ISSN (online): 2250-141X
Vol. 6 Issue 3, July 2016

JOINT RESOURCE ALLOCATION ALGORITHMS FOR UPLINK IN 5G AND LTE NETWORK

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Abstract: ***Recently, femtocell-based 5G is the hottest radio access technology, that meet the exponentially increased user-operator demand to enhance: indoor coverage, network capacity and quality of service and decrease latency. Intelligent allocation of the resources and interference management issues are the substantial challenges in such context. In this journal, we propose a joint power and channel allocation algorithms with Adaptive Modulation and Coding (AMC) for uplink. A linear optimization models for the SC- FDMA-based Uplink transmission are adopted and resolved. Both power and modulation/coding schemes are independently assigned to each user over each allocated subchannel. The user differentiation strategy ensures the QoS guarantee with respect to a priority level of each user: premium High Priority HP users and best effort BE users. As trade-off between distributed and centralized architectures, we consider a clustered network architecture. It combines the high performance (centralized) and the low computational complexity (distributed) advantageous effects. Extensive simulations prove that our proposals outperform different techniques in the literature and considerably improve two previously proposed methods QP-FCRA and Q-FCRA. We consider different metrics for performance evaluation such as spectral efficiency, throughput satisfaction rate, user outage and transmission power.***

Keywords: 5G, LTE, SC-FDMA, AMC, QoS, Resource Allocation, Femtocell**.**

1. Introduction

5G radio access technology is adopted as the enhancement of the previous generation technology such as the 4G that is not entirely deployed yet. 5G will provide better speeds and coverage than the current 4G. 5G operates with a 5GHz signal and can offer speeds up to 1Gb/s for tens of connections. Huawei, a major player in the Chinese mobile market, believes 5G will provide speeds 100x faster than 4G LTE offers. Main design objectives for 5G are: 1) realization of massive capacity and connectivity, 2) support to very diverse set of services, applications, users and requirements, and 3) efficient and flexible utilization of all available noncontiguous spectrum resources [2, 6, 8, 7].
Recently, more than 50% of total voice calls and more than 70% of data traffic are established indoors [19]. However, transmitted signal from Macrocell Base Station (MBS) is weakly received by the indoor User Equipment (UE) due to the penetration loss and barriers absorption effect causing a degradation of the signal quality. Unfortunately, the architectures mentioned above cannot guarantee the satisfied indoor coverage. Therefore, basing on the fact that the best way to increase the system capacity is by decreasing cell size or the transmitter-receiver distance, a new architecture appears and consists to deploy a small size home base station randomly by an end user (femto:10^{-15} size order). The femtocell base stations also called Femtocell Access Point (FAP) are connected to the MBS through a broadband connection. This is the Femtocell architecture that first improve the coverage in indoor environments, and secondly increase system capacity and spatial reuse by reducing cell sizes and offloading macrocells [18].
In order to provide a complete framework about the LTE-femtocell networks, we are motivated to perform the resource allocation problem for the uplink transmission taking into account many specifications. The 3GPP LTE standard adopts for the uplink connection the Single Carrier-Frequency Division Multiple Access (SC-FDMA). Therefore, in our contribution, we proposed a SC-FDMA uplink optimization resource allocation problem under the constraint of contiguous allocated physical resource blocks for each user. Unlike most previous uplink works considering constant power and fixed MCS over all resource blocks allocated to a user, we propose to adopt a joint power control and adaptive modulation/coding mechanisms over the resource blocks depending on the channel status. Moreover, we introduced a spectrum sensing technique, in order to estimate the interference power values over the occupied resource blocks and reduce the complexity of the optimization problem.
Recent works on the SC-FDMA uplink resource allocation and interference management issues are investigated in the literature [11, 17, 16, 15]. Authors in [16] design an energy efficient model to allocate power and sub-channels under the main constraints respected by the SC-FDMA adopted for the uplink LTE transmission; in particular, all resource blocks assigned to a user must be “contiguous”, and the power transmitted by a user over all allocated resource blocks must be constant. In addition, each resource block can be allocated to one user at most. To resolve the optimization problem of the effective capacity maximization under the cited constraints as well as the QoS constraints in term of services delay and data rate requirements, they referred to the Canonical Duality Theory (CDT) for the complexity considerations. In [15], authors proposed a distributed co-channel Radio Resource Management (RRM) method for the uplink transmission in the traditional LTE cellular systems.

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ISSN (online): 2250-141X
Vol. 6 Issue 3, July 2016

They considered different types of services to be taken into account in the scheduling strategy. As the first stage, they classed the served users with respect to the priority order. In a second stage, by an iterative way, the scheduler allocates jointly the Physical Resource Block (PRB), the transmit power as well as the Modulation/Coding Scheme (MCS). Unfortunately, beginning by the maximum allowed power transmission is not beneficial in sense of energy efficiency and the iterative strategy results higher time convergence. These facts are not appropriate for the small-Cell-Femtocell-networks where the energy efficiency is more crucial factor comparing with the traditional macrocell network. Previous works, although take into account the selection of the appropriate MCSs according to the channel quality, they don't present enough description of the Adaptive Modulation and Coding (AMC) technique based on the physical layer argumentation. In addition, they jointly allocate sub-channels, power and MCS, but, effectively, the scheduler must fix power for select the corresponding MCS and/or fix the MCS to calculate the transmit power, which significantly decelerates the convergence. Thus, we propose for the SC-FDMA-based uplink femtocell-LTE networks a joint resource allocation problem where the power, the RBs and the MCSs are simultaneously and optimally allocated while mitigating the interference. Neither the power nor the MCS are enforced to be constant over all RBs allocated by one user. Doing that we aim to deal with our main scope in this journal in sense of increasing the data rate and offering an enhanced user experience while increasing the spectral and power efficiencies.

