A New Performance Characterization Framework for Deployment Architectures of Next Generation Distributed Cellular Networks

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Abstract— **Performance of next generation OFDM/OFDMA based Distributed Cellular Network (ODCN) where no cooperation based interference management schemes are used, is dependent on four major factors: 1) spectrum reuse factor, 2) number of sectors per site, 3) number of relay station per site and 4) modulation and coding efficiency achievable through link adaptation. The combined effect of these factors on the overall performance of a Deployment Architecture (DA) has not been studied in a holistic manner. In this paper we provide a framework to characterize the performance of various DA's by deriving two novel performance metrics for 1) spectral efficiency and 2) fairness among users. These metrics are designed to include the effect of all four contributing factors. We evaluate these metrics for a wide set of DA's through extensive system level simulations. The results provide a comparison of various DA's for both cellular and relay enhanced cellular systems in terms of spectral efficiency and fairness they offer and also provide an interesting insight into the tradeoff between the two performance metrics. Numerical results show that, in interference limited regime, DA's with highest spectrum efficiency are not necessarily those that resort to full frequency reuse. In fact, frequency reuse of 3 with 6 sectors per site is spectrally more efficient than that with full frequency reuse and 3 sectors. In case of relay station enhanced ODCN a DA with full frequency reuse, six sectors and 3 relays per site is spectrally more efficient and can yield around 170% higher spectrum efficiency compared to counterpart DA without RS.**

I. INTRODUCTION

Next Generation Cellular Networks differ from the existing cellular networks on two important accounts. Firstly, they are aiming for highly distributed architecture in order to achieve the goals of low signaling overheads, low complexity, higher scalability and better self organization [1-3]. Secondly, they are being built on OFDM/OFDMA based physical and MAC layers. The reason for this is that OFDM based physical layer provides robustness to multipath environment while OFDMA based MAC layer provides higher capacity through interference mitigation in multiple access scenarios. Another very important advantage of OFDM/OFDMA is its granularity in sub-carrier allocation. This feature of OFDM/OFDMA cellular networks not only allows differentiated services to be supported easily but also allows to dynamically adapt individual user links according to time varying channel conditions. This enables the use of modulation and coding schemes with higher Modulation and Coding Efficiency (MCE) for users with better link quality, thus exploiting the multi user diversity to improve the overall Spectrum Efficiency (SE). Higher MCE can also be achieved through other means e.g. by designing a Deployment Architecture (DA) which improves the overall SINR distribution in the whole coverage area of the system. In this paper we provide a framework to investigate the effects and tradeoffs of three factors of such DA. These factors are the Spectrum Reuse Factor (SRF), Number of Sectors per Site (NSPS), and Number of Relays per Site (NRPS).

In fully loaded ODCN that does not resort to any feedback and cooperation based interference mitigation techniques, lower the SRF better will be the average available SINR in the coverage area. In ODCN, this brings in a new tradeoff between increase in SE achievable by increasing SRF and increase in SE by resorting to higher MCE through link adaptation. Another degree of freedom is added to this tradeoff through sectorization since sectorization can potentially improve SINR in the coverage area by reducing the effective number of interfering cells. However, at the same time it incurs loss in terms of spectrum reuse efficiency due to the division of available spectrum among the sectors.

In addition to the improvement in average SE, another very desirable performance goal is fairness among the users, or specifically the improvement of service profile of cell edge users as they are most vulnerable to receive lowest SINR due to their distance from desired cell and their proximity to interfering cells. This goal is one of the top priorities of 3GPP [4]. To achieve this goal, addition of Relay Stations (RS) is being considered in ODCN e.g. LTE-A and 802.16m. RSs have been shown to yield a significant improvement in SINR distribution in the low coverage areas e.g. cell edge or heavily shadowed zones [5]. Although RS also offer potential for reduction in cost but a down side of RSs is that they need extra radio resources to multiplex either in time or frequency with their parent BS in order to avoid mutual interference. This introduces another tradeoff between the SE gain that the RSs can provide by boosting SINR and the SE loss that the RSs cause due to multiplexing with BS.

Most of the studies on RS enhanced ODCN report the advantage of relays assuming centralized resource allocation scenario and the heavy amount of signaling required to implement an interference mitigation technique is neglected in their analysis [6-8]. Therefore, in this paper we consider system without any feedback or cooperation based interference mitigation techniques i.e. a distributed OFDM/OFDMA cellular system where interference is determined mainly by DA i.e. SRF, NSPS and NRPS. We call it ODCN or R-ODCN (RS enhanced ODCN).

