A Dynamic Resource Management Scheme for Two-Tier LTE Femtocell Networks

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Abstract— **Recently, the femtocell concept has received considerable attention both in academic and industry as a promising solution for the deep indoor coverage problem as well as the increasing data demand of mobile devices. Large scale femtocell deployments are hindered mainly by the cross tier interference problem spawned by their inherent uncoordinated deployment and the shared use of the limited spectrum resource by the macro and femtocell networks. The spectrum sharing scheme used has a high impact on the total network throughput. Balance is needed between shared and dedicated spectrum to achieve high spectral efficiency and reduce the co-channel interference. This paper proposes a new hybrid spectrum management scheme for the downlink of OFDMA based systems (e.g. LTE system). The proposed scheme dynamically changes the dedicated spectrum bands of macro and femtocell networks based on the level of interference experienced by users. The throughput performance of the proposed scheme is investigated using simulation and is shown to be considerably better than that of the widely used static spectrum partitioning.**

Keywords— Dynamic Spectrum Management, Femtocell, Macrocell, Hybrid Resource Management, Two-Tier Network,

I. Introduction

Mobile network operators are continuously engaged in meeting ever increasing coverage and data demands of ubiquitous mobile broadband access. Adding more network infrastructure is the most widely adopted conventional solution. The addition of cell towers or transmitters inherently increases the interference level of the network due to the reuse of the limited spectrum resource. Nevertheless, the infrastructure cost for the deployment of a large number of macrocells is excessively high. Distributed antenna systems can provide indoor coverage improvement but is only viable for large buildings considering its cost. With the trend of wireless traffic shifting towards indoors, and most of it being for data services, it becomes increasingly important for operators to focus towards better indoor coverage and quality for best return on investment [1],[2]. The concept of femtocells has long been around which could effectively bridge the gap between good network quality and operator cost. Femtocells are intended to be indoor coverage solutions which can be self-installed by users and connected to an available Digital Subscriber Line (DSL) for backhaul. It makes use of the available wire line capacity to offload traffic from the macro cellular network. This allows increasing the capacity for indoor users without being limited by the macro network resources, so that the macro network can dedicate its resources for truly mobile users [2].

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The co-channel interference in a two tier network is inherent due to the unplanned deployment of femtocells and the reuse of limited spectrum resources. The most prominent is the macrocell downlink interference to nearby femto users and femtocell downlink interference to nearby macro users. Hence, in two-tier networks, it has become essential to employ an efficient spectrum management scheme in order to achieve good system performance. In literature, there are several shared spectrum allocation schemes presented where both tiers share the total available spectrum with certain limitations imposed to minimize co-channel interference. For example in [3], the macrocell operates on the entire spectrum and the femtocells cognitively identify spectrum with minimal interference to be used. This scheme manages to improve spectral efficiency, although the probability remains that the femtocells face increased interference especially closer to the macrocell.

Spectrum partitioning can eliminate the cross-tier interference by assigning mutually exclusive spectrum bands to the macro and femto networks. Such a scheme was proposed in [4] in combination with Fractional Frequency Reuse (FFR) to mitigate macrocell interference. In [5] the spectrum allocation was done dynamically based on the number of femtocell users. The drawback of spectrum partitioning is the reduced spectral efficiency. Spectrum partitioning can improve the Signal to Interference and Noise Ratio (SINR) of users, although they may not achieve high throughput due to limited spectrum resources.

Hybrid spectrum management adopts a combination of shared spectrum usage and partitioned spectrum usage. It generally yields better spectral efficiency and interference mitigation than both shared spectrum usage and partitioned spectrum usage. In hybrid schemes of [6],[7] a dedicated portion of the spectrum for macro users and a shared portion for macro and femto users were proposed. The spectrum management schemes of [8],[9] proposed dedicated spectrum usage for both tiers as well as a shared portion. The radio resources available to the femtocells are determined based on their relative position with respect to the macro Base Station (BS). Dedicated spectrum is assigned to the femtocells, which are closer to the macro BS. Femtocells measure the Reference Signal Received Power (RSRP) of the macro BS and estimate their distance. In [8] the spectrum portions for shared and dedicated bands are fixed and more dedicated spectrum is assigned for macro users as compared to femto users. Users are allocated with shared or dedicated spectrum based on their distance from the macro cell centre. In [9] it was proposed to have variable spectrum portions for the shared and dedicated bands according to the distance from the macro BS. Hence in the middle area of the macro cell, the spectrum is fully partitioned and no shared portion is available. The sizes of the dedicated portions decrease, whereas the size of the shared