The rest of this paper is organized as follows. In Section II, we describe the system model. In Section III, we present the adaptive modulation and coding technique. In Section IV, we present and explain our algorithms on uplink resources allocation approaches. Simulation metrics and result evaluation are provided in Section V and VI respectively. Finally, the conclusions are drawn in Section VII.

2. System Model and Description

We present in this section a global description of our system including the network model, the physical propagation model and lastly summarize all notations used in the sequel. Two-tier femto-macro network is assumed, where a set F of N Femtocells base stations (FBSs), also known as Femtocell Access Points (FAPs), submerge in a macrocell base station coverage area (Figure 1). As femtocell network architecture, we distinguish between three different categories known in the literature:

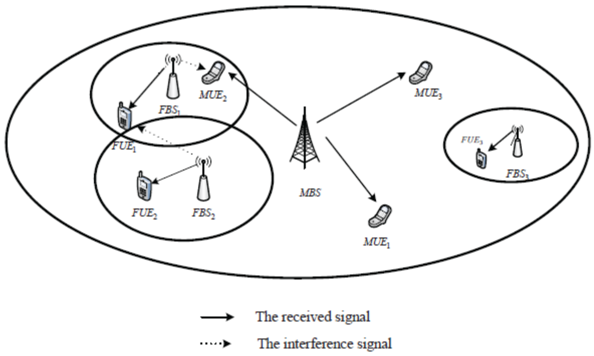

Figure 1: Two-tier Femto-Macro Heterogeneous Network

- *Centralized*: in this case, the scheduling and the resource allocation take place uniquely at a centralized base station referred as allocator. This central scheduling collects information about available resources, user positions and channel quality measurements. All users send their requests and the allocator responds considering the available resources and the interference relative to each user. The main advantage of this way is the high accuracy and service performance since all necessary allocation parameters are known. However, it cannot be applied to dense networks, since the allocator gets heavily loaded and the bottleneck connection increases the network complexity.
- *Distributed*: conversely, in the distributed way, each FAP presents a self-scheduling to allocate resources for its own users. It should be able to learn about the surrounding environment and efficiently allocate resource to ensure satisfied user experience. This approach reduces the network complexity especially for high density networks. However, due to the lack of knowledge about the surrounding, this way is less reliable.
- *Clustered*: in order to tradeoff between the centralized and the distributed techniques, a hybrid approach is adopted in many references [14, 13]. It aims to enhance scheduling reliability while reducing the network complexity. Several neighboring femtocells constitute one entity basing on the mutual interference criterion. The scenario is explained as follows:
  - First, each FAP collects the knowledge about the surrounding network by sensing the transmissions of the neighboring cells as well as receiving reports from its own users.
  - Second, a set of one-hop neighbors interfering FAPs is formed by each FAP regarding to the received knowledge. The element number of this set is the basic-key useful for constituting the clusters, so-called "interference degree".
  - Third, each FAP interference degree is broadcasted to each element of the set.
  - Final, the FAP that has the highest interference degree is selected as the cluster head (CH) and others FAP are the cluster members.

The cluster architecture is a promising approach for urban dense environment, since it reduces the bottleneck and complexity while providing relative knowledge about the FAPs cluster members.

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ISSN (online): 2250-141X
Vol. 6 Issue 3, July 2016

2.1. Propagation Model

The indoor femtocell base stations (FAPs) are assumed to be in a corridor or in rooms. Thus, two link types are considered: corridor-to-corridor link referred to the line of sight (LOS) case and corridor-to-room link referred to the non-line of sight (NLOS) case. In addition, for rooms farther away from the corridor, wall-absorptions must be applied to the walls parallel to the corridors. Further, Floor Loss (FL) of the vertical radiations for propagation from floor to floor is modeled, and the Floor Loss must be added to the path-loss calculated for each floor. Therefore, the A1-type generalized path loss model is considered as the propagation model for the frequency range 2 – 6 GHz developed in WINNER [6]. The path loss models are thus summarized in the following form:

$$PL = A\log_{10}(d[m]) + B + C\log_{10}\left(\frac{f_c[GHz]}{5.0}\right) + X \quad (1)$$

In Equation 1, d is the distance transmitter to receiver in [m], f_c is the carrier frequency in [GHz], the fitting parameter A includes the path-loss exponent, parameter B is the intercept, C describes the path loss frequency dependence, the shadow fading distribution is log-normal. X is an optional, environment-specific term.

2.2. Notations

A list of notations is presented in what follows summarizing essential parameters useful in this paper:

- $F = \{F_1, ..., F_N\}$ is the set of FAPs, where N is the total number of femtocells.
- $H = \{u_1, ..., u_{nhp}\}$ is the set of HP users.
- $B = \{v_1, ..., v_{nbe}\}$ is the set of BE users.
- $S = \{S(1), ..., S(L_v)\}$ is the set of SINR thresholds for different MCSs. Where L_v is the total number of MCS levels. In our work, we consider 6 MCS levels L_v as shown in Table 1.
- $C = \{C(1), ..., C(L_v)\}$ is the set of the MCS efficiencies.
- R_u denotes the demand of the user $u \in H \cup B$.
- $K = \{1, ..., K\}$ is the set of available physical resource blocks (RBs).
- $\Delta_u(k)$ is the binary resource allocation vector for user $u \in H \cup B$, with 1 or 0 in position k according to whether the RB k is used or not.
- $\alpha_{u,k}(l)$ is the binary resource and MCS allocation vector for user , with 1 or 0 in position k according to whether the MCS l is selected by the user u on RB k or not.
- $P_u^n(k)$ is the power transmitted from FAP F_n to its user u on the RB k, where $P_{min} < P_u^n(k) < P_{max}$ if RB k is used by the user u or $P_u^n(k) = 0$ otherwise.
- P_{max} is the maximum power transmission fixed by the operator. P_{min} is the antenna power sensitivity.
- $\gamma_{u,k}$ is the required SINR for user u on RB k.