The dependence of SE and user-fairness on deployment parameter like SRF, NSPS and NRPS and the tradeoff between the gain due to the improved SINR distribution and loss due to the higher multiplexing and trunking losses has not been studied rigorously, to the best of our knowledge. This investigation is the focus of the paper. To this end, we propose two performance metrics for spectrum efficiency and fairness each. Contrary to conventional measures for these performance indicators, the proposed metrics are designed to explicitly reflect the combined effect of SRF, NSPS, RSP and MCE on overall SE and user-fairness offered by various DAs, enabling the investigation of the aforementioned tradeoffs.

Performance in terms of proposed metrics is evaluated for various DAs for ODCN and R-ODCN through extensive system level simulation for a range of SRF, NSPS and NRPS. Spectral efficiency metric is evaluated using theoretical Shannon bound as well as practical LTE modulation and coding schemes. Results provide a performance comparison of various DAs in terms spectral efficiency and fairness and also provide a novel insight into the underlying tradeoffs.

The rest of the paper is organized as follows. Section II investigates the tradeoff among SRF, NSPS, NRPS and MCE and their effect on overall system throughput and SE. In section III, proposed performance metrics for spectrum efficiency and fairness are derived and explained. IV explains the simulation scenario, Section V discusses the results and finally section VI concludes the study.

II. FACTORS EFFECTING THE PERFORMANCE OF DA’S

We consider downlink scenario of a multi cellular R-ODCN where $\mathcal{N}=\{1,2,3\ldots N\}$ is a set of BSs in the coverage area, $\mathcal{S}=\{1,2,3\ldots.S\}$ is a set of sectors per BS and $\mathcal{R}=\{1,2,3\ldots.R\}$ is a set of RSs per BS. $\mathcal{K}=\{1,2,3\ldots.K\}$ is the set of users in the coverage area of the system, out of which $|\mathcal{K}^b|$ are in the coverage area of the BSs and $|\mathcal{K}^r|$ are in the coverage area of RSs, such that $|\mathcal{K}^r| + |\mathcal{K}^b| = |\mathcal{K}|$. $\mathcal{M}=\{1,2,3\ldots M\}$ is a set of sub carriers allocated to each BS which further shares it with its child RS either in time or frequency with a sharing factor $\rho^b < 1$ such that $\rho^r = 1 - \rho^b$. Since BS and RS multiplex in frequency/time as in IEEE802.16j, hence they do not interfere to each other. Received signal level in dBm from sector s of nth BS on mth subcarrier for kth user at a given location in the coverage area can be given as

$$\mathrm{S}_{s,k,m}^{n} = \mathrm{P}_{m,s}^{n} + \mathrm{G}_{s,k}^{n}\left(\theta_{k,s}^{n}, \varphi_{k,s}^{n}\right) + \mathrm{L}_{k,n}^{n}(\mathrm{D}_{k}^{n}, \mathrm{f}) + \alpha_{k,s}^{n} \qquad (1)$$

$\mathrm{P}_{m,s}^{n}$ is the transmission power on mth sub-carrier from the sector s of nth BS. $\mathrm{G}_{s,k}^{n}$ is the antenna gain of sector s of nth BS towards user k. It is a function of the elevation angle $\theta_{k,s}^{n}$ and azimuth angle $\varphi_{k,s}^{n}$ between location p of kth user and bore site of respective antenna. $\mathrm{L}_{k,n}$ is the pathloss as a function of distance D_{k}^{n} between user k and BS n and the frequency of operation f. $\alpha_{k,s}^{n}$ is the log normal shadowing faced by the ith user, while receiving signal form sth sector of nth BS. Similarly, the received signal level from the rth RS of nth BS for user k on mth carrier can be written as.

$$\mathrm{S}_{k,m}^{r} = \mathrm{P}_{m}^{r} + \mathrm{G}_{k}^{r}\left(\varphi_{k,s}^{r}\right) + \mathrm{L}_{k}^{r}(\mathrm{D}_{k}^{r}, \mathrm{f}) + \alpha_{k}^{r} \qquad (2)$$

SINR for the kth user associated to a BS on mth subcarrier will be

$$\mathrm{SINR}_{k,m}^{n} = \frac{\mathrm{S}_{s,k,m}^{n}}{\sigma_{k,m}^{2} + \mathrm{I}_{k,m}^{n}} \qquad \ldots (3)$$

$$\mathrm{I}_{k,m}^{n} = \sum_{\forall n \in \mathcal{N}} \sum_{\forall s \in \mathfrak{S}} \mathrm{S}_{s,k,m}^{n} \,.\, \mathrm{u}(n, s, m) \qquad \ldots (4)$$

$$\mathrm{u}(n, s) = \begin{cases} 1 & m = m^{k}, n \neq n^{k}, s \neq s^{k} \\ 0 & \text{otherwise} \end{cases} \qquad \ldots (5)$$