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portion increases gradually when moving towards the edge of the macro cell from the centre. In this way, at the cell edge, there is only shared spectrum available for users. Both these schemes consider the user location as the main criterion to decide its spectrum mode. These two schemes can be regarded as the most closely related work to the proposed scheme in this paper, as they introduced the idea of shared and dedicated spectrum for both the macro and femto networks.

In this paper we propose a hybrid spectrum management scheme which dynamically determines the shared and dedicated spectrum portions to maximize the overall throughput of the system. As opposed to the schemes of [8],[9], the decision to allocate a user with shared or dedicated spectrum is done based on the user's SINR. The amount of the spectrum allocated for the shared and dedicated portions are determined by the number of users in each spectrum band. A simulation based approach is used to obtain the optimal spectrum partitioning for the shared and dedicated band users. The throughput performance of the proposed hybrid spectrum management scheme is compared with that of the shared spectrum and partitioned spectrum management schemes.

The rest of this paper is organized as follows. Section II presents the proposed scheme. The system model and the algorithm is described in III. Simulation results and discussion are provided in Section IV. The paper concludes with Section V.

II. PROPOSED SCHEME

In this section we propose a hybrid spectrum management scheme which uses dynamic spectrum partitioning to provide dedicated and shared spectrum portions to both the macro and femto tiers. The spectrum decision is made by the serving transmitter of the user based on the user's SINR. Initially, total spectrum is shared by all the users. This is equivalent to $F_d = 0, M_d = 0$ in figure 1, where F_d, M_d are expressed in terms of LTE Resource Blocks. A Resource Block (RB) is the smallest radio resource unit in an LTE system which can be scheduled to a user. The macrocell assigns the total available spectrum to its users on round-robin non-overlapping basis. The femtocells are also given access to the total spectrum, which then allocates to its connected users in the same manner. The co-channel interference is then measured for each user on Resource Block (RB) level by its connected transmitter using measurement reports. The serving cell decides to keep the user in the shared band or to shift to the dedicated band based on the SINR measurements.

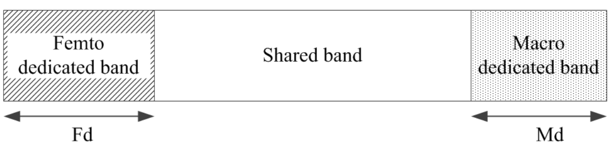

Fig. 1 Spectrum partitioning used in the proposed scheme

The criteria to add a user to the macro and femto dedicated spectrum bands can be expressed as:

$$SINR_f(n) \leq TH_f \quad (1)$$

$$SINR_m(n) \leq TH_m \quad (2)$$

Where,

$SINR_f(n)$	Average SINR of all RBs of femto user (n)
$SINR_m(n)$	Average SINR of all RBs of macro user (n)
TH_f	SINR threshold for femto user
TH_m	SINR threshold for macro user

The users having SINR lower than the threshold are shifted to the dedicated band. Similarly a threshold can be imposed for the users in the dedicated band to shift back to the shared band. This threshold can be either SINR or throughput based since a user in dedicated band could be interference or resource limited. The network makes a decision on the spectrum partitioning between dedicated and shared portions F_d, M_d based on the number of users in each band in order to maximize the total throughput of the system. The number of users is considered as a measure of the system load assuming per user demand is fixed. The proposed scheme essentially allocates the spectrum for the two tiers proportional to the number of users in the shared and dedicated spectrum bands. The spectrum partitioning in terms of resource blocks (RB) can be given as:

$$F_d = 1.6509 * N_{fd} + 5.8799 \quad (3)$$

$$M_d = 0.977 * N_{md} + 0.8394 \quad (4)$$

Where,

F_d	Femto dedicated spectrum RB
M_d	Macro dedicated spectrum RB
N_{fd}	Number of femto users in dedicated band
N_{md}	Number of macro users in dedicated band