$$\gamma_{u,k} = \frac{P_u^n(k).g_u^n}{\sum_{m \neq n} P_{u'}^m(k).g_u^m + \sigma^2} \quad (2)$$

g_u^n is the gain of the physical link between the FAPs F_n and the user u. It is the inverse value of the path-loss value just modeled above. σ^2 is the Additive White Gaussian Noise (AWGN) variance.

For each resource block, if the SINR value at a mobile receiver is less than its minimum required threshold, it suffers from interference. Thus, the scheduler discards the transmission link on such RB and tries other resources. Therefore, fixing a unique SINR threshold value is a hard condition that threats to reduce the spectral reuse and the global system throughput while increasing the rejected rate. Consequently, the user satisfaction rate and the overall system capacity radically decrease. Motivating by this fact, we propose to switch between several SINR thresholds depending on the channel status on the considered resource block. The transmission rate is harmonically selected accordingly to the adopted SINR threshold, AMC.

3. Adaptive Modulation and Coding Technique

Adaptive Modulation and Coding (AMC) is a smart technique that optimizes usage of the network resources and efficiently exploits the channel capacity depending on its quality [4]. Therefore, scheduling with AMC automatically reacts to the channel fluctuations and dynamically matches the modulation and coding rate with the radio link quality for each RB. This is a “rate control” mechanism as shown in Table 1 and Figure 2. Each system fixes its proper TBLER that must not be exceeded. With respect to this BLER threshold, the AMC approach provides a set of discrete SINR thresholds picked corresponding to the predefined set of MCSs [7, 14, 5].

Table 1: Modulation and Coding Schemes (MCSs)

Modulation Type	*Coding Rate*	*Efficiency (bits/sym)*	*SINR level (dB)*
QPSK	1/2	1	9.4
QPSK	3/4	1.5	11.2
16-QAM	1/2	2	16.4
16-QAM	3/4	3	18.2
64-QAM	2/3	4	22.7
64-QAM	3/4	4.5	24.4

In fixed MCS, the base station transmits signal with the same MCS that is the same for all allocated resource blocks. So, if the MCS selected has a high-order, it is exclusively suitable for good condition RBs; else, unfortunately, the performance degrades and the power efficiency decreases since a considerable amount of transmitted information bits is erroneous received by the user equipment. Otherwise, if the low-order MCSs has applied to avoid losing the transmission on the corresponding RBs. For better channel quality it leads dissipating available spectrum and profitless decreasing rating amount; as the results, throughput, spectral efficiency and the system capacity significantly decrease.

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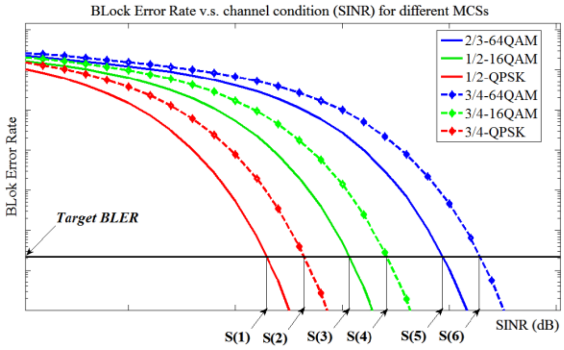

Figure 2: SINR thresholds selection for different MCSs

Alternatively, adaptive MCS allocation is a promising way to efficiently allocate RBs in accordance to their relative statuses. Thus, the overall operator-user goals are thoughtfully achieved with respect to two major considerations: 1) Throughput and spectral efficiency, and 2) Availability and maintenance link quality. With regard to the description above, the benefits of the AMC technique clearly shine to tradeoff between desirable throughput and satisfied system performance.

4. AMC-based Joint Resource Allocation approaches

In this section, we present our optimization scheduling and resource allocation problem for SCFDMA uplink femtocell networks. Our objective is to perform an optimal resource allocation problem that jointly assigns RBs, transmit power values and MCSs for each active FUE in order to fully satisfy HP users and then serve BE users as much as possible.

4.1. Problem Formulation

Our allocation and interference mitigation problem are formulated while carefully taking into account the Uplink transmission specifications. First, we cite the Uplink interference scenarios that differ from the downlink case. Then, we introduce the spectrum sensing technique as a beneficial way before formulating the resource allocation problem.

Uplink Interference Scenarios We classify three interference scenarios as summarized in Table 2. Manage these interference scenarios is the main challenge in order to provide an efficient uplink transmission.