$\sigma^2{}_{k,m}$ is thermal noise floor of kth user’s receiver and n^k and s^k, respectively denote that particular BS and the sector to which user k is associated on subcarrier m^k. The MCE achievable on a given link is dependent on the SINR available on that link. Theoretically, the maximum achievable MCE on link can be determined by the Shannon bound i.e.

$$\mathrm{MCE}_{k,m} = \log_2\left(1 + \mathrm{SINR}_{k,m}\right) \qquad (6)$$

However, in practice MCE is a discrete function of SINR at the receiver and depends on the set of modulation and coding schemes being used by the system i.e.

$$\mathrm{MCE}_{k,m} = f\left[\mathrm{SINR}_{k,m}\right] \qquad (7)$$

where [.] represents discrete function and $\mathrm{MCE}_{k,m}$ is modulation and coding efficiency of the link for kth user on mth sub-carrier. Thus the total throughput of users attached to BS can be given by.

$$\mathrm{C}_{achievable}^{b} = \sum_{\forall k \in \mathcal{K}^{b}} \sum_{\forall m \in \mathcal{M}^{k}} \frac{B}{\rho^{b}} \times \mathrm{MCE}_{k,m} \qquad (8)$$

where $\mathcal{M}^k$ is set of sub-carriers allocated to user k, and B is the sub-carrier Bandwidth.

By substituting Eq. (3)-(6) in Eq. (8), the maximum theoretically achievable aggregate throughput of users attached to BS in the R-ODCN can be determined by

$$\mathrm{C}_{th}^{b} = \sum_{\forall k \in \mathcal{K}} \sum_{\forall m \in \mathcal{M}^{k}} \frac{B}{\rho^{b}} \log_2 \left(1 + \frac{\mathrm{S}_{s,k,m}^{n}}{\sigma_{k,m}^{2} + \sum_{\forall n \in \mathcal{N}} \sum_{\forall s \in \mathfrak{S}} \mathrm{S}_{s,k,m}^{n} \,.\, \mathrm{u}(n, s, m)}\right) \qquad (9)$$

However, in ODCN where link adaptation is in operation, the actual achievable aggregate throughput of all users attached to BS can be represented by substituting Eq. (7) in Eq. (8)

$$\mathrm{C}_{achievable}^{b} = \sum_{\forall k \in \mathcal{K}^{b}} \sum_{\forall m \in \mathcal{M}^{k}} \frac{B}{\rho^{b}} \,.\, f\left[\mathrm{SINR}_{k,m}\right] \qquad (10)$$

Similarly if the user k is attached to a RS instead of BS the SINR perceived can be given as

$$\mathrm{SINR}_{k,m}^{r} = \mathrm{S}_{k,m}^{r} \Big/ \left(\sigma_{k,m}^{2} + \sum_{\forall r \in \mathcal{R} \backslash r^{k}} \mathrm{S}_{k,m}^{r} . \mathrm{u}(m)\right) \qquad (11)$$

Then the aggregate theoretical and practical throughputs of all users attached to RS in the coverage can be given as.

$$\mathrm{C}_{th}^{r} = \sum_{\forall k \in \mathcal{K}^{r}} \sum_{\forall m \in \mathcal{M}^{k}} \frac{B}{\rho^{r}} \log_2 \left(1 + \left(\frac{\mathrm{S}_{k,m}^{r}}{\sigma_{k,m}^{2} + \sum_{\forall r \in \mathcal{R} \backslash r^{k}} \mathrm{S}_{k,m}^{r} \,.\, \mathrm{u}(r, m)}\right)\right) \qquad (12)$$

$$\mathrm{C}_{achievable}^{r} = \sum_{\forall k \in \mathcal{K}^{r}} \sum_{\forall m \in \mathcal{M}^{k}} \frac{B}{\rho^{r}} \,.\, f\left[\mathrm{SINR}_{k,m}\right] \qquad (13)$$

The total achievable throughput in the coverage area can be written using Eq. (9) and (12)

$$
\begin{aligned}
&\mathrm{C}_{\mathrm{achievable}}^{\mathrm{total}} \\
&= \sum_{\forall \mathrm{k}\in\mathcal{K}} \sum_{\forall \mathrm{m}\in\mathcal{M}^{\mathrm{k}}} \frac{\mathrm{B}}{\rho^{\mathrm{b}}} \log_2 \Bigg(1 \\
&+ \frac{\mathrm{S}_{\mathrm{s,k,m}}^{n}}{\sigma_{\mathrm{k,m}}^2 + \sum_{\forall \mathrm{n}\in\mathcal{N}} \sum_{\forall \mathrm{s}\in\mathfrak{H}} \mathrm{S}_{\mathrm{s,k,m}}^{n} \,.\, \mathrm{u(n,s,m)}}\Bigg) \\
&+ \sum_{\forall \mathrm{k}\in\mathcal{K}^{\mathrm{r}}} \sum_{\forall \mathrm{m}\in\mathcal{M}^{\mathrm{k}}} \frac{\mathrm{B}}{\rho^{\mathrm{r}}} \log_2 \Bigg(1 \\
&+ \left(\frac{\mathrm{S}_{\mathrm{k,m}}^{r}}{\sigma_{\mathrm{k,m}}^2 + \sum_{\forall \mathrm{r}\in\mathcal{R}\backslash \mathrm{r}^{\mathrm{k}}} \mathrm{S}_{\mathrm{k,m}}^{r} \,.\, \mathrm{u(r,m)}}\right)\Bigg) \qquad (14)
\end{aligned}
$$

