an astute handover process algorithm ensuring load balance in 5G networks and enhanced the QoS during the handover of videos from mobile cameras in environmental monitoring. They utilize base station limits, the movement of mobile nodes, signal strength, and generated traffic as parameters for handover decision-making. However, they do not indicate the criteria utilized for choosing candidate BS.

To the best of our knowledge, the majority of intelligent handover schemes are based on skipping technique. In this context, Demarouch, Psomas, and Krikidis [9] developed two different handover techniques adapted to ultra-dense networks. They managed to reduce the handover rate and handover cost in order to meet the required quality of service. Therefore, based on skipping techniques, the principal objective of the proposed techniques is to decrease the high handover rates. Another different handover issue was studied by Arshad et al. [10,11], where reducing handover delay was the principal objective of their research. Using stochastic geometry, they propose a mathematical framework that incorporates handover delay into the rate analysis. The proposed handover schemes sacrifice prioritization of user connection to reduce the handover delay and enhance the long-term average rate. Arshad et al. in [12] redefine their past work for a multi-level system and introduce a compelling arrangement of topology-aware handover skipping. Based on BS intensity, they handle the interaction between a handover cost and a client throughput. In this paper [12], they propose an intelligent handover scheme, while making use of topology awareness and user trajectory estimation.

2.2. DUDe Association

Recently the concept of decoupled association has received a great deal of interest in various works [2,13–15]. It is important to hypothetically approve and evaluate the general uplink execution enhancement brought by the DUDe mode for a heterogeneous wireless network. The outcomes and discoveries could supply profitable rules and proposals for growing new-age mobile network engineering by engaging decoupling uplink–downlink association. Therefore, in their paper, Sial, Nadeem, and Ahmed [2] generate a closed-form scheme for affiliation, coverage, and outage probabilities alongside normal throughput for joint DUDe dual-connectivity by admitting uplink prominence, receiver noise, and K-tiers heterogeneous wireless networks (HetNets). Results demonstrate that the cell affiliation scheme in view of joint DUDe dual-connectivity can essentially enhance load balancing, mobility management, and uplink execution for upcoming 5G HetNets. Nevertheless, to get exact execution measurements, the noise ought to be recognized amid examination of joint DUDe dual-connectivity. Furthermore, there was another study introduced by Fazal et al. [13] appropriating a tractable stochastic geometry framework for investigation; they probabilistically portrayed the coverage performances of the proposed access schemes and perceived the impact of a user and small BS' densities, signal-to-interference-plus-noise ratio (SINR) threshold, and several parameters of association biases on the coverage probability. Analytic outcomes demonstrated that DUDe association considering the reverse frequency allocation outperformed the coverage performance of different techniques (e.g., coupled uplink–downlink relationship with and without considering coverage performance, traditional load adjustment). Additionally, the work realized by Zhang et al. [14] deals with the huge unevenness among uplink and downlink transmissions in light of stochastic geometry theory. They exploit fractional power control indicated by a third-generation partnership project standard to demonstrate a location-dependent UE control and to determine cell affiliation probability for DUDe and coupled uplink–downlink affiliation modes. These two association modes were individually approved by concentrating the framework execution regarding uplink transmission load, normal client rate, system spectral efficiency, and energy efficiency for under two basic client appropriations: uniform and clustered user assignments. Moreover, in light of the probability of user association calculated for uplink and downlink, a productive decoupled association technique is proposed by Naghshin, Reed, and Liu [15], where the BS with the most astounding probability of user association is chosen as the serving BS.

From another perspective, a set of research works handles the uplink and downlink user associations as an optimization problem. For instance, Liao, Aziz, and Stanczak [16] displayed a utility capacity as the base level of the QoS fulfillment in order to accomplish reasonable service-centric execution. Based on the user-centric context-aware communication background in 5G systems, the utility maximization issue for the uplink and downlink decoupling-enabled HetNet will simultaneously upgrade the uplink and downlink bandwidth capacity and power control, under various affiliation arrangements. Additionally, in their research, Boostanimehr and Bhargava [17] define the joint downlink and uplink issues in a form that can efficiently be altered to downlink adapted, uplink adapted, or downlink and uplink adapted. They consider boosting the sum of the weighted uplink–downlink long-term data rate while maintaining the QoS. Therefore, the joint downlink and uplink cell affiliation issues in a multi-tier system are planned and settled through cell affiliation and resource block designation. However, they submitted a report in the reference signs of BSs announcing the uplink impedance, which can prompt an overload signalization in dense HetNets. Furthermore, another study conducted by Zhou, Huang, and Yang [18] outlines an association technique as a sum-utility maximization issue that jointly augments the downlink sum rate and limits uplink sum power.