Table 2: Uplink interference scenarios in two-tier network

Scenario	*Aggressor*	*Victim*	*Interference Type*
1	MUE	FAP	Cross-tier
2	FUE	MBS	Cross-tier
3	FUE	FAP	Co-tier

- *MUE to FAP interference* When the MUE communicates with the far-away Macro base Station (MBS), this latter gives the order for the MUE to increase its transmission power to overcome the path-loss and other propagation attenuation effects along the MUE-MBS trajectory. The goal is to achieve a minimum SINR at the MBS receiver side allowing surpassing the interference effect and reaching the MCS considered. If the MUE location becomes close to a femtocell region, severe cross-tier interference occurs on the RBs commonly used by the MUE and a FUE of the corresponding FAP. This interference type is considered very frequently. In our scheduling strategy, we benefit from the HP/BE user's differentiation to resolve the cross-tier interference between the MUEs and the FAPs. In fact, when the MUE passes nearby a FAP, it automatically switches its communication from the MBS to the corresponding FAP.
- *FUE to MBS interference* The cell-edge FUE aims to increase its uplink transmitted power trying to attain the target SINR that guarantees reliable transmission. When the FUE is in the vicinity of the MBS, the interference occurs only if the FUE uses the same frequency as the MUE in transmission mode. However, in our uplink scheduling strategy, we neglected the influence of the FUE transmitted power on the MBS. Indeed, by definition, the femtocell is a short range region.
- *FUE to neighboring FAP interference* The third scenario represents the co-tier uplink interference, where FUE is the cause of the interference and neighboring FAP is the victim. In fact, the cell-edge FUE radiates with an enough power to its FAP respecting the required SINR value. This results a leakage of power to the adjacent FAP through the walls. Due to the frequency reuse policy, the cell-edge FUE signal and a neighboring femtocell-user signal interfere at the corresponding neighboring FAP over the common RBs. Consequently, a severe interference degrades the signal reception.

In our uplink scheduling approach, we focus on the third interference scenario and we benefit from the potential spectrum sensing technique next presented to be aware of the surrounding interference transmissions

Spectrum Sensing Phase The spectrum sensing technique is performed to detect and analyze the wireless spectrum. It is originally used to identify free spaces considered as available resources in the whole spectrum for dynamic cognitive radio (CR) transmissions. For the LTE Heterogeneous Network, by performing the spectrum sensing technique, each FAP listens to its surrounding environment and detects over all available RBs, the free and occupied ones; further, it can measure the interference level on the occupied RBs by measuring the received signal energy. Indeed, the FAP can more reliably detect the closed transmissions and consider them as aggressor interference.

The most applications introducing the spectrum sensing technique are mainly based on the occupied/free decision. Whereas, our uplink allocation problem is based on the spectrum-sharing approach, so the occupied/free decision is not the unique critical factor, but also the energy value of the detected signal on each occupied RB. To give a considerable knowledge about the interference on the corresponded RB. In the downlink, the interference power value is unknown and is introduced in the downlink model as variable to be found. In the uplink, the interference powers are assumed known due to the spectrum sensing; this significantly simplifies our

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ISSN (online): 2250-141X
Vol. 6 Issue 3, July 2016

scheduling model and reduces its complexity as well as the convergence time needed after the first allocation process.

Resource Allocation Phase We take into account the specific constraints of the SC-FDMA Uplink transmission. Particularly, the 3GPP LTE standard adopts the "localized SC-FDMA" for the uplink transmission where all RBs allocated to each user are forced to be contiguous to each other.

By this way, each user reserves a continuous portion of the overall licensed spectrum. The previous uplink literature works consider that each user allocates a constant power over all assigned subcarriers, so the total power transmitted by each user equipment allocated $|K_u|$ RBs is given by the following Equation [15]:

$$P_u^n = |K_u| . P_u^n(k)$$

Furthermore, some of the previous works enforce each user to perform a fixed MCS over all assigned RBs, hence, the spectral efficiency of each user becomes constant for these RBs. These two assumptions are closely correlated. In fact, the selection of the MCS depends on the channel status over each RB, which is represented by the SINR level on such RB. So, the constant power over all allocated RBs imposes a constant channel status and consequently constant MCS over those RBs.

In contrast, our uplink resource allocation strategy is based on the "power control mechanism" where the transmit power may be different over the allocated RBs with respect to the minimum required SINR level on each one. In addition, it is not mandatory that each user is assigned the same MCS over all allocated RBs since the interference status becomes different for each RB, which allows increasing the user spectral efficiency and the overall system throughput.

4.2. Problem Resolution

Our uplink resource allocation and interference management model handles the link adaptation issue in terms of both: 1) power control and 2) Adaptive Modulation/Coding mechanisms. The overall transmitted power is minimized under user demands constraints; at the same time, the overall data rate is maximized under performance constraints.

In this paper, each FAP exploits the spectrum sensing for getting on each occupied RB the interference level and allows the control for each user of the power transmission with additional surrounding knowledge. This information is provided to the cluster head to which the FAP is attached. So, the optimization model becomes simpler since the power constraint is thus relaxed to match the linear form which will be discussed next. On each assigned RB, the power is controlled independently. Thus, for this purpose the overall transmit power of the whole system is thus "minimized" under the constraint to be as enough as to satisfy the minimum SINR required for a reliable signal reception and decoding. On the other hand, the AMC technique is adopted in order to maximize the overall system data rate, increase the spectrum reuse and reduce the outage probability. Several consecutive SINR thresholds are taken into account corresponding to several MCSs with different efficiencies are adopted. We allow that each user performs on each RB a specific MCS unlike some previous approaches [15]. Therefore, independently for each RB, our optimization problem starts by allocating the highest order MCS respecting the corresponding SINR threshold. If it fails to reach this SINR level, it switches to the lower order MCS corresponding to lower SINR threshold while minimizing the transmitted power. The SC-FDMA transmission mode is considered as an additional constraint for our optimization problem. The RBs assigned to one user are independently distributed respecting the channel status only without taking into account any arrangement rule.