In this scheme, the decision on how the spectrum is partitioned is taken centrally by the network based on information received from the macro and femto cells. Information gathered by the femtocells and the macrocell is used to determine the spectrum allocation for the shared and dedicated bands. The algorithm requires less signalling towards the central network since the spectrum allocation of an individual user is done by its serving cell. It is part of this study to find the optimal spectrum partitioning for the shared and dedicated spectrum bands. The criterion is to maximize the total throughput by finding optimal values for F_d and M_d (F_d^{opt}, M_d^{opt}). Equations 3 & 4 provide this optimal spectrum allocation based on the number of users assigned to the dedicated bands. The analysis to find the optimal values for F_d and M_d is detailed in section IV.

III. SYSTEM MODEL FOR SIMULATION

The simulation environment comprises of a single sector circular macrocell and multiple femtocells uniformly distributed within the coverage area of the macrocell. Multiple macrocell users are also assumed to be evenly distributed within the coverage area and a number of femto users are distributed within the femtocell area as shown in Figures 2. Users are assumed to be homogeneous with no mobility considered and closed access is assumed where only femto users have access to the femtocells and macro users to the macrocell. A single macro cell sector is assumed for simplicity. The proposed hybrid spectrum management scheme (Hereafter referred to as the proportional spectrum scheme) is investigated for the case of changing macro cell radius and is detailed in section IV.

A maximum throughput limit is imposed on a user to avoid greedy behaviour in the algorithm where femto users in the dedicated band could be allocated more spectrum (larger F_d) to maximize the overall throughput whereby leaving less resources for the macro layer. A modified Okumura-Hata model is used as the macro and femto propagation channel as presented in [8],[9]. Femto users are assumed to be placed indoor and macro users to be outdoor. Wall penetration losses are considered for indoor to outdoor interference signals and vice versa. Downlink interference to macro users is only generated from femtocells since a single macrocell scenario is used. Also since the spectrum allocation of the macrocell is orthogonal and on a non overlapping basis, it is assumed that there is no co-channel interference among users served by the same cell. Adjacent channel interference is not considered in this study. Downlink interference to femto users include co-channel interference from the macro cell and from femtocells other than the serving cell.

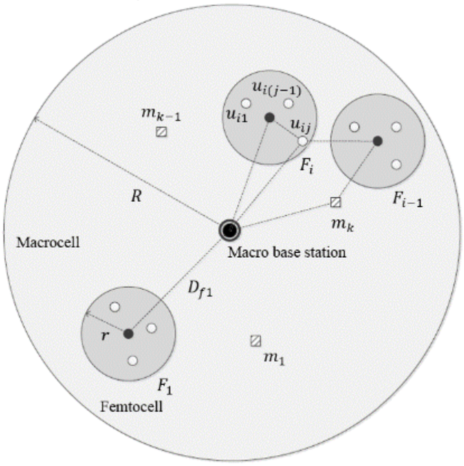

Fig. 2 Parameters for system modelling

TABLE 1
KEY SIMULATION PARAMETERS

Parameter	Value	
System bandwidth	18 MHz, 100 RB	
Thermal noise (N_0)	-174 dBm/Hz	
Wall penetration loss (L_w)	10 dB	
Number of indoor walls (n)	2	
UE throughput limit	30 Mbps	
Direction	Downlink	
Scheduler	Round-robin	
Macro path loss L_m (dB)	$128.1 + 37.6log_{10}d$, d in (Km)	
Femto path loss L_f (dB)	$127 + 30log_{10}d$, d in (Km)	
	Macrocell	**Femtocell**
Cell layout	Single cell, circular cell, single sector	Multiple cells, circular cell, single sector per cell
Cell radius	300, 500, 700, 1000 m	10m
Number of UE per cell	10, 20, 30, 40, 50, 60, 70, 80	5
Number of cells	1	1, 2, 3, 4, 5, 6, 7, 8
Transmit power	49 dBm	25 dBm
Antenna gain	BS:14 dBi, UE:0 dBi	BS:0 dBi, UE:0 dBi
Lognormal shadowing	8 dB	10 dB
SINR threshold (TH_{cell})	20 dB	10 dB
Dedicated spectrum (RB)	M_d	F_d