Another group of research studies [19–22] uses game theory to get an optimal solution and conceive a model for a rival attitude of UE, BSs, and the access controller of a HetNet; for example, the stable matching technique that was used by different works to evaluate the uplink–downlink user association benefit separately. For instance, there is a work carried out by Semiari et al. [19] which presents a solution to downlink user association for small cell networks based on utility functions, taking into consideration the rate and fairness for cell edge users. To provide a better BS services to UE experiencing a relatively low SINR, Semiari et al. [19] propose a promotion function representing the amount of promotion given to each class of users. Furthermore, the Nash bargaining technique was used by Liu et al. [20] to get beneficial user association maximizing the sum of log-scale uplink and downlink energy inefficiency among all UEs. The proposed model aims to improve the uplink and downlink system capacity and reduce the uplink transmit power by introducing the Hungarian method to adjust the model to a Nash bargaining solution. Additionally, in another study by Tuan et al. [21], the authors coordinate between matching and coalition games to manage the uplink user association issues based on optimizing the utility function in terms of packet success rate and delay. Moreover, in their paper, Gao, Duan, and Huang [22] handle the cooperative spectrum sharing issue between multiple primary and secondary users as a two-sided market, and study the market equilibrium under both complete and incomplete cases. The outcome attests that the performance gap between Pareto-optimal equilibrium and robust equilibrium for primary users is considerably small for the critical case where every primary user guaranteed the utility under all possible misrepresentation actions of secondary users.

The work in this paper extends prior art—most notably the recent works conducted by Gu et al. [23] and Sekander, Tabassum, and Hossain [24]. The main contributions are summarized in Table 1.

Table 1. The improvement brought by our method.

Issues of Past Work	Main Commitment to Our Strategy
The matching game is applied for network selection and does not take into account a mobile environment.	We adopt the matching game as a handover process to offer an aspect of intelligence and self-organization.
The externalities considered was the impact of the new association on the existing UE preferences solved by swap-matching.	Since we are dealing with a mobile UE, the former externalities treated in most research is no longer valid. We take into consideration the influence of the up-coming association in the preferences of the player.
The most of the research working with the matching game realizes BS agents based on all BS available in the region as a player	In our case, we use an assignment step to maintain only the beneficial BS based on a QoS requirements of a UE.
Most of the research in network selection was confirmed by an analytical study	In our approach to evaluate the model we use a simulation scenario on network simulator-3 (NS-3).

3. System Model and Problem Formulation

In this section, we first introduce the system model of a two-tier HetNet. Then, we discuss the handover issue formulation to support utility maximization while allowing load-balancing.

3.1. System Model

We consider a two-tier system where a macro BS is surrounded by open-access femto BSs. In any case, this work is substantial for a general N-tier network where the BSs have distinctive coverage and capacity. Let $\mathfrak{M}$ denote the set of macro BSs and femto BSs. The UEs are arbitrarily assigned to the two-tier network and denoted by $\mathfrak{N} = 1, 2, 3, ..., N$. For $m \in M, G_m \in \mathfrak{N}$ is the subset of UEs served by the BS_m.

To model the UE association, we outline an association matrix x as:

$$x^{(.)} = \begin{cases} 1, \, if \; UE_n \; is \; associated \; with \; BS_m \; for \; uplink \; or \; downlink \\ 0, \, otherwise, \end{cases} \tag{1}$$

where $(.) = u$ for uplink and $(.) = d$ for downlink. $\gamma_{mn}^{(.)}$ is the SINR of UE_n associated with BS_m in uplink or downlink, and is calculated as follows:

$$\gamma_{mn}^{(d)} = \frac{P_m^d g_{mn}}{\sum\limits_{i=1, i \neq m}^{M} P_i g_{in} + \sigma^2}, \tag{2}$$

$$\gamma_{mn}^{(u)} = \frac{P_{mn}^u g_{mn}}{\sum\limits_{j=1 j \neq n}^{N} \sum\limits_{i=1, i \neq m}^{M} (x_{ij} P_{ij}^u / K_i) g_{mj} + \sigma^2}, \tag{3}$$

where P_m^d is the transmit power of BS_m, σ^2 is the noise power level, and g_{mn} is the channel power gain between UE_n and BS_m, and the path-loss and shadowing are considered. Let K_i be the effective load of BS_i, characterized as the number of UEs associated $K_i = \sum_{n=1}^{N} x_{in}$. At each association with BS_m, the UE gets a fraction $1/\sum_{n=1}^{N} x_{mn}$ of all the radio spectrum; Accordingly, the UE_n' s data rate associated with BS_m can be achieved by Shannon's capacity formula:

$$r_{mn}^{(.)} = (\sum_{n=1}^{N} x_{mn}^{(.)})^{-1} W \log_2(1 + \gamma_{mn}^{(.)}), \tag{4}$$

where W is the operating frequency band. A list of key mathematical notation used in the paper is given in Table 2.

Table 2. Mathematical notations.