It is to be noted, from Eq. (3) and (6), that on downlink SINR perceived by user in a fully loaded ODCN or R-ODCN i.e. when $\mathrm{u(.)} = 1$, is mainly dependent on the SRF, NSPS and NRPS. Furthermore, Eq. (14) shows that the system throughput and hence the spectral efficiency is also dependent on resource sharing factor between BS and RS as well as actual mapping of SINR to MCE i.e. *f*[.]. This mapping is determined by the set of modulation and coding schemes used in the system. We will build on these dependencies when designing the performance metrics in section III.

III. PROPOSED PERFORMANCE METRICS

A. *Effective spectrum efficiency*

The conventional definition of SE is

$$\eta = \frac{\mathrm{trhoughput}}{\mathrm{BW}} \ \text{(bps/Hz)} \qquad (15)$$

where BW=B× M. Now we present and alternative way to define SE which can be used more directly to characterize the SE of various DA's while explicitly accounting for SRF, NSPS,NRPS and MCE.

Since the sub carrier bandwidth in the ODCN system is fixed so the throughput on single sub-carrier in a given link and hence the total throughput of the system depends on MCE (in bps/Hz) on each link. The MCE in turn depends on SINR available on that link. Thus, from Eq. (10), (13) and Eq. (14) it can be seen that in ODCN or R-ODCN, with total bandwidth fixed, the theoretical and actual throughput hence the SE of system depends on the SINR distribution in the coverage area and SRF, NSPS and NRPS. In interference limited scenario, $\sigma_{\mathrm{k,m}}^2 << \mathrm{I}_{\mathrm{k,m}}$, hence the SINR available on sub-carrier m to user k is mainly dependent on the location *p* of the user within cell and can be written as.

$$\mathrm{SINR}_p = \frac{\mathrm{S}_p}{\sum_{\forall \mathrm{n}\in\mathcal{N}\backslash \mathrm{n}^p} \sum_{\forall \mathrm{s}\in\mathfrak{H}\backslash \mathrm{s}^p} \mathrm{S}_p} \qquad (16)$$

Where n^p and j^p denote the respective sector and BS in which location p lies. Where $\mathcal{P} = \{1,2,3 \dots\dots P\}$ is set of all points in the coverage area.

Now let $\mathcal{L}$ ={0,1,2,3….L } is set of modulation and coding schemes available to be used in ODCN or R-ODCN and MCE_l denotes the respective modulation and efficiency of l^{th} scheme. Where *l*=0 means modulation and coding scheme with zero spectral efficiency i.e. no link and L is modulation and coding scheme with highest spectral efficiency. Now we can define a metric ζ as follows.

$$\zeta = \sum_{L=0}^{L} \left(\mathrm{MCE}_l \times \frac{|\mathcal{P}_l|}{|\mathcal{P}|}\right) \qquad (17)$$

where $|\mathcal{P}_l|$ is the cardinality of set of all points where available SINR is such that l^{th} modulation and coding scheme can be used. In order to have an actual area measure $|\mathcal{P}| \rightarrow \infty$, but for sake of practicality and implementation in the simulations we assume point p to be a bin of such finite area within which SINR remains constant (square bins of 10m^2 are considered in simulations). In this case Eq. (17) can be written in terms of area A as follows

$$\zeta = \sum_{\mathrm{L}=0}^{\mathrm{L}} \left(\mathrm{MCE}_l \times \frac{\mathrm{A}_l}{\mathrm{A}_t}\right) \qquad (18)$$

where A_t is total coverage area of the system

$$\mathrm{A}_l = \sum_{\forall \mathrm{p}\in\mathcal{P}} \mathrm{U}_l(\mathrm{p}) \ , \quad \forall \mathrm{l} \in \{0,1,2,3..\mathrm{L}\} \qquad (19)$$

and $U_l(p)$ is defined as follows.

