A Novel Self Organizing Framework for Adaptive Frequency Reuse & Deployment in Future Cellular Networks

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Abstract: **Recent research on Frequency Reuse (FR) schemes for OFDM/OFDMA based cellular networks (OCN) suggest that a single fixed FR cannot be optimal to cope with spatiotemporal dynamics of traffic and cellular environments in a spectral and energy efficient way. To address this issue this paper introduces a novel Self Organizing framework for adaptive Frequency Reuse and Deployment (SO-FRD) for future OCN including both cellular (e.g. LTE) and relay enhanced cellular networks (e.g. LTE Advance). In this paper, an optimization problem is first formulated to find optimal frequency reuse factor, no of sectors per site and number of relays per site. The objective is designed as an adaptive utility function which incorporates three major system objectives 1) spectral efficiency 2) fairness, and 3) energy efficiency. An appropriate metric for each of the three constituent objectives of utility function is then derived. Solution is provided by evaluating these metrics through a combination of analysis and extensive system level simulations for all feasible FRD's. Proposed SO-FRD framework uses this flexible utility function to switch to particular FRD strategy, which is suitable for system's currant state according to predefined or self learned performance criterion. The proposed metrics capture the effect of all major optimization parameters like frequency reuse factor, number of sectors and relay per site, and adaptive coding and modulation. Based on the results obtained, interesting insights into the tradeoff among these factors is also provided.**

I. Introduction

Future generations of wireless networks (e.g. LTE and LTE advance) have unprecedented high targets in terms of capacity, reliable QoS, low complexity and low operational and maintenance cost [1]. Most of these objectives are mutually contradictive and call for unconventional ways to improve the cellular system performance. Extensive ongoing research on physical layer (OFDM, MIMO, Smart antennas) and MAC layers (scheduling and RRM in general) of OCN, is already pushing the boundaries of capacity and QoS mainly at expense of higher complexity and cost [2]. Furthermore, the solutions yielded by these two mature research regimes, address the scheduling and power allocation problems at shorter time-scales but lack the ability to cope with long term spatiotemporal dynamics of traffic and cellular environment. These long term dynamics include, change of traffic patterns over day and night, gradual relocation of hot spots, popping up hot spots due to events e.g. games etc, or even site failures. Just recently Self Organization (SO) has emerged as promising research area to deal with these time persistent problems [3]-[5] in an efficient and cost effective manner. Ideally a SO system shall adapt itself to all changes it faces in its operational environment, without requiring an external or internal central control or extensive cooperation among its entities [3]. Furthermore, a SO system will achieve and adhere to a predefined objective or group of objectives by non-complex but well defined actions taken by its entities independently or semi independently [3,5]. In context of cellular system, this translates into a cellular network which can adapt itself to short, as well as, long term spatiotemporal dynamics to achieve specific objectives e.g. spectral efficiency, energy efficiency, QoS or a combination of these, while having very low complexity and signaling overheads. Low complexity is important to ensure scalability which is very desirable feature in future cellular networks which aim to provide ubiquitous coverage and homogeneous service profiles. Another great advantage of SO in cellular networks is that it can significantly save cost paid for expensive well trained human resources required to continually adapt and maintain cellular networks manually to accommodate traffic patterns which keep changing over span of months, weeks and even days.