Notation	Description
$\mathfrak{M}$	Set of macro BSs and femto BSs.
$\mathfrak{N}$	Set of UEs.
G_m	The subset of UEs served by the BS_m.
$x^{(.)}$	Association matrix for a UE.
$\gamma_{mn}^{(.)}$	Signal-to-interference-plus-noise ratio of UE_n associated with BS_m in uplink or downlink.
K_i	Effective load of BS_i.
$r_{mn}^{(.)}$	The UE_n' s data rate associated with BS_m.
μ	Result of the UE–BS matching game.
$\succ_n$	Preference relations of every UE_n.
$\succ_m$	Preference relations of every BS_m.
b_{in}	Benefit for the UE_n to be served by BS_i.
α_i	Scaling effects factor of UE_n.
$\phi_{th,n}$	Capacity threshold determined by the QoS requirements of UE_n.
h_{ij}	Assignment matrix describes when UE_n is served by BS_i for uplink and BS_j for downlink

3.2. Problem Formulation

To associate UEs to BSs, each UE try to recognize the greatest arrangement of BSs for which it can reach the particular QoS prerequisites. In order to display a UE and BS association issue, we determine an adjusted setting mindful utility capacity for a UE_n ($n \in N$) served by BS_m ($m \in M$).

We manage an adjusted context-aware optimization issue which includes finding pointers $x_{ij}^{(.)}$ relating to the association. The pointers variable upholds exceptional association, which is combinatorial. Along these lines, we concentrate only on the examination of how the UEs should be related to rates $r_{ij}^{(.)}$ in order to enhance network throughput and admit fairness. Specifically, the logarithmic function is an exceptionally popular alternative to the utility function; this logarithm is concave and thus has unavoidable diminishing statements. This property promotes load balancing. This is consonant with association theory in concrete systems, where a relationship for a more overloaded BS is viewed as a low advantage. Accordingly, in the rest of this work, we employ a logarithmic utility function. Our goal is to boost the network sum rate with SINR requirements, and we define the UE association issue as follows:

$$\begin{aligned} &\max_{x} \sum_{m \in M} \sum_{n \in N} \log(x_{mn}^{(.)} r_{mn}^{(.)}), \\ &s.t \sum_{n \in N} x_{mn}^{(.)} = 1, \forall m \in M, \\ &\quad x_{mn}^{(.)} \in \{0,1\}, \forall n \in N \ and \ \forall m \in M. \end{aligned} \tag{5}$$

Besides, the association optimization issue defined by Equation (5) will be redefined as Equation (6), since $\sum_{n \in N} x_{mn}^{(.)} = 1, \forall m \in M$ and $x_{mn}^{(.)} \in \{0,1\}, \forall n \in N$ and $\forall m \in M$.

$$\begin{aligned}
&\max_{x} \sum_{m\in M}\sum_{n\in N} x_{mn}^{(.)} \log(r_{mn}^{(.)}),\\
&s.t \sum_{n\in N} x_{mn}^{(.)} = 1, \forall m \in M,\\
&\quad x_{mn}^{(.)} \in \{0,1\}, \forall n \in N \; and \; \forall m \in M.
\end{aligned} \tag{6}$$

It is effectively perceived that the foregoing enhancement issue is a mixed-integer non-linear programming problem (MINLP), which is frequently NP-hard and engenders a complexity which increases exponentially with the included quantity of a BS and a UE. This unpredictability joined with the self-coordination necessarily requires the consideration of a disseminated arrangement where every UE exclusively picks the best BS to relate, in light of its nearby estimate. Then, we build up a distributed BS selection process for the support of comparable and reasonably fair throughput.

Along these lines, we apply matching theory, which allows a distributed process for the combinatorial issue that groups players in two sets in view of their individual capabilities. In this manner, the involved UE affiliation issue positively belongs to the matching system. In particular, having characterized this improvement issue in Equation (6), we intend to settle the issue of affecting every UE n $\in$ N to the pre-eminent serving BS m $\in$ M according to a matching $\mu : M \longrightarrow N$, where $U_{mn}(r_{mn}^{(.)}, \mu) = x_{mn}^{(.)} \log(r_{mn}^{(.)})$ is the UE_n utility function served by BS_m. Basically, it supplies the following improvement issue:

$$\begin{aligned}
&\underset{\mu:(m,n)\in\mu}{\operatorname{argmax}} \sum_{m\in M}\sum_{n\in N} U_{mn}(r_{mn}^{(.)}, \mu),\\
&s.t \sum_{n\in N} x_{mn}^{(.)} = 1, \forall m \in M,\\
&\quad x_{mn}^{(.)} \in \{0,1\}, \forall n \in N \; and \; \forall m \in M.
\end{aligned} \tag{7}$$

4. Proposed Model

The strategy of coupled association with a similar BS for uplink and downlink no longer ensures a rate optimality to UE in a two-tier network, where a UE benefit is mainly influenced by the varying transmit powers, distance, and unbalancing a load of traffic for BSs in both the downlink and uplink. Consequently, we consider the issue of maximizing the general uplink and downlink transmission rates for the UE in a two-tier HetNet with supplied decoupled affiliation. Specifically, we model the context-aware handover issue as an assignment technique and the UE affiliation issue as a matching game.