$$\text{For } l \in \mathcal{L}\backslash\{0,\mathrm{L}\} : \quad \mathrm{U}_l(p) = \begin{cases} 1, & \mathrm{T}_{l-1} < \mathrm{SINR}_p < \mathrm{T}_{l+1} \\ 0, & \text{Otherwise} \end{cases}$$

$$\text{For } l = \mathrm{L} : \quad \mathrm{U}_l(p) = \begin{cases} 1, & \mathrm{T}_{L-1} < \mathrm{SINR}_p \\ 0, & \text{Otherwise} \end{cases}$$

$$\text{And for } l = 0: \quad \mathrm{U}_l(p) = \begin{cases} 1, & \mathrm{SINR}_p < \mathrm{T}_0 \\ 0, & \text{Otherwise} \end{cases}$$

T_l=is the threshold SINR required to use l^{th} modulation and coding scheme form set $\mathcal{L}$. T_0 is the threshold of minimum SINR below which link cannot be maintained with pre-decided performance criterion and all such points in coverage area constitute the outage area A_0. Note that

$$\sum_{l=0}^{\mathrm{L}} \mathrm{A}_l = \mathrm{A}_{\mathrm{t}} \qquad (20)$$

Hence the metric ζ in equation (19) is actually *expected* value of MCE i.e.

$$\zeta = E(\mathrm{MCE}) = \sum_{\forall\, l\in\mathcal{L}} \mathrm{MCE}_l \times \gamma_l \qquad (21)$$

where $\gamma_l = \frac{A_l}{A_t}$ is probability of user being at point in coverage area where *l*th modulation and coding scheme can be supported. So ζ is the average MCE in the whole system, Eq.(15) and Eq. (21) imply that ζ = η. Now we can define the new metric for spectrum efficiency of ODCN which takes into account the effect of MCE, SRF, NSPS and NRPS and call it Effective SE (ESE). It can be written as

$$ESE = \frac{\zeta\times\mathrm{SRF}}{\mathrm{MF}} \qquad (22)$$

where SFR is spectrum reuse factor and represents number of times spectrum is reused within a cell. It depends on the number of sectors per cell and frequency reuse. For example, if in system with 6 sector per cell, if total spectrum is divided in two parts (i.e. FR=2) and is used in each alternative sectors of the same site then SRF $= \frac{6}{2} = 3$ and MF=2. If DA has RS as well and ρ^{r} is the factor with which spectrum is shared between BS and RS associated to it then MF=2× 1/ ρ^{r}. In this study we assume that spectrum is equally shared among BS and RS either in time or frequency so $\rho^{\mathrm{r}} = \rho^{\mathrm{b}}$=0.5. Thus, MF is actually the number of parts total spectrum is divided into.

Since in Eq. (21) ζ reflects the *expected* MCE and thus reflects SE achieved through the use of higher order modulation and coding schemes, MF denotes the multiplexing loss due to the use of sectors/RS and SRF denotes the SE achieved through spectrum reuse. Hence the above metric represents SE while directly reflecting the effect of key factors and respective tradeoffs highlighted in section II.

B. FAIRNESS

To define a suitable metric for fairness which reflects the effect of MCE, SRF, NSPS and NRPS we build on above derivations and define the metric for fairness and name it *Service Profile Fairness* (SPF) as follows

$$SPF = 1\Bigg/\sqrt{\frac{1}{L}\sum_{l=0}^{L}\left(\left(\mathrm{MCE}_l \times \frac{\mathrm{A}_l}{\mathrm{A}_t}\right)-\sum_{\mathrm{l}=0}^{\mathrm{L}}\left(\mathrm{MCE}_l \times \frac{\mathrm{A}_l}{\mathrm{A}_t}\right)\right)^2} \quad (23)$$

SPF characterizes fairness among the users in the coverage area of a system by measuring *how much the data rates within the coverage area deviates from the average data rate in the coverage area.* This deviation depends on the SINR geographical distribution as well as mapping of that SINR to actual data rate achievable by a user. Advantage of this metric of fairness is that it exclusively captures the actual effect of link adaptation which is key factor in determining fairness in future OBCN. Furthermore, this fairness metric treats justly all the users in the coverage area. This is because it gives the cell edge users judiciously higher importance because as area is square function of radius so more area lies farther from the cell center. In case of uniform user distribution this means more users will lie farther from the cell center and thus should have naturally larger influence in determining fairness. SPF is maximum i.e.∞ when all users can receive at same data rate.

