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Optimal Radio Access Network Selection in Multi-RAT HetNets Using Matching Game Approach

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Abstract— Due to the dramatic growth in mobile data traffic, Multiple Radio Access Technologies (Multi-RAT) heterogeneous Networks (HetNets) have been proposed as a promising solution to cope with the high traffic demand in mobile networks. In this work we propose a User Equipment (UE) radio access network selection algorithm in a Wireless Local Area Network (WLAN) and LTE Multi-RAT HetNet, where matching game approach is applied. In this algorithm, UEs propose to their best candidate based on a utility function that is formulated to maximize their achieved downlink data rate. Then base stations accept or reject the proposals based on their utility. The performance of the proposed approach is investigated and compared to other models, and simulation results proved its outperformance.

Keywords—Multi-RAT, HetNet, network selection, matching game.

I. INTRODUCTION

Recently it has been noticed a dramatic growth in wireless connectivity by User Equipment (UEs), which in turn led to unprecedented growth in data traffic. It has been predicted that by 2021 monthly global mobile data traffic will exceed 49 exabytes [1]. This puts high pressure and becomes one of the serious challenges for cellular mobile network operators and their resources.

Particularly Wireless Local Area Network (WLAN) has been introduced by 3GPP Release 8 [2], as a candidate for interworking with cellular networks, due its high capacity, low deployment complexity, and low cost. However, for an operator adopting Heterogeneous Network (HetNet) with trusted WLAN, some important challenges should be addressed such as seamless authentication, seamless mobility between different RATs, and more importantly the UE association and RAT selection decision. In this paper we will use the terms network selection and UE association alternatively. Mobile operators require appropriate UE association for efficient utilization of Long Term Evolution (LTE) and WLAN network resources. A UE can associate with WLAN Access Point (WAP) or an LTE base station (BS). Thus, a UE association technique that optimizes network performance becomes necessary [3].

Recently, matching game has emerged as a promising technique for wireless resource allocation, and user association [4]. It is a Nobel Prize winning framework that provides mathematically tractable solutions for the combinatorial problem of matching players in two distinct sets, depending on the individual information and preference of each player [4]. It has been used widely for resource allocation in wireless networks, such as in cognitive radio (CR) networks [5-7], heterogeneous cellular networks [8], physical layer security systems [9], distributed orthogonal frequency-division multiple access

(OFDMA) networks [10], routing, and queuing systems [5].

In HetNets, UE association is considered a significant challenge that received researchers' attention. In [11] WLAN-first strategy was analyzed, in which UEs should select WLAN whenever it is available. WLAN-first is considered one of the pioneer works for LTE and WLAN interworking. It is also considered as a baseline access strategy among network selection approaches [12].

In [13] the authors proposed a Q-learning algorithm to find the optimal policy that maximizes a reward parameter. Although the reward parameter depends on the load of each detected WAP, the Signal to Interference plus Noise Ratio (SINR), the handover duration, and the achievable rate, it does not consider the different technologies represented by the effect of WLANs MAC protocols on the achievable rate calculations.

Authors in [14] introduce a practical probabilistic RAT selection approach in a heterogeneous network with two throughput classes, these association probabilities are calculated with the aim of network throughput maximization. However it considers only a general throughput classes, and does not consider the different network parameter that could affect these classes, and consequently the association probabilities.

Multiple Attribute Decision Making (MADM) methods are widely adopted in HetNet selection as in [15-19]. Authors in [15] propose a HetNet selection algorithm based on the combination of network attributes and user preferences, by the use of a combination of three MADM methods, namely Fuzzy Analytic Hierarchy Process (FAHP), Entropy and Technique for Order of preference by Similarity to Ideal Solution (TOPSIS). Also [16] proposed a strategy that depends on Analytic Hierarchy Process (AHP) for UEs to select best RAT based on Signal to Noise Ratio (SNR), available bandwidth, delay, and jitter. Moreover, authors in [17] proposed a flexible hybrid MADM algorithm consisting of FAHP, standard deviation, and Grey Relational Analysis (GRA) for the HetNet selection problem. However

none of the previous aims to provide an optimum solution, since users individually take selfish RAT selection decisions.