To our best knowledge, few works have been published addressing a DUDe handover-based matching game. Throughout this paper, a solution that provides a self-organization technique based on QoS-context aware of an urban model has been proposed for LTE and Wi-Fi environments. The differences between our proposed approach and the existing ones are as follows: (i) We adopted a new strategy, where we express the BSs detected by a UE in an agent BS set, which offers a beneficial service in terms of QoS for uplink and downlink; (ii) Through the defined utility function, the handover is realized while achieving fairness between BSs; (iii) Since the approach will be proposed for a mobile UE, consideration has been given to the convergence time which must be minimized; (iv) A new concept of externalities was addressed. This externality treats the nomadic UE preference, which is strongly influenced by other UEs asking for the association at the same time. Therefore, we decided to deal with this externality using dismissing-matching.

In this section, we will first itemize the adaptation of the assignment method to form the new BSs players as a set of agent BSs. At that point, we characterize the preference list count strategy for various players in the planned many-to-one matching game [25]. Finally, we depict the implementation details of the proposed context-aware handover algorithm.

4.1. Matching Game

A matching games framework [25] is a suitable tool which can solve a self-organization BSs and UEs association approach as defined by Equation (7).

Definition 1. *The UEs and BSs matching game is characterized by two arrangements of players: UEs N and BSs M, and the preference relations of every UE* ($\succ_n$) *and BS* ($\succ_m$)*; these allow UEs* $n \in N$ *and BSs* $m \in M$ *to give preference over one another, to rank the BSs in M and UEs in N, respectively.*

The function μ will be the result of the UE and BS matching game, which assigns each UE $n \in N$ to a BS $m = \mu(n)$, $m \in M$. The preference relation $\succ$ assigns a binary relation between UE in N and BS in M. Consequently, for any UE k, the preference relation $\succ_n$ is determined over a set of BSs M. Similarly, for any BS m, the preference relation $\succ_m$ is determined over a set of UEs N. Let $\mu, \mu' \in N \times M$ two matchings, with $(m, n) \in \mu$ and $(i, n), (m, j) \in \mu'$. The preference relations $\succ_n$ for any UE n and $\succ_m$ for any BS m are respectively described over the sets of BSs M and UEs N thereby, for any two BSs $m, i \in M^2, m \neq i$, and two UEs $n, j \in N^2, n \neq j$, they are respectively:

$$\begin{aligned} (m, \mu) \succ_n (i, \mu') &\Longleftrightarrow U_{mn}(r_{mn}^{(.)}, \mu) > U_{in}(r_{in}^{(.)}, \mu'), \\ (n, \mu) \succ_m (j, \mu') &\Longleftrightarrow U_{mn}(r_{mn}^{(.)}, \mu) > U_{mj}(r_{mj}^{(.)}, \mu'). \end{aligned} \tag{8}$$

The current matching as defined in Equation (8) proves that the preferences of each UE (BS) will be affected by the set of BSs M (UEs N).

Remark 1. *The proposed matching game has externalities, where the preference values of UE depend not only on the actual number of UEs served by the BS that they are matched with, but also on the other UEs asking for a matching, at the same time with the same BS.*

In other words, for a UE and BS association $(m, n) \in \mu$, the interference generated from other upcoming associations $(i, j) \in \mu, (m, n) \neq (i, j)$ considerably affects its uplink and downlink received SINRs in Equation (2), Equation (3), and long-term rates in Equation (4). Moreover, externalities are used to depict the dynamic effects of these outer consequences on the execution of each UE and BS association. To manage the externalities, we incorporate a suitable iterative step in Algorithm 1 based on dismissing-matching.

4.2. Construction of Players

Every UE will have two different preference lists for uplink and downlink. Therefore, in addition to the existing BS, we create a new set of BSs. The new virtual BS will be a combination of existing ones, where one will serve the uplink traffic and the other one will be for downlink. Gathering BSs into pairs while looking for an ideal matching with maximum gain is a task issue, which we can successfully solve by utilizing the assignment step between BSs. We plan the issue in detail as below:

The b_{in} characterizes the benefit of the UE_n served by different BS for uplink and downlink, which is the component of the matrix b.