While most of initial research in SO is focusing on extension of the already available solutions in MAC and physical layer to bring in large time scale adaptability, relatively less attention is being given to potential improvement possible through the way we will deploy future cellular network in general and OCN in particular . One particular aspect of deployment which is studied substantially in context of OCN is Frequency Reuse (FR) [6]-[8]. In addition to conventional FR e.g. FR=1, FR=3, many advanced FR schemes are proposed specially for OCN to achieve a tradeoff between the spectrum efficiency achievable by spectrum reuse factor and spectral efficiency achievable by using higher coding and modulation schemes, adaptively. These advanced FR schemes can be classified in three main categories 1) fully isolated fractional FR [6], 2) partially isolated fractional FR [7], 3) dynamic fractional FR [8]. In fully isolated fractional FR, cell is divided into two geographical parts. Central part uses FR=1 and edge part uses higher FR e.g. 3 for three sector case. This schemes improves the cell edge performance but sacrifices significant throughput at the same time due to FR=3[6]. In partially isolated FR schemes, all cells use all subcarriers but outer parts of the cells use a group of carriers with low power. This same carrier then can be used in adjacent cell with high power. This scheme yields better throughput than fully isolated fractional reuse because of resorting to FR=1 but its performance degrades rapidly as the system load increases [7]. Dynamic fractional FR does not divide cell area on geographical basis into cell edge or cell center, neither does it split subcarriers. Rather it establishes virtual groups of carriers to be used by virtual groups of users. These virtual groups of subcarriers and corresponding users are determined dynamically for each frame by estimating the channel condition for each user on each subcarrier in each BS. Although this scheme has been shown to have relatively better average throughput compared to other two schemes but throughput at cell edge is worst in this case [8]. Furthermore, the need for global cooperation based on heavy signaling and huge computational power required to implement this scheme renders it effectively impractical.

In summary, each of these FR scheme proposed so far is optimal for a specific scenario and meets high performance criterion for some metrics while sacrificing performance in other metrics.

In order to address these issues of complexity and signaling overhead in RRM for next generation networks, this paper introduces a SO framework which combines the simplicity of conventional FR with the adaptive deployment potential of future wireless networks and we call it SO-FRD. By FRD we mean a cellular system deployment configuration characterized by the frequency reuse factor F, number of sectors S and relays per site R. The main idea of proposed SO-FRD framework is that, in order to cope with spatiotemporal changes in traffic or cellular environment, cellular network will dynamically switch to a suitable FRD scheme, based on an adaptive utility function proposed in this paper. This utility function incorporates major system objectives e.g. spectral efficiency, power consumption, and fairness among users and can prioritize among these objectives. The performance metrics used to manifest these objectives are designed to include the effect of F, S, R, and modulation and coding efficiency achievable through link adaptation as well. Since pure analytical solution is too complex if not impossible, we use a hybrid approach i.e. analysis and extensive system level simulations to generate the whole solution space for all feasible FRD's. The SO-FRD framework then adapts the utility to set an optimization target according to predefined or self learned criterion in response to varying system dynamics and switches to most suitable FRD mode.

The contributions of this paper can be summarized as follows: First we propose a self organizing framework SO-FRD for future wireless networks which enables an optimum FRD without requiring system wide cooperation and heavy computations. Then we propose adaptive utility function which can simultaneously characterize the spectral efficiency, fairness & energy efficiency of a FRD. We also workout appropriate metrics for each of these three objectives and evaluate them for all FRDs feasible for LTE and LTE Advance through analysis and extensive system level simulations. Finally we demonstrate how our proposed SO-FRD framework uses the worked out solution space to switch to an optimal FRD in a self organizing manner.

The rest of the paper is organized as follows. Section II describes system model briefly. Section III highlights basic principles and mechanisms of self organization and explains the proposed frame work. Section IV presents metrics designed to represent optimization objectives. Section V presents results and discusses some interesting tradeoffs involved. It also explains the operation of SO-FRD framework. Section VI concludes the study with final comments and directions for future work.

II. System Model

We consider downlink scenario of a multi cellular OCN system where $\mathcal{N}$={1,2,3…N} is set of BS's in the coverage area, $\mathfrak{H}$={1,2,3….S} is set of sectors per BS and $\mathcal{R}$={1,2,3….R} set of RS per BS. $\mathcal{K}$={1,2,3….K} is the set of users in the coverage area of the system, and $\mathcal{M}$={1,2,3…M} is set of sub carriers allocated to each BS. BS and RS multiplex on frequency or time as in IEEE802,16s and hence do not interfere to each other. Received signal level from sector s of n^{th} BS in dBm on m^{th} subcarrier for k^{th} user at a given location in the coverage area can be given as

$$S_{k,m}^{b} = P_{m,s,n}^{b} + G_{k,s,n}^{b}\left(\theta_{k,s,n}^{b}, \varphi_{k,s,n}^{b}\right) + L_{k,n}^{b}\left(D_{k,n}^{b}, f\right) + \alpha_{k,s,n}^{b} \quad \ldots(1)$$

where post script *b* indicates association with BS. $P_{m,s,n}$ is the transmission power on m^{th} sub-carrier from the sector s of n^{th} BS. $G_{k,s,n}$ is the antenna gain of sector s of n^{th} 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 k^{th} user and bore site of respective antenna. $PL_{k,n}$ is the pathloss as 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 s^{th} sector of n^{th} BS. Similarly, the received signal level from the rth RS of nth BS for user k on mth carrier can be written as.