Although matching game has been used widely in resource allocation for cellular networks, it is still amateur in the HetNets user association [5]. In [20], authors proposed a context-aware user association approach based on matching theory for small cell networks, which exploit the information about the velocity and trajectory of the users while also taking into account their quality of service (QoS) requirements. Also authors in [8] consider a HetNet and propose a solution that jointly associates UEs to the Femto Access Points (FAPs), and allocates the FAPs to the SPs such that the total satisfaction of the UEs in an uplink OFDMA network is maximized. They propose a distributed algorithms to find the optimal UE association and FAP allocations based on dynamic matching game theory. However, all the previous consider only the heterogeneity in transmit power, and they did not consider the heterogeneity in RATs.

The rest of the paper is organized as follow: The next section describes the system model and the problem formulation. Section III presents the data rates modeling in different RATs. In section IV, the matching game user association algorithm is proposed. Then we evaluate the performance of our algorithm in section V, and the conclusion is presented in section VI.

II. SYSTEM MODEL AND PROBLEM FORMULATION

In this work, we consider an integrated cellular and small cell network, where small cells are WLAN access points (WAP), overlaid under a macro base station (MBS) as shown in Figure 1. The set of all base stations (BS) is denoted by $\mathcal{M} = \{1, 2, \dots, m, \dots, M\}$, with cardinality M , where $m = 1$ refers to MBS, $m = 2, 3, \dots, M$ implies WAPs covered by MBS. Moreover, the set of WAPs are represented by $B = \{2, \dots, M\}$ with cardinality B , such that $B \subset \mathcal{M}$. A set of UEs are distributed in a certain area (i.e. small building, or a mall) under the

MBS and WAPs coverage and are denoted by $I = \{1, 2, \dots, N\}$ with cardinality N . Also, the set of interfering MBSs is denoted by $K = \{1, 2, \dots, K\}$ with cardinality K , where $k \in K$ is the index of the interfering MBS.

Furthermore, the number of UEs associated with MBS, and WAPs are denoted by N^M , and N_m^W respectively, such that $m \in B$ for WAPs. Moreover a quota for WAPs is represented by the maximum number of UEs that can be associated with a WAP $\hat{N}_m^W \forall m \in B$, and it can be pre-calculated to achieve maximum throughput, considering a constant minimum and maximum contention window sizes (CW_{min} and CW_{max} respectively) using Giuseppe Bianchi's model [9]. Furthermore, a quota for MBS is represented by the maximum number of associated UEs \hat{N}^L , in which it can be calculated to give a minimum number of physical resource blocks per user N_{min}^{PRB} in an LTE system with \hat{N}^{PRB} physical resource blocks (i.e. $\hat{N}^L = \frac{\hat{N}^{PRB}}{N_{min}^{PRB}}$).

Since our aim is to maximize the overall network throughput by maximizing the UEs downlink data rates, the user association problem can be formulated as follows,

$$OPT - UA: \quad \max_x \sum_{m \in M} \sum_{i \in I} x_{im} R_{im} \quad (1)$$

s.t.

$$\sum_{m \in M} x_{im} \leq 1, \quad \forall m, i \quad (2)$$

$$x_{im} = \{0, 1\}, \quad \forall m, i, \quad (3)$$

$$\sum_{i \in I} x_{im} \leq \hat{N}^L, \quad \forall m \in \mathcal{M} \setminus B, i, \quad (4)$$

$$\sum_{i \in I} x_{im} \leq \hat{N}_m^W, \quad \forall m \in B, i, \quad (5)$$

where objective function in (1) aims to maximize the total system throughput as a summation of UEs downlink data rates. Constraint (2) ensures that each UE is associated to only one BS, constraint (3) ensures that the decision variable x_{im} is a binary decision variable, constraint (4) and (5) ensures that each BS will not exceed its quota.