To better understand the optimization model, let us describe the problem constraints as follows:

- Constraint (a) ensures that the SINR threshold $S(l)$ corresponding to the MCS l value must be obtained if this scheme is used on the allocated RB k, $\alpha_{u,k}(l) = 1$. Due to the spectrum sensing technique introduced before the transmission, the overall power interference level sensed by each user u on each RB k becomes a known value equal to $E_u(k)$.
- (b) takes into account the antenna sensitivity.
- (c) means that the total sum of powers transmitted by a FAP cannot exceed a maximum value P_{max}.
- (d) ensures the "contiguous condition" of the allocated RBs for each user.
- (e) ensures that HP user requirements must be fully satisfied over the sum of the allocated RB.
- in (f), s_v represents a slack vector, it is defined as the difference between the required and the obtained throughput for the BE users. $s_v(k)$ needs to be minimized.
- (g) ensures the exclusivity, at least one MCS should be used on the RB k if it is allocated.
- (h) denotes that $\alpha_{u,k}(l)$ is a binary variable $\Delta_u(k)$ is a binary variable and that it is impossible to use more than MCS level l on the same RB k if it is allocated.
- (i) ensures the orthogonality assignment between users in the same femtocell.

This model is solved as a linear optimization problem using the "IBM ILOG CPLEX" optimization solver [1].

In award, the uplink scheduling task can be summarized as follows: through the spectrum sensing technique, the FAP detects the energy transmitted, exploits, and sends it to the Cluster Head. The Cluster Head collects information from all FAPs attached to its cluster (FAPs members) and at each scheduling period, it associates the set of RBs/powers/MCSs that must be used by each FAP. All FAPs will obtain the RBs/powers/MCSs vectors to be used and will not change until the next scheduling period. As the Cluster Head associates for each FAP its vector, it will have the visibility of the interference during this "scheduling period". Consequently, the intra-cluster problem does not arise.

For inter-cluster case, as the Cluster Heads do not coordinate with each other, it is possible that two or more neighboring and interfering FAPs are attached to two different clusters and they are assigned the same resources. In this case, the resolution happens at the FAPs in the third phase of the algorithm using a "Bernoulli distribution" to keep or discard

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ISSN (online): 2250-141X
Vol. 6 Issue 3, July 2016

the resources used.

5. Performance Metrics

The performance evaluation of our proposal is based on the following QoS metrics:

5.1 Throughput Satisfaction Rate (TSR)

TSR denotes the satisfaction degree of a user with respect to the requested resources. For each user u attached to a FAP $F_n \in F$, TSR(u) is defined as the ratio of the allocated number of RBs to the requested ones and can be expressed as follows:

$$\forall u, \quad TSR(u) = \left(\sum_{k=1}^{K} \Delta_u(k)\right) / R_u$$

For a network with U users, the TSR metric can be thus given by: $TSR = \sum_u TSR(u)/U$

5.2 Spectrum Spatial Reuse (SSR)

SSR denotes the average portion of FAPs using the same RB within the network. Therefore, it is defined as the mean value of RBs' spatial reuse. The SSR metric can be thus expressed as follows: $SSR = \frac{1}{K \times |F|} \sum_{k=1}^{K} \sum_{u \in H \cup B} \Delta_u(k)$

5.3 Rate of rejected users

It represents the percentage of HP and BE users not admitted in the network during the scheduling period. Recall that, once accepted, HP users are completely satisfied, whereas for BE users, their satisfaction degree will be maximized.

5.4 Average channel efficiency

It represents for each resource block (RB) the mean value of achieved efficiency over the whole network expressed in bits/symbol. It is thus expressed as follows:

$$Eff_{average}(k) = \frac{1}{|F|} \sum_{l=1}^{L_v} \sum_{u \in H \cup B} C(l) \times \alpha_{u,k}(l)$$

5.5 Transmission power

We compute the transmission power allocation on each tile. This parameter is computed regarding: i) The variation in demand or users' requirements, to show the impact of the number of allocated RBs for each user on the total received power. ii) the average distribution of power over the different available resource blocks in the network used for transmission.

5.6 Fairness

The Jain's fairness index [3], which determines how fairly the resources are distributed among N existing users, is considered to highlight the performance of the algorithm with regards to user satisfaction rate. It expressed as follows:

$$\beta = \frac{\left(\sum_{u=1}^{N} TSR(u)\right)^2}{N.\sum_{u=1}^{N} TSR(u)^2} \qquad (3)$$

6. Performance Evaluation

We compare performance of our method with three different techniques: 1) UPLINK FMC-QRAP (same problem but with fixed modulation and coding) 2) Downlink AMC-QRAP presented above to show the difference between the OFDMA and the SC-FDMA schemes where we compare the downlink and uplink user experience. 3) QP-FCRA [12] which considers power control but with fixed modulation and coding in the downlink.