$$S_{k,m}^{r} = P_{m,r}^{r} + G_{k,r}^{r}\left(\varphi_{k,s,n}^{r}\right) + L_{k,r}^{r}\left(D_{k,r}^{r}, f\right) + \alpha_{k,r}^{r} \quad \ldots(2)$$

where post script r indicates association with a RS.

In case of full FR, i.e. F=1, when the system is fully loaded i.e. each subcarrier is being used in each sector, signal to interference and noise ratio i.e. SINR for the k^{th} user on m^{th} subcarrier will be

$$SINR_{k,m}^{b} = \frac{S_{k,m}^{b}}{\sigma_{k,m}^{2} + I_{k,m}^{b}} \quad \ldots(3)$$

$$I_{k,m}^{b} = \sum_{\forall n \in \mathcal{N} \setminus n^{k}} \sum_{\forall s \in \mathcal{J} \setminus s^{k}} S_{k,m}^{b} \,.\, u(m) \quad \ldots(4)$$

$$u(m) = \begin{cases} 1 & m = m^{k} \\ 0 & \text{otherwise} \end{cases} \quad \ldots(5)$$

Where $\sigma^2{}_{k,m}$ is thermal noise floor of k^{th} user's receiver and n^{k} and s^{k}, respectively denote that particular BS and the sector to which user k is associated. m^{k} denotes the carrier being used by the use k.If the user k is attached to a RS the instead of BS the SINR can be given as

$$SINR_{k,m}^{r} = S_{k,m}^{r} \Big/ \left(\sigma_{k,m}^{2} + \sum_{\forall r \in \mathcal{R} \setminus r^{k}} S_{k,m}^{r} . u(m)\right) \quad \ldots(6)$$

It is to be noted, from Eq. (1)-(6), on downlink SINR perceived by user in a fully loaded OCN i.e. when $u(m) = 1$, is mainly dependent on the, the frequency reuse i.e. F , number of sectors, S, and number of relay stations R. We will exploit this fact in the rest of this paper.

III. SELF ORGANISATION

A. Self organization: definition and main concepts

Self organization is a behavior in which a system can organize itself *without any external or central control entity* to achieve a single or multiple system objectives [3,4]. The self organization framework proposed in this paper is built on same principles as highlighted in [3,4 & 5]. The main idea can be explained as following three steps: 1) *Identify the objective* or group of objectives to be achieved and maintained by the system. 2) *Map the complex objective to a simple goal*. 3) The simple *goal is then achieved by the local actions of entities* of large systems such that only local observations are required for execution of these actions.

B. Problem description: Objective of SO-FRD

Future wireless networks have multiple target objectives like, spectral efficiency, energy efficiency, cost minimization, QoS and fairness. For the purpose of illustration, and without loss generality, we choose spectrum efficiency, fairness and energy efficiency as target objectives for our SO-FRD framework. It should be noted that these three are most important objectives as they reflect other two implicitly. A possible approach to map these complex objectives into a single simple goal is through multi objective optimization [9]. If ε, ζ, and η represent performance metrics manifesting spectrum efficiency ,fairness and power consumption respectively, then the problem can be written conventionally as

$$\min_{F,S,R}\{-\varepsilon(F,S,R), -\zeta(F,S,R), \eta(F,S,R)\} \quad \text{... (7)}$$

It should be noted that these objectives are mutually contradicting due to inter dependence of their controlling parameters. For example, from the previous studies discussed above, we know that no single fixed frequency reuse is optimal simultaneously for, power, fairness and spectral efficiency. This makes such problem non convex hence difficult if not impossible to solve with purely analytical approaches. In next section we present our SO framework for a pragmatic solution of this problem.