IV. SIMULATION SCENARIO

Since, there are many potential candidate DA's for next generation ODCN or R-ODCN with different SRF, NSPS and NRPS, So in order to evaluate and compare ESE and SPF and the tradeoff between the them in various DA, total of 26 DA's with a wide range of SRF, NSPS and NRPS as listed in Table 1 are modeled in system level simulations. For all these possible DA's ζ in Eq. (18) and thus ESE and SPF is evaluated through extensive simulations. ζ is evaluated through two different methods. 1)Pragmatic: Based on the SINR thresholds for set of modulation and coding schemes described in LTE standard used in [9], 2)Theoretic: i.e. based on Eq.(6). The major system design parameters used in simulations of various DA's are given in Table 2. Two tiers of cells are modeled in each DA to consider realistic amount of interference in multi cellular scenario. Other real features like, shadowing, and antenna tilting and appropriate Pathloss models for BS and RS considering both LOS and NLOS conditions similar to [10] are used in order to model a realistic ODCN and R-ODCN propagation environment. In R-ODCN, RS are optimally located at half of inter site distance where the SINR is minimum i.e. where the far end corners of adjacent sectors join.

Table 1: Simulation Parameters

Frequency	2Ghz
Site to Site Distance	1200m
Number of BS	19
RS height	10m
RS Antenna	Omni direction, Gain= 10 dB
BS Antenna	3GPP model, Gain= dependent on no. sectors
BS Tx Power	39dBm
RS Tx Power	24dBm
Cell Antenna Height	32m
Shadowing Mean	0dB
Shadowing Std for BS	LOS =4dB, NLOS=8dB
Shadowing Std for RS	LOS=6dB, NLOS=10dB
Fast Fading	3GPP SCM, URBAN_MACRO
Path loss	As in [10] for micro, macro and LOS and NLOS
LOS to NLOS breakpoint	300m

Table 2: Various DA's Architectures Investigated

NSPS	1	2	3	4	6
FR	1	1, 2	1, 3	1, 2, 4	1, 2, 3, 6
NRPS	0, 1	0, 1	1, 3	0, 1, 4	0, 3

V. RESULTS & DISCUSSION

In this section, first we will discuss the results of ESE & fairness separately to highlight the gains and respective tradeoffs in performances of different DA's (both OBCN and R-OBCN) offer. Following this, we will compare the performance of OBCN and R-OBCN in general.

A. ESE of Various DA's for ODCN

Fig. 1 shows the ESE evaluated through extensive simulations of multi cellular scenarios for 12 different DA's of ODCN. The tradeoff among NSPS, SRF and MCE can be seen playing its role in the overall ESE of different DA. For ease of discussion while probing into the underlying trends and tradeoffs we focus on DA's 9-12, all with NSPS=6. It can be seen that for DA=9 where full frequency reuse (FR=1) is used, ESE is lowest and gap from single link Shannon bound is largest. This is due to high inter-sector interference which results in very low ζ and hence low ESE. In DA=10, 11 when FR increases to 2 and 3, although SRF decreases from 6 to 6/2 and 6/3 respectively, still the ESE increases. This is because the increase in ζ due to decreased interference is more than the loss in SRF. Hence as a net result ESE is larger in DA=10, 11 compared to DA=9. But in DA=12, where FR further rises to 6, the loss in ESE due to low SRF (6/6) is much larger than the gain in ζ through lower interference. This results in a lower ESE in DA=12 as a net result. On the other hand, the gap between practically achieved and theoretical bound on ESE, monotonically decreases as FR increases in DAs 9-12 mainly because higher ζ is yielded with larger FR due to the decreased interference. Furthermore, results clearly show that, for ODCN, the DA that has potential to yield practically highest ESE is DA=11. Although DA=11 is not among those DAs that resort to full frequency reuse, but it still provides highest ESE by optimally trading off the SE achievable through MCE and through SRF and NSPS. It can be further seen in Fig.1 that the gap between the theoretical and practical ESE is minimum for DA=8. This is because the average interference is minimum in this DA due to low FR and the sector design. This results in to high ζ in coverage area and hence the practical ESE reaches closer to theoretical one for this DA. But overall ESE for this DA is low because MF is high due to low spectrum reuse efficiency.

Further comparisons of ESEs in Fig.1 for DA's with different NSPS show that by deploying higher number of sectors per site while keeping FR=1, slightly better ESE can be achieved (Compare DA=4 with DA=9 in Fig 1). Although this increases the interference slightly due to increased interference among sectors (compare CDF of SINR for the two DA's in Fig. 5), but the increase in SRF factor outweighs the decrease in ζ in this case. (See Eq. 22)

B. SPF of Various DA's for ODCN

Fig. 3 shows the values of fairness indicator SPF evaluated for all the 12 DAs of ODCN using Eq. (23). In general it can be noted that in ODCN, SPF increases with increase in number of sectors but it decreases with increase in FR (or in other words decrease in SRF). This is because increasing the number of sectors in general decrease the cell edge interference thus makes SINR's geographical distribution more uniform in a cell. On the other hand a low SRF has same effect but in different way. A low SRF makes the interfering cells farther, thus making SINR distribution less dependent on distance from the cell center hence more uniform geographically.