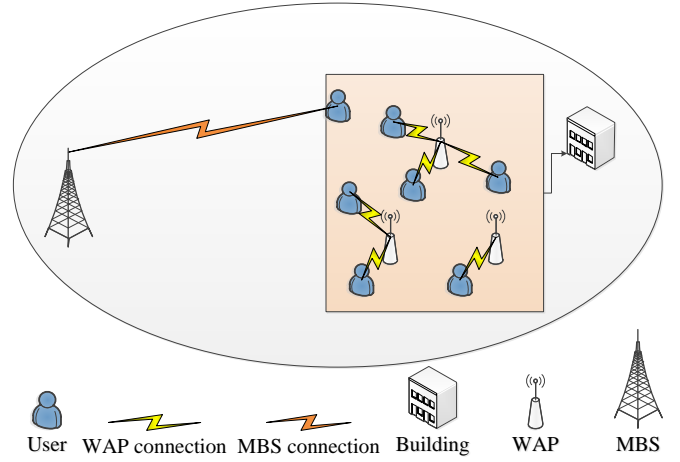


Figure 1. System Model.

III. DATA RATE MODELLING

For modelling the UE's downlink data rate from LTE MBS, Shannon's capacity formula can be used as follow,

$$R_{im} = N^{PRB} W^{PRB} \log_2(1 + SINR_{im}), \quad \forall m \in \mathcal{M} \setminus B \quad (6)$$

where W^{PRB} is the bandwidth per each PRB, and $SINR_{im}$ for UE i when associated with BS m can be formulated as follows,

$$SINR_{im} = \frac{P_m g_{mi}}{\sum_k P_k g_{ki} + \sigma^2} \quad \forall m = 1, k \in K \quad (7)$$

where K is the set of neighbor interfering MBSs; P_m , and P_k denote the downlink transmit powers from MBS $m = 1$ and interfering MBS k over one radio channel respectively; g_{mi} , and g_{ki} represent the average channel gains of the link between MBS $m = 1$ and UE i , and between interfering MBSs k and UE i , respectively; and σ^2 denotes the additive noise power over each channel.

Furthermore, the downlink data rates achieved by UE i from BS $m \geq 2$ can be calculated as follows,

$$R_{im} = R_m^{MAC}(n) W_m^{WLAN} \log_2(1 + SINR_{im}), \quad \forall m \in B \quad (8)$$

Here $R_m^{MAC}(n)$ is the UE's normalized throughput that depends on associated users n as in [21], and

W_m^{WLAN} is the WLAN channel bandwidth. The UE's normalized throughput $R_m^{MAC}(n)$ can be reformulated as follows,

$$R_m^{MAC} = \frac{\tau(1-\tau)^{N_m^W} D / (W_m^{WLAN} \log_2(1 + SINR_{im}))}{T + D\tau(N_m^W + 1)(1-\tau)^{N_m^W} \left(\frac{1}{W_m^{WLAN} \log_2(1 + SINR_{im})} \right)} \quad \forall m \in B \quad (9)$$

Here N_m^W represents the number of users associated with WAP $m \in B$; τ denotes the channel contention probability; D is the maximum allowed size of user packets; and W_m^{WLAN} is the bandwidth of each WAP for $m \in B$. For clarification, the numerator represents the average data transferred in a time slot, and the denominator is the average length of a time slot [21,22]. Moreover T can be calculated by,

$$T = (1-\tau)^{N_m^W+1}e + \left(1 - (1-\tau)^{N_m^W+1}\right)(T_{RTS} + T_{DIFS}) + (N_m^W + 1)\tau(1-\tau)^{N_m^W}(T_{CTS} + T_{ACK} + 3T_{SIFS}) \quad (10)$$

where e is the duration of an empty slot time; T_{RTS} , T_{DIFS} , T_{CTS} , T_{ACK} , and T_{SIFS} are the durations of the Request to Send (RTS) short frame, DCF Interframe Space, Clear to Send (CTS) short frame, Acknowledgment short frame, and Short Interframe Space respectively.

Furthermore the $SINR_{im}$ in (8) for UE i associated with WAP $m \in B$ can be calculated by

$$SINR_{im} = \frac{P_m^d g_{mi}}{\sum_{m' \in B, m' \neq m} P_{m'}^d g_{m'i} + \sigma^2} \quad \forall m \in B, m' \in B \setminus \{m\} \quad (11)$$

Such that m' is the interfering WAPs to the m WAP. Moreover equation (9) captures the MAC protocol effect on WLAN data rate calculation and reflects the difference in downlink data rate calculations between LTE and WLAN due to different technologies.