$$b_{in}^{(.)} = \max_{\forall i \in \{1,2,\ldots,m\}} (\log(\alpha_i r_{in}^{(.)}) - \phi_{th,n}, 0), \tag{9}$$

where $\phi_{th,n}$ represents the capacity threshold determined by the QoS requirements of UE_n. α_i gives scaling effects of UE_n for an uplink and a downlink data rate on the utility. The value of α_i displays the emphasis of UE_n on an uplink or a downlink data rate which often rely upon the type of device (e.g., smart-phone, tablet, laptop). With the objective of maximizing the gain, we outline the coalition task matrix h, with elements representing whether there is a coalition between two BSs:

$$h_{ij} = \begin{cases} 1, \ if\ BS_i\ serve\ the\ uplink\ and\ the\ BS_j\ serve\ the\ downlink, \\ 0, \ otherwise. \end{cases} \tag{10}$$

Then, the assignment problem shifts to grouping uplink and downlink problems in a pair of BSs, so as to maximize the overall benefit of UE_n. Therefore, the problem is formulated as:

$$\max_h \sum_{i=1}^{M} \sum_{j=1}^{M} h_{ij} b_{ij}, \tag{11}$$

where b_{ij} is the sum of the benefits of UE_n served by BS_i for uplink and BS_j for downlink, defined as follows: $b_{ij} = (b^u_{in} + b^d_{jn})$. Since the objective is to offer satisfaction to the user for uplink and downlink, the assignment will only be valid if both BSs are beneficial for UE. In other words, the agent BS must check the following condition: $h_{ij} = 1$ *if and only if* $b^u_{in} \neq 0$ *and* $b^d_{jn} \neq 0$.

4.3. Decoupled Uplink–Downlink Handover Algorithm

To resolve these challenges, we defined two principal stages. At the beginning, we radically change the issue from a many-to-many case to a many-to-one case by assigning BSs with each other in order to maximize the benefit of UE in terms of QoS. However, as described in Algorithm 1, we assume that all the UEs are first associated with the great BS primarily based on the SINR. At that point, with the target of maintaining a good UE QoS, when the mobile UE (denoted by k) experiences a degradation of the required QoS, it outlines the desired matching list considering Equation (8). The UE_k makes a ranking list based on $\succ_k$ of the accessible BSs and applies to the most favored one of them. As a result, if the actual BS service (denoted via m) for UE_k is no longer its most desired one compared to BS services (denoted via i), it makes a matching suggestion μ^k_{mi} to an agent BS_i.

Therefore, in our proposed Algorithm 1, we consider a matching suggestion μ^k_{mi} as a handover request. Once a matching suggestion is received, the concerned agent BS_i updates its utility. Specifically, BS_i accepts the suggestion only if it is strictly beneficial. Each BS_l in agent BS_i ranks the candidates based on the actual matching μ, then verifies if the μ^k_{ml} is strictly beneficial for both BS_l to get computed in the set of UEs asking for association (denoted via N^{req}). In other words, the agent BS_i will not accept hosting UE_k if and only if both BSs from agent BS_i benefit from this association.

The UE that was dismissed in the previous stage would follow to their next favored BS, then the BSs adjust their rejected list accordingly. However, if the μ^k_{ml} is beneficial for both agents BS_l, then we update the set of UEs sending requests to BS_l, the BSs adjust their waiting list accordingly, and will update the new matching solution (denoted via μ'), adding the link (k,i) to μ'.

Nevertheless, given our considered externalities in every progression μ', the utilities would be refreshed in view of the actual matching. Accordingly, an iterative approach will be embraced. The BS_l evaluates its utility for the new matching solution μ'; in that way, it will take into consideration all UEs asking for a handover at the same time as UE_k. Therefore, for all BS_l in agent BS_i will keep dismissing the worst case from its N^{req} until it gets a beneficial utility. The final resulted N^{req} will be associated with the agent BS_i. The procedure keeps running until achieving a beneficial matching based on $\succ_l$, described as follows.

Definition 2. *Given a pair of UEs $k, j \in N$ and BSs $m, i \in M$, a matching μ with $(m,k), (i,j) \in \mu$ is stable if no stable handover-matching $\mu^k_{m,i} = \mu \setminus (m,k) \bigcup (i,k)$ exists, such that:*

- $\forall x \in \{k, j, m, i\}, U_x(\mu^k_{m,i}) \geq U_x(\mu)$
- $\exists x \in \{k, j, m, i\}, U_x(\mu^k_{m,i}) \geq U_x(\mu)$

The UE and BS stable matching μ with $(m,k) \in \mu$ is achieved if no BS_i or UE_j, where BS_i lean toward UE_j to UE_k or UE_k lean towards BS_i to BS_m, exists. In other words, while considering the externalizations in a UE and BS matching, dismissing-matching should happen only in the event that it is entirely disadvantageous for the included BS to get balanced matching.

Algorithm 1 A context-aware handover algorithm.