C. Proposed SO framework: SO-FRD

The basic idea of proposed SO-FRD framework is that, in order to achieve desired objective each site in the cellular network can adapt its projected number of sectors i.e. S, frequency reuse among its sectors i.e. F and No. of active RS under that site i.e. R. In future OCN which feature highly intelligent BS's, and each site has smart antenna and RS, changing the radiation pattern of particular antenna or switching on or off a whole sector or RS should not be an issue. Rather it will be much simpler task compared to complexity and signaling overhead costs of dynamic frequency reuse schemes which need to be executed on per frame basis. The advantages of this approach is its low complexity of operation, effectively zero inter site signaling and potential to meet designated objectives in short and large time scales efficiently as would be shown later.

Next step in SO-FRD framework is mapping of problem in Eq. (7) into a simpler goal. As explained in last subsection a pure analytical solution is not feasible, we propose a very simple method as follows. Since, the number of possible F, S, and R in a practical cellular system is not very large. In fact only configuration listed in Table 1 are technically most feasible ones. So we can effectively search over this confined solution space easily and can tabulate our possible solutions. We will develop this solution space through analysis and extensive simulations in next sections. Here it is important to highlight that since the target objectives are mutually contradicting, there is large possibility that no single solution is optimal over all three performance metrics. Rather, each solution will be optimal in particular sense which is very much dependent on how we define these metrics ε, ζ, and η and

Table 1: Configurations of FRD's Architectures Investigated

S	1	2	3	4	6
F	1	1, 2	1, 3	1, 2, 4	1, 2, 3, 6
R	0, 1	0, 1	1, 3	0, 1, 4	0, 3

their resultant objective function. Below we propose a simple way around this problem by providing a general objective function which is a utility of all three objectives. Our SO-FRD framework then includes following simple set of rules to adapt this utility to achieve desired objectives to cope with changing spatiotemporal dynamics.

RULES FOR UTLITY ADAPTATION IN SO-FRD

1) ***If System does not have any specific Target Values for the performance metrics:***

In this case the optimization problem will be

$$\max_{F,S,R} \upsilon(\varepsilon,\zeta,\eta) = \lambda_1\varepsilon + \lambda_2\zeta - \lambda_3\eta \quad \text{... (8)}$$

a) *If the system does not have any priority among objectives in Eq. (8) set*

$$\lambda_1 = \lambda_2 = \lambda_3 = \tfrac{1}{3} \quad \text{... (9)}$$

b) *If system wants to maximize some objective, while neglecting others, In Eq. (8) set*

$$\lambda_n = \begin{cases} 1 & if\ n = d \\ 0 & otherwise \end{cases} \quad n=1,2,3 \quad \text{...(10)}$$

where d is index of desired objective

c) *If system has specific priority of each objective it represents it by weights such that*

$$\lambda_1 + \lambda_2 + \lambda_3 = 1 \quad \text{...(11)}$$

2) ***If System has Specific Target values for each performance metric:***

In this case the optimization problem can be written as

$$\min_{F,S,R} \tau(\varepsilon,\zeta,\eta) = \sqrt{\lambda_1(\varepsilon-\varepsilon_d)^2 + \lambda_2(\zeta-\zeta_d)^2 + \lambda_3(\eta-\eta_d)^2} \quad \text{..(12)}$$

a) *If system wants to achieve desired targets in each metric with same priority, substitute Eq. (9) in (12)*

b) *If system has desired target value in one objective, but has no priority in others set Eq.10 in (12)*

c) *If system has specific values of each metric as target but has different priority of each target to be met, set in Eq.(11) in (12)*

Having characterized our utility function, the fact that a given solution is truly optimal in its desired sense is very much dependent on how we define metrics ε, ζ, η. In next section we present these three metrics to be used to yield the required solution space to be searched over by our SO-FRD framework through Eq. (8)-(12).