C. ESE of R-OBCN

Fig. 3 shows theoretical and practical ESE evaluated for various DA's for R-ODCN. By comparing the ESE's of R-ODCN with those for ODCN it can be easily seen that RS's bring huge improvement in ESE. This improvement is due to two reasons. First the gap between the practically achievable and theoretical ESE is reduced significantly in R-ODCN compared to ODCN. This is because of the fact that RS boost SINR distribution more effectively than higher frequency reuse can. This argument can be justified by comparing the SINR distribution of ODCN and R-R-ODCN in Fig. 5. The relatively much better SINR distribution in R-ODCN is mainly because of much smaller height and lower transmission power of RS. This makes the interference caused by RS much lesser than caused by the sectors of BS. Secondly, in addition to better SINR distribution and hence higher ζ, there is a another positive contribution of RS towards higher ESE that explained as follows: Let's assume 3 RS are working in a cell, the spectrum is divided into two parts for sharing between BS and RS thus reducing the SRF by half only compared to scenario with three sectors as SRF will reduce by factor of 3 in this case. These two reasons make RS more advantageous method to boost ESE because they can boost SINR and thus ζ more effectively while causing relatively lesser decrease in SRF compared to FR or NSPS based method of improving SINR. This fact can be further confirmed by comparing the ESE for DA=23 to 26 in Fig 3. As the FR increases, Fig. 3 shows that SINR improves and thus the ζ improves boosting the ESE. But the net ESE decreases because the SRF decreases more rapidly than ζ can improve through increase in FR. Finally, it can be seen highest ESE is yielded by DA=23. This is so because it not only resorts to FR=1 to achieve high SRF but also avails better SINR distribution (see Fig=5) than counterpart DA=9 due to the advantages of RS explained above

D. FAIRNESS $\mathcal{F}$in DA's for R-ODCN

Fig. 4 shows the SPF for the all 14 DA's of R-ODCN. It can be seen that although the trends with respect to NSPS and SRF are same as for ODCN but in general SPF in R-ODCN is significantly lower than that in ODCN. The reason behind this is the drastic change in distribution of SINR brought by RS as can be seen in Fig. 5 the span of cdf of SINR in the R-ODCN is much larger than that of ODCN's. This is because, although RS's improve the SINR but not in the whole coverage area. Rather they provide an up shift in SINR in their own small coverage area only, leaving the rest of the coverage area served by sectors of BS unaffected. This increases the standard deviation of SINR distribution and hence the SPF decreases.

E. Comparison of performance of ODCN and R-ODCN

Results in Fig (1)-(4) show that R-OBCN has potential for higher ESE but they have naturally low SPF. Whereas ODCN DA although offer lesser ESE but have much higher SPF. So there is tradeoff between the ESE and SPF which can be exploited by adding RS. Furthermore, higher ESE of R-ODCN in general shows that with RS in place at the cell edges larger SRF without significant decrease in ζ.

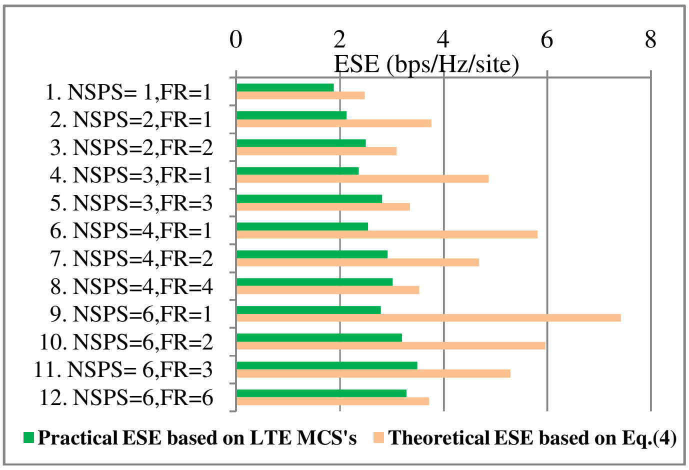

Figure 1: Effective Spectral Efficiency (ESE) for DA's for ODCN. FR stands Frequency reuse among sectors of same cell. e.g FR=6 means total spectrum is divided in 6 parts and each part is allocated to one sector of same site.