In the shared spectrum scenario the macrocell and femtocells have overlapping spectrum allocation to their users. The co-channel interference for each user is calculated for every RB of its allocated spectrum and is given by Eq. (5).

$$SINR_{mk}(RB) = \frac{S_{o-mk}}{\sum_{p=1}^{i} S_{Fp-mk} + \omega_{RB} N_0} \qquad (5)$$

S_{o-mk} - RSRP of the macrocell to user m_k
S_{Fp-mk} - RSRP of the femtocell F_p to user m_k
N_0 - Thermal noise power spectral density
ω_{RB} - Bandwidth of an LTE resource block

The total achievable throughput of the user m_k is the summation of the throughputs of its individual RBs.

$$Throughput_{mk} = \sum_{RB=1}^{RB_{mk}} \omega_{RB}.\, log_2[1 + SINR_{mk}(RB)]$$

Similarly for the femtocell user u_{ij} the serving signal strength is from the femtocell F_i and the received signal from all other femtocells F_1 to F_{i-1} as well as the macrocell is considered as interference. The total throughput of the system is the summation of the throughput of macro and femto users.

$$Throughput_{Shared} = \sum_{k} Throughput_{mk} + \sum_{ij} Throughput_{uij}$$

For the evaluation of the hybrid spectrum scenario, the achievable throughput for shared spectrum and dedicated spectrum users need to be calculated separately.

The SINR for a single RB of the macrocell user m_d allocated from dedicated spectrum M_d is expressed in Eq. (6).

$$SINR_{md}(RB) = \frac{S_{o-md}}{\omega_{RB} N_0} \qquad (6)$$

Macrocell users allocated with dedicated spectrum do not have co-channel interference since no neighbouring macrocells are assumed. The achievable throughput of the macrocell user m_d can be expressed as the sum of the achievable throughput of its individual RBs as follows:

$$Throughput_{md} = \sum_{RB=1}^{RB_{md}} \omega_{RB}.\, log_2[1 + SINR_{md}(RB)]$$

Similarly The SINR for a single RB of the macrocell user m_s allocated from shared spectrum S_s $(Spectrum_{Tot} - M_d - F_d)$ and the achievable throughput of the macrocell user m_s can be expressed as:

$$SINR_{ms}(RB) = \frac{S_{o-ms}}{\sum_{p=1}^{q} S_{Fp-ms} + \omega_{RB} N_0} \qquad (7)$$

$$Throughput_{ms} = \sum_{RB=1}^{RB_{ms}} \omega_{RB}.\, log_2[1 + SINR_{ms}(RB)]$$

The femtocell users allocated with dedicated spectrum are interfered by other femtocells $F_{(d-1)}$ which has users with dedicated spectrum usage.

$$SINR_{u_{dj}}(RB) = \frac{S_{Fd-u_{dj}}}{\sum_{p=1}^{d-1} S_{Fp-u_{dj}} + \omega_{RB} N_0} \qquad (8)$$

$$Throughput_{u_{dj}} = \sum_{RB=1}^{RB_{u_{dj}}} \omega_{RB}.\, log_2[1 + SINR_{u_{dj}}(RB)]$$

The femtocell users allocated with shared spectrum are interfered by other femtocells $F_{(s-1)}$ which has users with shared spectrum usage and the macro cell.

$$SINR_{u_{sj}}(RB) = \frac{S_{Fs-u_{sj}}}{\sum_{p=1}^{s-1} S_{Fp-u_{sj}} + S_{o-u_{sj}} + \omega_{RB} N_0} \qquad (9)$$

$$Throughput_{u_{sj}} = \sum_{RB=1}^{RB_{u_{sj}}} \omega_{RB}.\, log_2[1 + SINR_{u_{sj}}(RB)]$$