IV. MATCHING GAME BASED USER ASSOCIATION

In order to develop a distributed algorithm for user association, the one-to-many matching game is used as it can capture an optimal solution for the OPT-UA problem. Under this design, each UE will be matched to at most one BS, while each BS m can be assigned to at most \hat{N}^L UEs, $\forall m = 1$, and \hat{N}_m^W UEs, $\forall m > 1$.

In the matching game, we use the UE's modulation order and code rate (modulation efficiency E_{im}), to represent the UE's utility function when associated with BS m . It can be expressed as follows,

$$U_i(m) = E_{im} \quad (11)$$

Here $U_i(m)$ represents UE i utility function when connecting to different BS m , E_{im} denotes the modulation efficiency and it can be formulated as

$$E_{im} = N_{im}^{LMCS} \cdot CR_{im}^{LMCS} \quad (12)$$

where N_i^{LMCS} is the number of bits in one symbol, and CR_i^{LMCS} is the coding rate. Particularly N_i^{MCS} and CR_i^{MCS} are mapped to the Channel Quality Indicator (CQI) index which can be determined from the SINR values measured at the UE. This directly affects the achievable downlink data rate calculation for each UE when associated with BS m .

In order to maximize objective function (1), BS utility function must be efficiently designed in user association process. Therefore, the BS m utility function that sorts its preference list for bidding UEs i can be expressed as follows,

$$U_m(i) = SINR_{im} \quad (13)$$

where $SINR_{im}$ is the average signal to interference plus noise ratio measured by UE i when associated with BS m .

The proposed one-to-many matching game for radio access network selection is described in detail by Algorithm 1. After initialization, each UE

Algorithm 1 Matching Game for User Association*Initialization:* M, I, N .*Discovery and utility computation:*1: Every UE_i construct \succ_i using $U_i(m)$ *Find stable Matching:*2: **While** $\sum_{i,m} b_{i \rightarrow m} \neq 0$ **do:**3: *For each unassociated UE:*4: Find $m = \arg \max_{m \in \succ_i} U_i(m)$.5: Send a request $b_{i \rightarrow m} = 1$ to BS m .6: *For all BS m :*7: Update $I_m^{req} \leftarrow \{i : b_{i \rightarrow m} = 1, i \in I\}$.8: Construct \succ_m based on $U_m(i)$.9: **repeat**10: Accept $i = \arg \max_{i \in \succ_m} U_m(i)$.11: Update $I_m \leftarrow I_m \cup i$.12: **until** $I_m = \hat{N}_m^L, m \in \mathcal{M} \setminus B$ 13: **or** $I_m = \hat{N}_m^W, m \in B$ 14: Update $I_m^{rej} \leftarrow \{I_m^{req} \setminus I_m\}$.

15: Remove MBS or

 $WAP m \in \succ_i, \forall i \in I_m^{rej}$ 16: **end while**17: **Results:** A stable matching μ_{UA}^*

constructs its preference relations \succ_i using (7) and sends a bidding request $b_{i \rightarrow m} = 1$ to BS m with the highest utility (lines 1-5). In order to find a stable matching μ_{UA} , each BS insert all requesting UEs into the set I_m^{req} , and construct its preference relations for I_m^{req} based on (8) (lines 6-8), then it accepts bidding users and updates its matched list I_m under the matching $\mu_{UA}(m)$ until reaching its quota (\hat{N}_m^L for LTE-BSs, and \hat{N}_m^W for WAPs), and rejects the rest of the bidding users such that $I_m^{rej} = \{I_m^{req} \setminus I_m\}$ (lines 9-14). Each UE in the rejected list I_m^{rej} removes BS m from its preference relation \succ_i (line 15). This process is repeated until there are no bidding UEs.

V. PERFORMANCE EVALUATION

For performance evaluation, we consider a Multi-RAT HetNet comprises of two tiers, an MBS with three WAPs under its coverage, which represents a wireless network in a building (e.g. mall, campus, bank, etc.). A 20 MHz WLAN system for each of

Table I Simulation Parameters.