Initializing—each UE is initially associated with a BS i based on downlink max–SINR association.
if The UE_k triggers the handover process **then**
  Phase I—agent BS selection
  UE_k starts creating agent BS to satisfy QoS requirements based on the assignment method as described in Section 4.2
  UE_k ranks the agent BS according to $\succ_k$
  if $\mu^k_{m,i}$ the most preferred by $\succ_k$ **then**
    UE_k sends a proposal to an agent BS_i
    Each BS_l for agent BS_i updates $U_l(\mu)$ based on matching μ
    $\mu' \longleftarrow \mu$
    if $\forall BS_l \in BS_i(k, \mu^k_{ml}) \succ_l (k, \mu)$ **then**
      $N^{req} \longleftarrow N^{req} \cup k$
      $\mu' \longleftarrow \mu' \cup \mu^k_{ml}$
    else
      $N^{rej} \longleftarrow N^{rej} \cup k$
      UE_k sends request to the next agent BS preference.
    end if
  end if
  Phase II—dismissing-matching
  if $|N^{req}| \neq 0$ **then**
    while $U_l(\mu')$ not strictly beneficial **do**
      Delete the worst UE from N^{req} based on $\succ_l$
      Update μ' based on $\succ_l$
    end while
  end if
end if
Depending on the last N^{req}, each UE is associated with agent BS_i.

4.4. Convergence and Pareto-Optimality Analysis

In this section, we investigate the execution of Algorithm 1. Particularly, we outline and survey the convergence and Pareto-optimality. In disposing of the investigation in the above subsection, we have:

Lemma 1. *Regarding the convergence of the dismissing-matching step, Algorithm 1 achieves a stable matching.*

Proof. The explanation stems from two factors. Firstly, we found that their nature of transmission deployment leads BSs to reach a predetermined number of UE requests in their region, and consequently, the quantity of conceivable dismissing-matching is limited. In addition, only dismissing-matching which entirely increments a player's utility can happen. The second factor is that when all the worst conceivable cases have been dismissed, the dismissing-matching stage ends and every UE (BS) remains related to the most favored BS (UE). Subsequently, no further changes can be accomplished by dismissing among UEs requesting-matching. □

Definition 3. *If there is no Pareto upturn pair in a matching, it implies that this matching is Pareto-optimal. A couple of UE (n, n') is considered as a Pareto enhancing pair in a matching μ if $\mu(n') \succ_n \mu(n)$ and $\mu(n) \succ_{n'} \mu(n')$.*

Lemma 2. *The handover-matching algorithm is Pareto-optimal.*

Proof. Admitting that a Pareto upturn (n, n′) exists in our last matching μ infers that we can shape another matching μ' , where $\mu' = \mu - \{(n, \mu(n)), (n', \mu(n'))\} \cup \{(n, \mu(n')), (n', \mu(n))\}$ to boost our utility function. We take into consideration the utility of the accomplished matching μ be U(μ) and the utility of the Pareto upturn matching μ' be U(μ'). Based on the concept of preference process, it is clear that a UE dependably requests a matching from the most preferred agent BS first. In this way, if n leans towards $\mu(n')$, it has just reached $\mu(n')$ and been dismissed. The same is valid for n′. Consequently, $U(\mu') < U(\mu)$ and (n, n′) cannot be a Pareto change combine. Hence, our proposed coordination is Pareto-optimal. □

5. Simulation and Results

For the performance evaluation of the theoretical model created in the previous section, we used a scenario build in NS-3 to produce a two-level heterogeneous wireless network system. Therefore, simulation topology and numerical results are exhibited in the current section.

5.1. Simulation Environment

The validation was directed in a heterogeneous system comprising LTE and Wi-Fi technologies. Additionally, the simulation scenario ran under a similar system arrangement to a previous work [26], where media-independent handover and proxy mobile Internet protocol version 6 administrations were empowered. The adopted handover trigger mechanism is a velocity- and QoS-aware which we detailed in our last study [27].

For our simulation, we considered 5 macro BSs (MBS) of 500 m and a bandwidth of 20 MHz. In those BSs, N UEs and M femto BSs (FBS) were uniformly deployed. Figure 1 illustrates the topology used to demonstrate our approach. The transmit power of each femto BS m was $p_m = 22$ dBm, and transmissions were affected by distance-dependent path loss and shadowing. The minimum SINR required by each UE was $SINR_{min} = 9{,}56$ dB, and the noise level was $\sigma = -121$ dBm. The traffic rate was dependent on the QoS requirements of UE, assuming a standard packet size of 2000 bytes. The rest of the simulation parameters are outlined in Table 3.

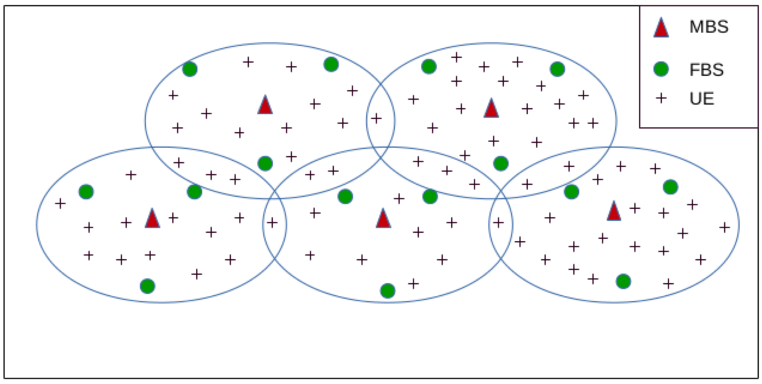

Figure 1. Simulation topology.