We consider a typical UPLINK LTE SC-FDMA frame with a system bandwidth of 10 MHz and a total number of K = 100 RBs. Different network densities are studied. It ranges from 50 FAPs for low density networks and reaches 200 FAPs in higher density deployments. The FAPs are randomly distributed in a 2-D 400m×400m area, within 10m×10m residences. Users are distributed uniformly in the residence with a maximum number of 10 users per FAP. The number of users, their bandwidth requirements as well as their locations is varied at each simulation. In each FAP we allow up to 4 HP users and 6 BE users. The simulation results for each of the described metrics are presented below:

6.1 Throughput Satisfaction Rate

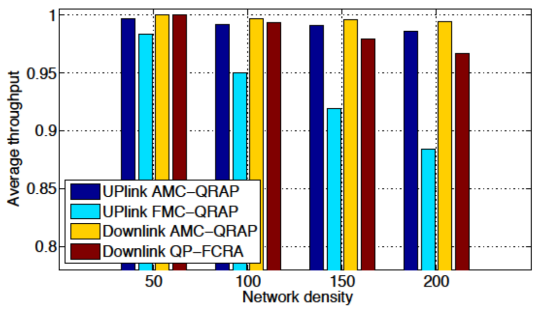

Figure 3: Throughput vs. Network Density

As mentioned earlier, the throughput difference between downlink and uplink is noticeable in both FDD and TDD schemes. It is clearly shown, in Figure 3, how the difference is very small in downlink and uplink when AMC is used. In fact, UPLINK AMC-QRAP performs very closely to downlink. When it comes to using AMC, we see the efficiency and the gain compared to uplink with fixed modulation and coding scheme. When comparing UPLINK AMC-QRAP and UPLINK FMC-QRAP, in low density scenario an average throughput of 99% and 98% is respectively achieved. Where in high density scenarios, the throughput for UPLINK AMC-QRAP remains high with about 98% satisfaction whereas the other scheme decreases to below 87%.

A very important point is noticed also in this figure: when considering high density scenario, the uplink scheme with AMC can perform even better than QP-FCRA for downlink using fixed modulation and coding, reaching 98% and 96% respectively. This is also due to the spectrum sensing phase used in UPLINK AMC-QRAP.

6.2 Spectrum Spatial Reuse

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ISSN (online): 2250-141X
Vol. 6 Issue 3, July 2016

Figures 4a and 4b plot respectively the mean SSR for the network for all densities and the average SSR per tile for the high density network. In the first figure we notice how the AMC scheme, for both downlink and uplink scenarios, gives a better spectral efficiency and reuse compared to the FMC scheme.

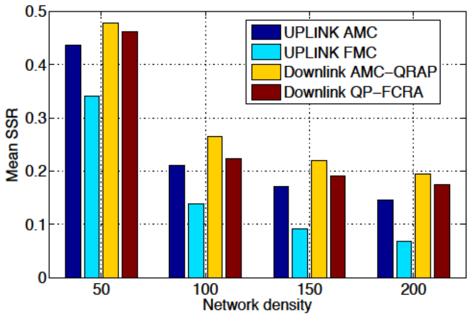

Figure 4a: Mean SSR vs. Network density

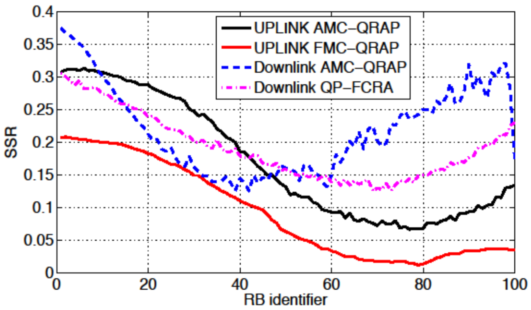

Figure 4b: Mean SSR vs. Network density

However, in the uplink mode we observe a lower SSR compared to the downlink. This is mainly due to the fact that in the uplink mode the allocated resources need to be contiguous, where this constraint does not exist in the downlink, as mentioned earlier. Thus, resulting a spread distribution of some of the resources allowing more flexibility for the downlink mode.

6.3 Rate of rejected users

When looking at Figure 5 we can make several observations on the outage probability or the number of rejected users. In fact, for low interference scenarios, UPLINK AMC-QRAP is better performing than the other schemes with less than 0.5%of rejection is observed compared to around 1% and 1.2% for the downlink schemes. If we look at the high density scenario, the benefit is evidenced with a rejection of about 2% compared to more than 13%, 7% and 10% respectively for UPLINK FMC-QRAP, Downlink AMC-QRAP and QP-FCRA.

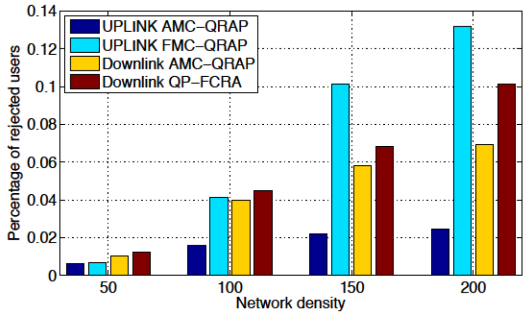

Figure 5: Outage Probability

The AMC clearly increases the performance of the algorithm for both uplink and downlink compared to the scheme with fixed modulation and coding. When comparing both uplink and downlink in the AMC mode, we can observe that the performance of the uplink reaches better results. This is due mainly to the spectrum sensing approach. Moreover, with a better view of the surrounding in the uplink, the spectrum sensing phase reduces the convergence time needed after the first allocation, thus enhancing the user experience and admission ratio.

6.4 Fairness

When comparing the above results, we can clearly see an improvement in different metrics. However, it is very important to verify the fairness of the algorithm and show if the resources are equitably distributed among users.