LTE parameters	Values
LTE system bandwidth	20 MHz
Path loss model for MBS (d : distance in Km)	$128.1 + 37.6 \cdot \log_{10}(d)$
Wi-Fi parameters	Values
WLAN system Bandwidth	20 MHz
WLAN technology	802.11n
Minimum contention window (W)	16
Maximum number of retransmissions (μ)	6
Slot time	9 μ s
DIFS	50 μ s
SIFS	10 μ s
ACK	160 bits
RTS	208 bits
CTS	160 bits

the 3 WAPs, and a 10 MHz LTE system bandwidth of 50 PRBs for an MBS are considered. The MBS has a coverage of radius 1000m, and the WAPs has radii of 50m each. The UEs are uniformly distributed in a 200m² area that is 700 m far away from the MBS. The transmit power of the MBS is considered to be 46dBm, while the transmit power of each WAP is considered to be 200mW. A constant maximum payload D of 1500 bytes is also considered. The rest of the parameters are summarized in Table I, and the results are obtained based on averaging out 500 simulation runs.

For performance evaluation, we compare our proposed association algorithm with the well-known WLAN-first algorithm, in which UEs are associated with WAPs whenever they are in coverage, and associate with the WAP that have the best SINR if more than WAP are in coverage.

In Figure 2, the performance of our proposed algorithm is compared to WLAN-first strategy, such that they are evaluated based on total system throughput. System throughput is defined as the sum of the achieved rate for each UE. It can be noticed that the proposed matching algorithm outperforms the WLAN-first at different number of UEs, this is because WLAN-first algorithm doesn't consider associating with other RATs while WLAN is available, although in many cases associating with

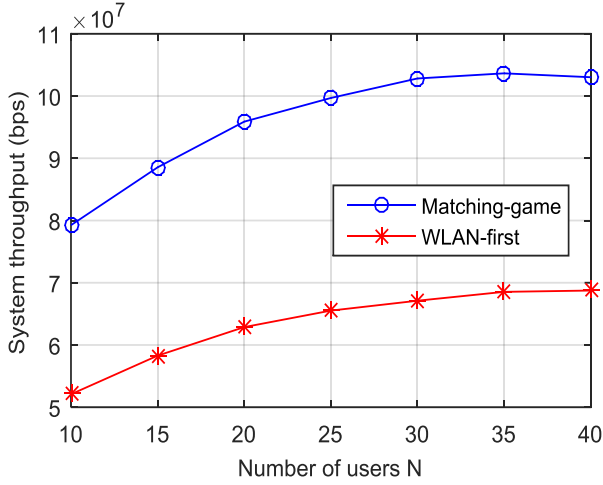


Figure 2 System throughput vs. number of users for different algorithms.

LTE can provide better achievable downlink data rates, thus our proposed algorithm which aims to achieve an optimal association that maximizes the total system throughput has a significant system throughput gain over WLAN-first. Moreover, it is also notable that the two algorithms has a concave behavior with the increase of UEs numbers, this is because of the WAPs MAC protocol effect from (9), where the rate of increasing the downlink throughput decreases with the increase of number of UEs until it reaches the maximum saturation throughput.

In Figure 3, the performance of our proposed algorithm is compared to WLAN-first algorithm in terms of outage probability. Here we define outage probability as the probability of failure to achieve a reference rate for each UE, which can be set by operator to measure quality of service (QoS). It can be noticed that the outage probability of the two algorithms is almost equal at small number of UEs, and our proposed algorithm has always a lower outage probability than WLAN-first algorithm with the increase of number of UEs. This is because when the number of UEs is small, the load on the system is low, and thus UEs can achieve high downlink data rates using any association algorithm. With the increase of number of UEs in the system, the load increases, and the number of UEs associated with each WAP increases, which decreases the achieved downlink data rates for each UE as shown in (9). Our proposed matching game algorithm has lower outage