The total macrocell area throughput can be expressed as the sum of the macrocell and femtocell user throughput as follows.

$$Throughput_{hybrid} = \sum_{d} Throughput_{md} + \sum_{s} Throughput_{ms} + \sum_{dj} Throughput_{u_{dj}} + \sum_{sj} Throughput_{u_{sj}}$$

IV. Simulation Results and Discussion

This section of the paper presents the analysis done using the simulation model to obtain the optimal spectrum allocation for the shared and dedicated bands. Afterwards the validation of the proposed scheme is provided with a performance evaluation in comparison to the total shared spectrum scheme and the fixed spectrum partitioning scheme.

A. Obtaining optimal values for dedicated spectrum bands

Optimal values for F_d and M_d that maximizes the throughput can be found by simulation as presented in Figure 4, where the results are obtained for an arbitrary user and femtocell distribution.

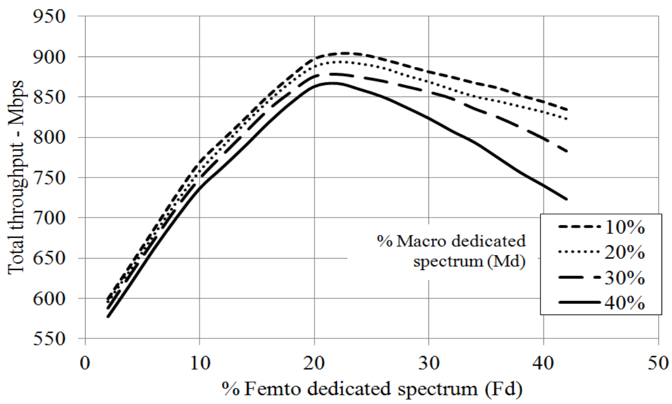

Fig. 4 Variation of maximum throughput with the portion of spectrum allocated to dedicated band

The total throughput displays a noticeable variation with the percentage of allocated femto dedicated spectrum. The variation of the throughput with macro dedicated spectrum is lower. Changing certain parameters such as the macrocell size and the number of users does change the graph in Figure 4 but the characteristics remain the same. Hence, a large number of simulations for different cell arrangements are needed to obtain a generalized output with different spectrum allocations. What we are interested is in the peak value for each combination of F_d, M_d values in Figure 4. Subsequently, the simulation is carried out for nearly 750 different cell distributions. The optimal F_d and M_d values (F_d^{opt}, M_d^{opt}) and the corresponding number of dedicated band users for the respective scenarios are also collected. Measures were taken to guarantee the fairness among users in spectrum allocation where some users with high SINR tend to be allocated with most of the spectrum in order to improve overall throughput. On the other hand, users with low SINR may suffer from insufficient resources.

Figure 5 shows the variation of optimal spectrum allocation (M_d^{opt}) for the dedicated spectrum for macrocell users with the number of macro users in the dedicated spectrum, for different cell radius. The criterion for this optimal allocation is to maximize the overall throughput. It can be observed that the optimal dedicated spectrum has a linear relationship to the number of macro users and that it is invariant with macrocell radius. Variation of the optimal dedicated spectrum allocation for femto users with the number of users in dedicated spectrum is depicted in Figure 6.