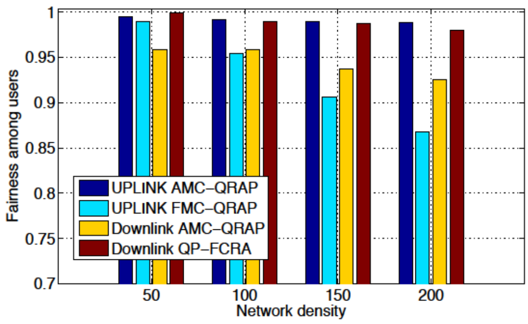

Figure 6: Fairness

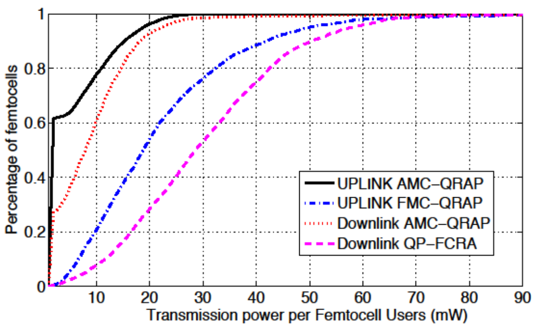

Figure 7: CDF power transmission per femtocell user

The Jain's Fairness Index, calculated as the average for entire the network and including both types of users, is used to study this metric. We note that in the best case, it reaches 1 and it is attained when all users receive the same allocation. Figure 6 shows the fairness for the different methods. It is observed that, for the low density networks, UPLINK AMC-QRAP and

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ISSN (online): 2250-141X
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DOWNLINK QP-FCRA are better performing that the others. While all the methods degrade with the network load, UPLINK AMC-QRAP keeps a high degree of fairness and is less affected by the density, where it varies from 99.5% to 98.5% compared to 96% to 93% for DOWNLINK AMC-QRAP and 98% to 87% for UPLINK FMC-QRAP, respectively for both low and high density networks.

6.5 Power allocation

In this part we investigate the power transmission and the energy efficiency of our algorithm. We use several metrics to study the power control mechanism and compare the different methods. We first start by showing the CDF of the power transmission per user over the entire network plotted in Figure 7. In this plot we can clearly observe that for UPLINK AMC-QRAP, 90% of users have a total transmission power less than 15 mW, compared to 18 mW for Downlink AMC-QRAP. This rate grows to approximately 40 and 50 mW for UPLINK FMC-QRAP and Downlink QP-FCRA respectively. This difference is obviously due to the AMC techniques which allowed the resources to be used with less transmission power when a lower MCS is needed, resulting in a lower interference over the RB and hence less transmission power required.

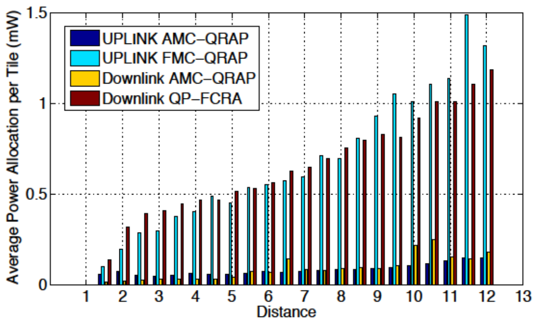


Figure 8: Transmit Power vs. Distance

The power transmitted vs. distance is plotted in Figure 8 where we can see the evolution in the total power used based on the distance from the center of the FAP. A power minimization model is used, as the algorithm tries to allocate the best channel to edge users far from their FAP. They will use the channel with less interference so they can consume a lower power and reduce energy consumption, especially when user equipment's are sensitive to battery and energy savings. The difference for both uplink and downlink schemes using AMC compared to the same scenarios without AMC is clearly highlighted. With AMC, when failed to provide the required SINR on some of the resource blocks, users in the uplink scheme will shift to a lower MCS which in most of cases will reduce their power transmission and the interference on neighboring FAPs, and in turn will reduce the transmission power of the other users.

Figure 9 displays the transmitted power and its variation over demand. Depending on users requests they will be allocated a number of resources to achieve their requirements. The number of resources depends on the MCS on each resource. We can see from the figure how the power per demand increases almost linearly. Indeed, when users ask for a few resources we tend to allocate them with a high order MCS. Demanding users might be more difficult to satisfy and hence their requests are spread over a larger number of resources if failed to provide the required SINR for the considered MCS.

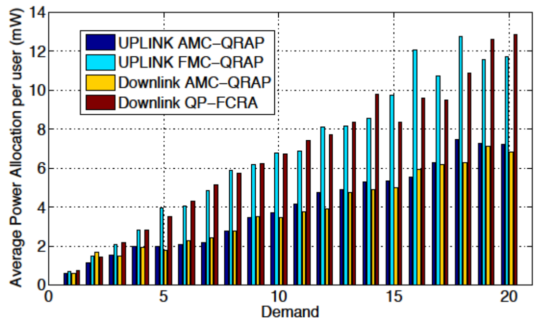


Figure 9: Transmit Power vs. Demand

Figure 10 represents the average distribution of transmission power per tile over the entire spectrum. As it can be seen from the figure, when using the AMC, the power per tile needed has an average lower than 0.3 mW independently of the network load. Whereas this ratio raises to more than 0.6 mW per tile for the schemes with fixed modulation and coding.