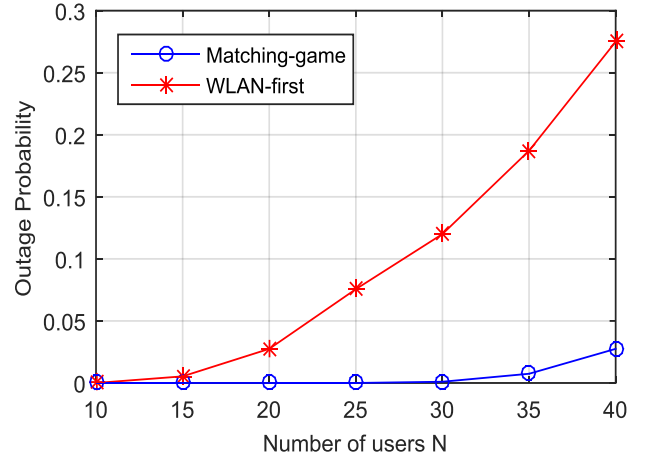


Figure 3 Outage probability vs. number of users for different algorithms.

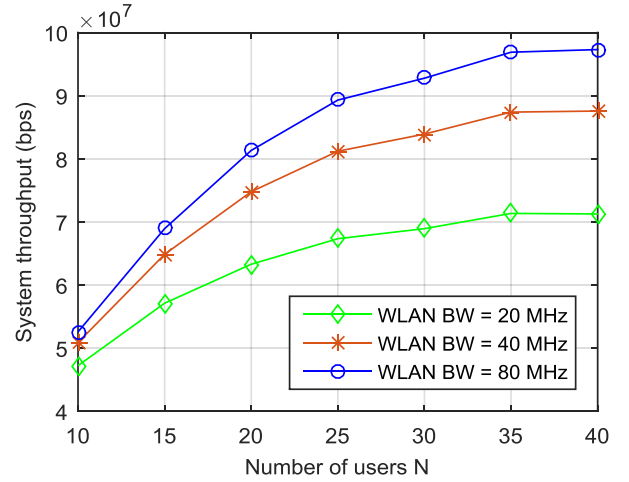


Figure 4 System throughput vs. number of users at different WLAN system bandwidths.

probability, because it aims to the find best RAT match for UEs which provides higher achieved data rates, also because it provides a quota \hat{N}_m^W for each WAP that achieves the maximum saturation system throughput, this WAP quota maintains better downlink data rates for associated UEs compared to WLAN-first when the load on the system increases.

The effect of using different WLAN system bandwidths is illustrated in Figure 4. It evaluates the performance of matching game algorithm using WAPs with different system bandwidths (i.e. 20 MHz, 40 MHz, and 80 MHz). It can be noticed that increasing the system bandwidth will lead to increase in the total system throughput, however the difference between the three curves increases with the increase of number of UEs. This is because

system throughput is the sum of UEs throughput, and increasing the number of UEs increases the total gain of using larger system bandwidths for each UE. Moreover, it is notable that the difference between the 20 MHz system bandwidth and the 40 MHz system bandwidth is greater than the difference between the 40 MHz and the 80 MHz system bandwidths. This is because of the MAC protocol effect in (9), in which increasing the system bandwidth results in an exponential decrease in the normalized system throughput, while when multiplied with the physical rate as in (8), it gives a concave increase in the total system throughput. This implies that the system throughput gain from increasing the system bandwidth decreases with the increase of system bandwidth.

VI. CONCLUSION

In this paper, a distributed algorithm is proposed to optimize radio access network selection in Multi-RAT HetNet. In this Multi-RAT HetNet, a set of WAPs are deployed under an MBS, where the WAPs represent a WLAN in a building (i.e. mall, bank, etc.). The Multi-RAT HetNet user association has been formulated as an optimization problem, which aims to maximize the total system throughput while guaranteeing a defined quota for the MBS and the WAPs. To solve this problem, a distributed algorithm based on matching game theory has been proposed, where the one-to-many matching game is used. In this game, users are matched to the base station that serves them with the highest downlink data rates, while considering a predefined quota to achieve maximum saturation throughput for WAPs. Simulation results have shown that our proposed algorithm outperforms the WLAN-first algorithm in terms of system throughput, and in terms of outage probability as well. Simulation results also have shown that when using matching game, increasing the WLAN's system bandwidth increases the system throughput but with a decreased gain.

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