Table 3. Simulation parameters.

Parameter	Value
Channel bandwidth	20 MHz
Macro BS radius	500 m
Femto BS radius	40 m
Network Element	5 macro BSs & 15 femto BSs
Max. macro BS transmit power	46 dBm
Max. femto BS transmit power	22 dBm
Max. UE transmit power	20 dBm
Path-loss model	$15 + 36\log_{10}(d)$
Log-normal shadowing fading	4 dB
Device mobility	3 km/h
Device mobility direction	Random
Noise level	−121 dBm
Overlapping region between macro BSs	100 m

5.2. Results and Discussion

We studied the performance of the utility per BS in a HetNet where we had 15 femto BSs and 5 macro BSs. To add an aspect of a dense environment, we opted to create base stations with limited resources relative to demand. Thus, the max number of UEs associated with uplink and downlink were $q_{ul} = 10$ $q_{dl} = 10$ for macro BSs and $q_{ul} = 5$ $q_{dl} = 5$ for femto BSs. As a result, Figure 2 proves that there was a considerable improvement in terms of utility values per BS for our proposed algorithm compared to the following two cases:

1) Traditional downlink (DL) handover where the UE is associated based on downlink received power.
2) Traditional DUDe handover where the UE choose two different BSs based on received signal strength for downlink and the distance between BS and the UE for the uplink.

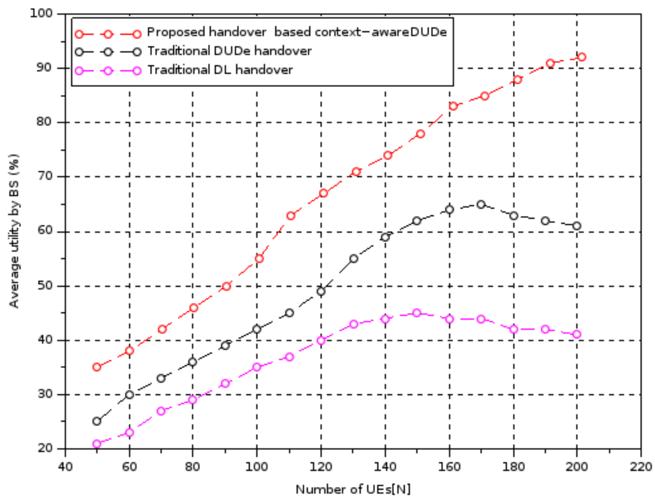

Figure 2. The utilities rate for the BS regarding the number of UEs N, under the considered approaches: 5 macro BSs with $q_{ul} = 10$ $q_{dl} = 10$ and 15 femto BSs with $q_{ul} = 5$ $q_{dl} = 5$. DL: downlink.

Despite the great improvement brought by the association with BS that offered the best downlink received power, it can be noticed that at a very high number of UEs the evolution of the curve begins to slow down, and at some point it can even be judged that it will begin to decrease. We can conclude that choosing a BS that offers the best downlink received power in neither case guarantees a better service, since at some point the problems of delay, interference, and congestion will appear with increasing demand. Nevertheless, our context-aware algorithm offers a considerable improvement, especially for the network which is experiencing high demand, which means that the improvement of the congestion will offer us the possibility to reduce the delay and to offer a better QoS for a large population. In terms of numerical results, we found that the DUDe context-aware handover algorithm could reach up to 35% over the traditional DUDe handover and 52% over the traditional downlink handover in terms of utility.

In changing the number of N^{Req} UEs set, Table 4 exhibits the average delay in the handover procedure when the number of N^{Req} UEs set requests a handover at the same time as the UE_k. Accordingly, we presume that the proposed scheme grants quick and stable convergence.

Table 4. Delay based on the number of N^{Req} set.

Number of N^{Req} Set	**50**	**60**	**70**	**80**	**90**	**100**
Delay (ms)	14.440	27.340	39.490	52.615	64.340	76.167

We assessed the load distribution between the macro BS and femto BS in terms of the average rate of UE served by femto BS in the framework. Figure 3 demonstrates the behavior of the average rate of UE served by femto BS against the fluctuating UE number. Therefore, based on Figure 3, we can perceive that the average rate of femto BS serving UEs generally did not change with the expanded number of clients for all plans. Additionally, as should be obvious in this figure, around 66% of the clients were served by the femto BS in the traditional DUDe handover. Then again, only 10% were served by traditional downlink handover. Thus, with the proposed plan, the level of femto BSs serving UEs was approximately halved. Accordingly, considering that in our case there were three femto BSs per macro BS and the macro BS has large transmission power with improved system efficiency compared to the femto BS, this distribution can be considered as reasonable.