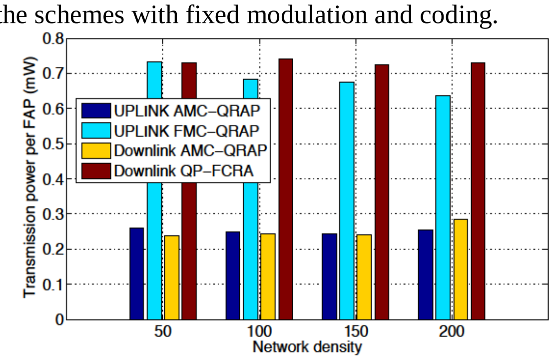
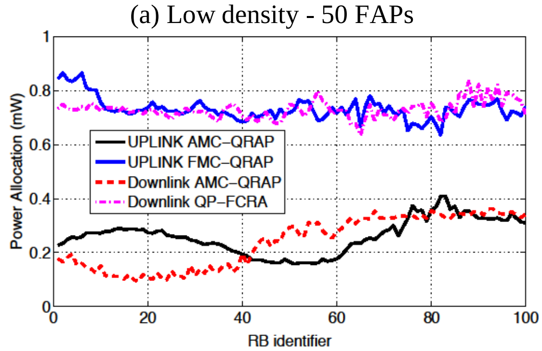


Figure 10: Mean Power per RB vs. Network Density

Let us have a more detailed view on the average power transmission on each tile of the spectrum by looking at the Figure 11. As shown for the four different network densities, we can observe that the distribution of power for the UPLINK is much smoother that the downlink case. As clearly shown in Fig. 11(d) for the high density network, we observe how the power fluctuates for the Downlink AMC-QRAP compared to the UPLINK AMC-QRAP. In fact, since the PAPR in the OFDMA is higher compared to the SC-FDMA, we can see the power distribution accordingly.

(a) Low density - 50 FAPs



(b) Medium density - 100 FAPs

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ISSN (online): 2250-141X
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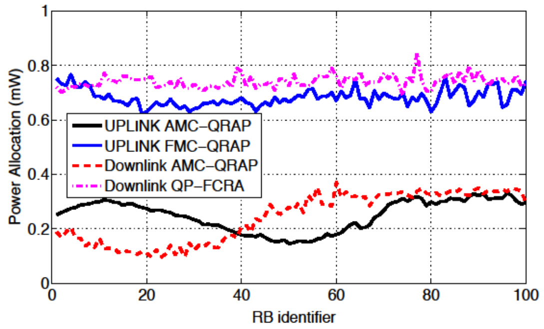
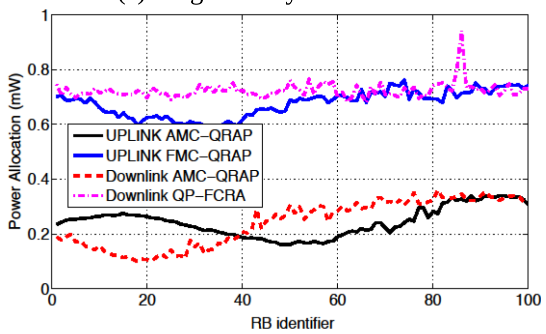


(c) Large density - 150 FAPs



(d) High density - 200 FAPs

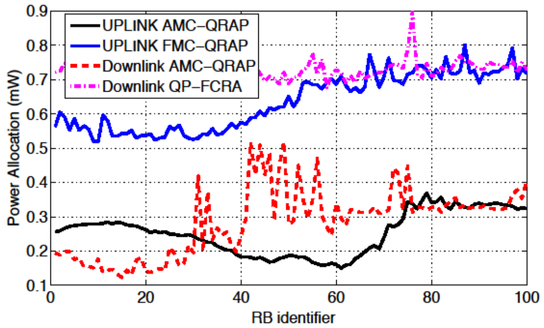


Figure 11: Average power transmission per tile

7. Conclusion

The essential questions we aimed to answer here are: *How we can provide higher data rates, higher energy efficiency, better spectrum utilization, enhanced performance and increased capacity for the advanced LTE-based Femtocell networks; and what are the degrees of freedom that can be exploited yet*? In this journal, we are oriented according to both: multi-user scheduling on the data link layer and basic transmission enhancements on the physical layer. We have first exhibited the main features offered by the high-speed SmallCell-LTE network while citing its main challenges as a network submerging in the macrocell area. We have got an overview of the literature works on the uplink scheduling and resource allocation algorithms. After that, we began to explain our contribution on the management of the radio resource allocation of the SC-FDMA-based uplink connection basing on the adaptive modulation and coding(AMC) technique and the power control where an additional hard constraint imposes that the resource blocks assigned to each user must be adjacent. This is referred as: Uplink AMC QoS-based resource allocation with power control or “uplink AMC-QRAP”. the cluster architecture is considered as a hybrid between the centralized and the distributed architectures. Therefore, the power control mechanism is introduced to mitigate the resulted interference, where the power transmission of each user must respect a minimum required SINR level at the receiver side. To avoid rejecting user who cannot reach this fixed SINR threshold on its allocated resource, we have proposed to adopt a set of several SINR threshold and respecting them adaptively to the effective channel quality on such resource block. Each SINR threshold corresponds to a specific modulation and coding scheme (MCS) selected under a block error rate performance constraint. We began by the highest SINR threshold value corresponding to the highest order MCS in order to maximize the data rate. This is what we refer to the “rate control” or AMC mechanism. The proposed problems are modeled in accordance to the linear programming tools. As results, the system capacity, the overall throughput, the spatial spectrum reuse and the spectral efficiency are all enhanced as proved by extensive simulations using the IBM ILOG CPLEX solver.
Finally, we consider that delivering the high-speed services and application of the next generation wireless systems require complementary improvement on both physical and link layer levels. Intelligently and jointly allocating power, sub-channels and power resources while enhance the transmission mode, provides a competent issue for the future generation standards.

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