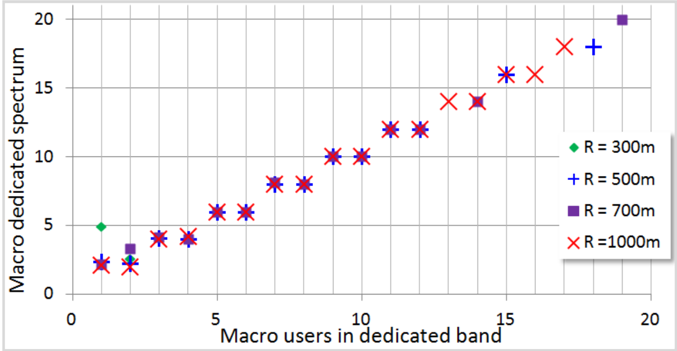

Fig. 5 Variation of M_d^{opt} in RBs with dedicated band macro usrs

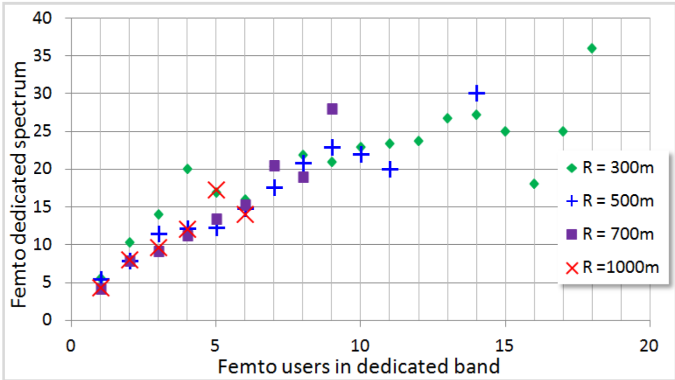

Fig. 6 Variation of F_d^{opt} in RBs with dedicated band femto users

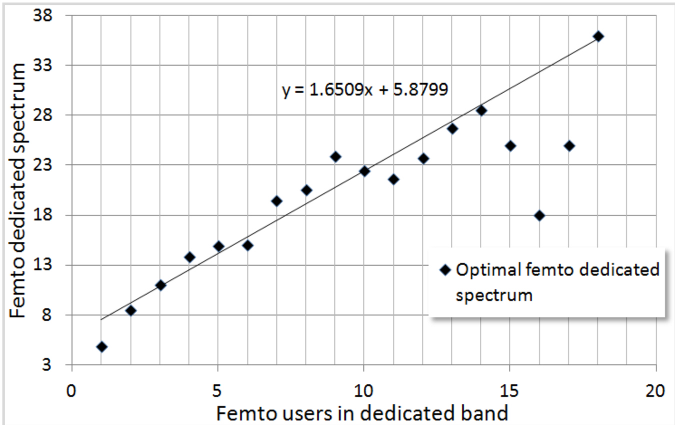

Fig. 7 Approximation for F_d^{opt} as a function of number of dedicated band femto users

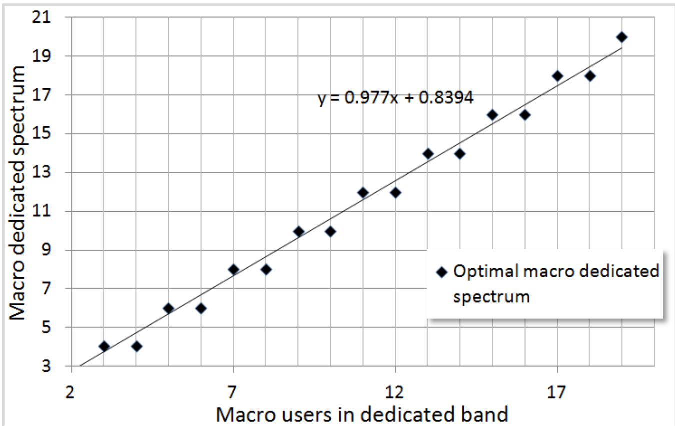

Fig. 8 Approximation for M_d^{opt} as a function of number of dedicated band macro users

As the Figure Illustrates a majority of the measured values can be approximated to a linear relationship. The algorithm for allocating dedicated spectrum for femtocells was based on a linear approximation of the measured values depicted in Figure 7. The represented data are averaged from around 750 data points obtained from the simulation model. Figure 8 shows the linear approximation done for macro dedicated spectrum with the number of macro users. It is in fact intuitive to expect that more dedicated spectrum is required with increasing the number of users allocated with the dedicated spectrum.