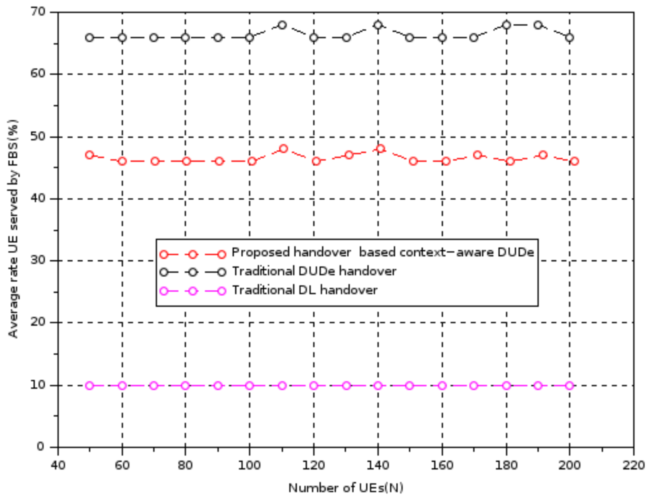

Figure 3. The average rate of UEs served by femto BSs (FBSs) in terms of the total number of UEs.

In order to study the impact and the gain brought by the femto BS (thus contrary to the initial topology), the number of femto BSs will be variable up to 100 femto BSs, which allows us to study the performance of the handover decision in a dense network environment. Figure 4 demonstrates the average utility per UE according to the number of femto BSs in a network with $N = 100$ UEs. For the proposed context-aware approach, the UEs moved toward becoming related to femto BSs, which is mutually not loaded and gives an improved rate. Accordingly, during context-aware decision making, the subsequent UE–BS association considerably expands the UEs utilities. The proposed context-aware handover yields a huge performance gain, growing with the network dimension M, reaching 31% and 43% over the traditional downlink handover and traditional DUDe handover schemes, respectively.

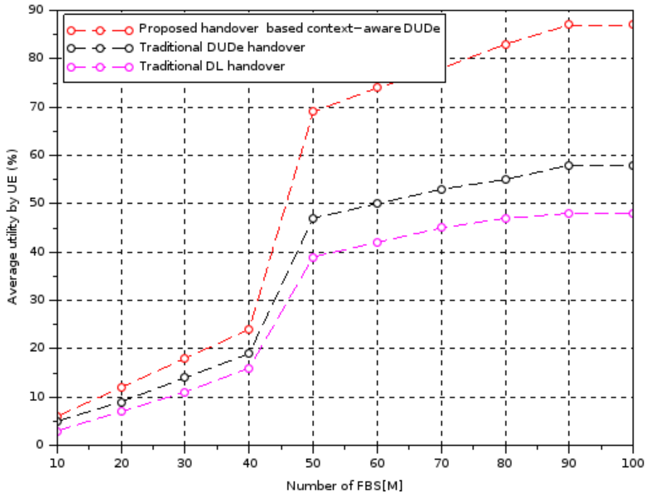

Figure 4. The utility rate for UEs regarding the number of femto BSs (FBSs) M, under the considered approaches ($N = 100$ UEs).

6. Conclusions

In this paper, we consider uplink performance during the association step for the handover scheme to meet the service requirements. Therefore, in contrast to the conventional handover, it deals with the case where the BSs chosen for the downlink may not be useful for the uplink. Thus, we define new context-aware handover algorithms for the two-tier networks. By introducing a well-designed utility function, our proposition considered the load balancing and data rate for maximizing the sum of the utility function. Furthermore, we have modeled the problem as a many-to-one matching by using the assignment step. In addition, this assignment step will help to confirm the minimum requirement QoS while creating a virtual set of BSs, where those virtual sets of BSs would enable the decoupled handover process. Validation was conducted by a scenario built in NS-3 for a heterogeneous system including LTE and Wi-Fi technologies. Simulation results have shown that the proposed approach yields significant beneficial gains over the traditional techniques.

Nevertheless, we are conscious that the system can give ideal execution with complete information. However, the signaling cost for the use of complete information algorithms is high. Hence, to address this issue, in our future work we will explore the trade-off between signaling overhead and ideal system execution. Moreover, we can address various intriguing open inquiries and headings; for example, assessing the execution of the proposed scheme in the extended situation with high speed while running diverse application types as well as examining the situation in which nodes are deceiving, which can constitute a captivating subject.

Author Contributions: Asmae Ait mansour: Main writing and designing the total system, analyzing and improving the proposed system. Nourddine Enneya and Mohamed Ouadou: Total supervision of the paperwork, review, and comments, etc. All authors have read and approved the final manuscript.

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