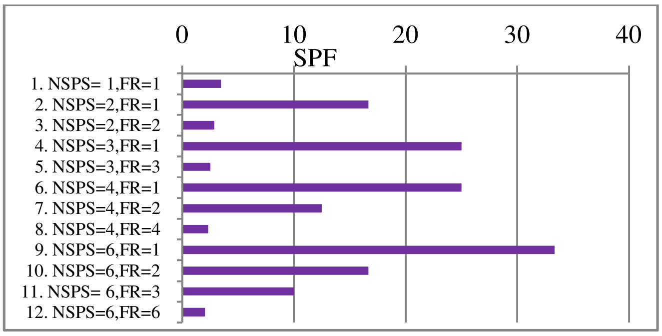

Figure 2 Service Profile Fairness (SPF) for DA's for ODCN

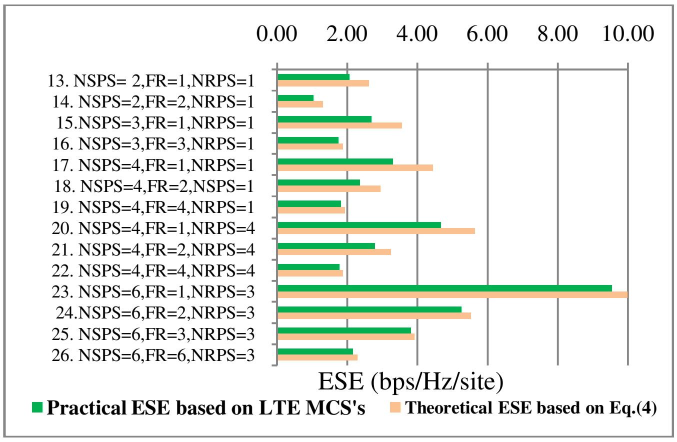

Figure 3: Effective Spectral Efficiency (ESE) for DA's for R- ODCN. =0.5 i.e. Total spectrum is equally divided among BS and set RS attached to that BS.

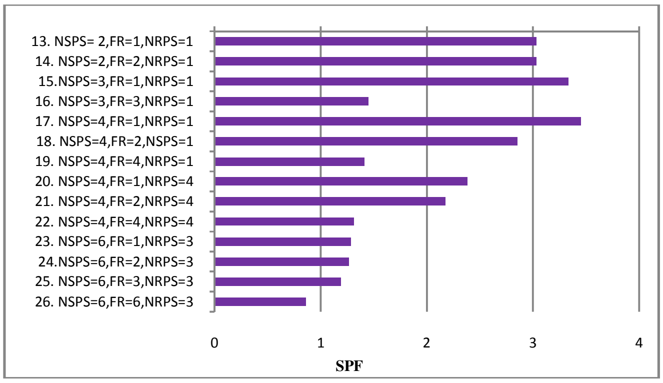

Figure 4: Service Profile Fairness (SPF) of DA's for R-ODCN

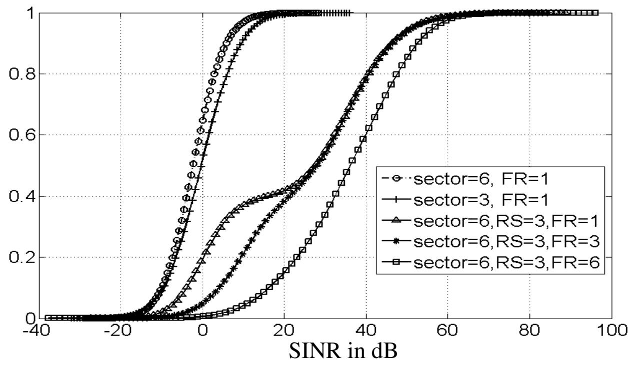

Figure 4: Comparison of CDF of SINR in selected DA's for ODNC and R-RODCN

VI. CONCLUSIONS

This paper provides a framework to compare the performance of various Deployment Architecture (DA) options for next generation of distributed OFDM/OFDMA based cellular network. Gains and respective tradeoffs offered by four major factors of DA i.e. 1) spectrum reuse factors, 2) No. of sectors per site, 3) Number of RS per Site and 4) link adaptation, are investigated in detail. In order to quantify the performance of resulting DAs including the effect of these factors, we propose two new performance metrics namely ESE (Effective Spectrum Efficiency) and SPF (Service Profile fairness). Both ESE and SPF are evaluated for wide set of possible DAs by modeling and simulating them in full scale system level simulations. ESE was evaluated using practical LTE modulation and coding schemes and comparing the performance with theoretical bounds. Numerical results showed that an intelligent design of DA for next generation OFDM/OFDMA based cellular networks can yield significant improvement in spectrum efficiency of overall system even for full load conditions without relying on feedback based or cooperation based interference management schemes. Further, contrary to common notion in ODCN, DA's with highest spectrum efficiency are not necessarily those that resort on full frequency reuse. In fact, for ODCN a DA with SRF=3, NSPS=6 yield highest ESE of 3.5 bps/Hz/site. And for R-ODCN e.g. LTE advance DA with SRF=1, NSPS=6 and NRPS=3 has potential to yield around 9.5 (bps/Hz/site) which is 170% higher compared to equivalent DA for ODCN.

In future, it will be interesting to investigate the further improvement in performance of R-ODCN through efficient scheduling of radio resources with minimal signaling requirements by using a self organizing framework.

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