B. Performance Analysis

The performance of the proposed proportional spectrum partitioning scheme is evaluated against the fixed spectrum partitioning scheme and the total shared spectrum scheme. The fixed spectrum scheme allocates dedicated spectrum portions for both the femto and macro networks and also provides a shared portion for the two. in this scheme, the spectrum margins are fixed with equal amount of spectrum allocated as dedicated spectrum and shared spectrum. Furthermore the dedicated spectrum is divided equally for femtocell and macrocell users as $F_d = 25RB$ and $M_d = 25RB$. The total shared spectrum scheme allocates the same spectrum to both the macro and femto networks. This results in overlapping spectrum allocation among users of the two network tiers. The simulation is carried out for 2500 different user distributions with changing macrocell radius as given in Table 1. The average user throughput is obtained for each simulation and the CDF of the average user throughput is given in Figure 9.

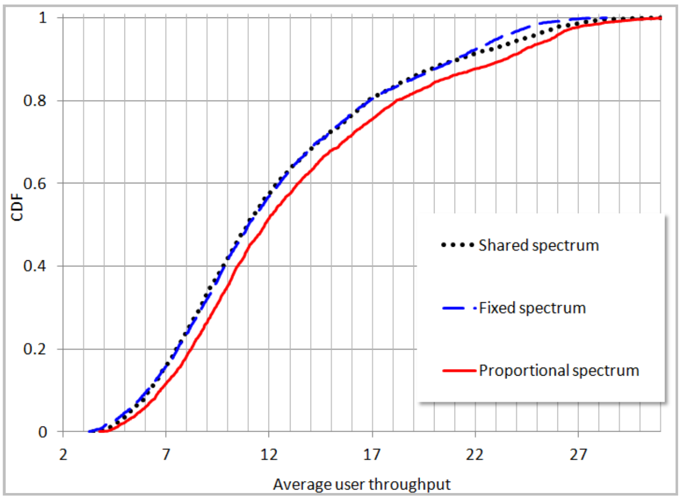

Fig. 9 CDF of average user throughput for different user distributions

The proposed scheme outperforms the fixed spectrum partitioning and the total spectrum sharing schemes. The fixed spectrum partitioning scheme does not demonstrate a noticeable improvement over the total spectrum sharing scheme. The total throughput for different values of F_d and M_d and for the different spectrum allocation schemes are provided in Table 2 for comparison.

It is evident from Table 2 that spectrum partitioning schemes improve the average user SINR compared to total shared spectrum scheme. However the fixed spectrum partitioning scheme does not always achieve higher total throughput compared to shared spectrum scheme. This is because fixed allocating spectrum in certain instances limit the achievable throughput due to limited spectrum resources even though the SINR of the user is better. The proposed proportional spectrum partitioning scheme on the contrary is capable of achieving improved throughput and SINR than shared spectrum scheme in all the scenarios considered.

TABLE 2
COMPARISON OF RESULTS

	Number of users		Scheme	Average SINR (dB)	Dedicated spectrum (RB)		Throughput (Mbps)
	Macro	Femto			Fd	Md	Total
1	60	30	Shared	51	-	-	792
			Fixed	60	25	25	748
			Proportional	60	16	8	858
2	80	20	Shared	57	-	-	502
			Fixed	67	25	25	593
			Proportional	67	17	4	608
3	40	30	Shared	65	-	-	733
			Fixed	67	25	25	790
			Proportional	67	21	6	879
4	40	40	Shared	54	-	-	890
			Fixed	65	25	25	1063
			Proportional	65	26	7	1179
5	80	40	Shared	58	-	-	943
			Fixed	65	25	25	970
			Proportional	65	24	6	1102

V. CONCLUSIONS

We have developed a dynamic hybrid spectrum allocation scheme to improve the throughput performance for overlaying LTE macrocell and femtocell networks. The proportions of the spectrum allocated for the dedicated and shared band users are decided centrally by the network. The amount of the dedicated spectrum available in the system is determined based on the number of user in the dedicated band. The femtocell and macrocell users are able to select the preferred spectrum band based on their received signal quality. We have investigated the throughput performance of the proposed scheme through computer simulation for various network scenarios. Our results have demonstrated that the proposed proportional spectrum allocation scheme achieves better throughput performance as opposed to the fixed spectrum allocation and total spectrum sharing schemes. Further research includes the extension of the proposed scheme for a multi-cell system.

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