IV. PERFORMANCE METRICS FOR UTILITY FUNCTION

A. Spectrum efficiency ε

We will use the metric for spectrum efficiency given as follows:

$$\varepsilon = \frac{\rho_{MCE}}{\rho_{MF}} \times \rho_{FR} \quad \text{... (13)}$$

where ρ_{MCE} spectrum efficiency achieved by use of higher order and modulation and coding schemes in OCN and is defined as

$$\rho_{MCE} = \sum_{L=0}^{L}\left(MCE_l \times \frac{A_l}{A_t}\right) \quad \text{... (14)}$$

$$\text{where,} \quad A_l = \sum_{\forall p \in \mathcal{P}} U_l(p), \quad \forall l \in \{0,1,2,3..L\} \quad \text{... (15)}$$

Where as $U_l(p)$ is defined as follows:

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

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

where SINR_p is SINR at point p in the coverage area. 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 $\mathrm{A}_0 \rho_{\mathrm{FR}}$ is factor representing spectrum efficiency gained through spectrum reuse. ρ_{MF} is factor representing spectrum efficiency lost either by trunking loss due to sectorization, or by multiplexing loss due to relaying.

Advantage of using above metric, is that it is unique single metric, which characterizes overall spectrum efficiency considering effect of frequency reuse i.e. F, sectorization i.e. S, and relays i.e. R, as well as, link adaptation which are essential features of future cellular networks but are not captured by conventional measures.

B. Fairness ζ

We can characterize fairness feature of given FRD scheme by measuring how much the data rates within the coverage area deviates from the average data rate in the coverage area. It depends on the SINR distribution as well as mapping of that SINR to actual data rate achievable by a user and can be given as

$$\zeta = 1 \Bigg/ \sqrt{\frac{1}{L}\sum_{l=0}^{L}\left(\left(\mathrm{MCE}_l \times \frac{\mathrm{A}_l}{\mathrm{A}_t}\right) - \sum_{\mathrm{l}=0}^{\mathrm{L}}\left(\mathrm{MCE}_l \times \frac{\mathrm{A}_l}{\mathrm{A}_t}\right)\right)^2} \quad \ldots (16)$$

Advantage of using this metric of fairness is that in addition to considering the elements of FRD i.e. F, S, and R, it also captures the actual effect of link adaptation which is key factor in determining fairness in future OCN.

C. Power consumption η

We propose η as a negative measure of energy efficiency (i.e. energy consumption instead of saving) given as

$$\eta = \frac{P}{\varepsilon} \quad \ldots (17)$$

where P is power consumption per site which incorporates both fixed, as well as, variable power consumption per site, on downlink in a cellular system. Fixed power consumption is that, which is consumed in keeping the circuitry of BS sectors or RS alive no matter if there is traffic or not, until that sector or RS is switched off. Variable power consumption is power required for transmission on air interface and varies with the traffic load. Thus, power consumption on a site can be written as

$$\mathrm{P} = \sum_{\mathrm{s}=1}^{\mathrm{s}}\{\mathrm{P}_{\mathrm{f}}^{s} + \mathrm{P}_{\mathrm{v}}^{s}(\mathrm{G}(\xi^{\mathrm{s}}, \mathrm{D}^{\mathrm{s}}), \mathrm{P}_{\mathrm{t}}^{s}, \gamma^{\mathrm{s}})\} + \sum_{\mathrm{r}=1}^{\mathrm{R}}\{\mathrm{P}_{\mathrm{f}}^{\mathrm{r}} + \mathrm{P}_{\mathrm{v}}^{\mathrm{r}}(\mathrm{G}(\xi^{\mathrm{r}}, \mathrm{D}^{\mathrm{r}}), \mathrm{P}_{\mathrm{t}}^{\mathrm{r}}, \gamma^{\mathrm{r}})\} \quad \ldots (18)$$

where subscripts f, v and t denote fixed, variable, and transmission powers respectively. Post scripts s, and r denote sector and relay respectively. For sake of simplicity we are not considering any stray losses e.g. feeder loss, connectors loss as they are negligible nevertheless for the purpose of this analysis. Variable power consumption further depends on the transmission power P_t , traffic loading factor γ and antenna gain G. Antenna gain is further a function of efficiency of antenna ξ, and directivity D. The directivity of antenna has important role in determining its gain and hence the transmission power required to provide a certain coverage level. It can be written as

$$D = 4\pi \Bigg/ \left(\frac{\int_0^{2\pi}\int_0^{\phi} \beta(\theta, \phi) \sin\theta \, d\theta \, d\phi}{\beta(\theta, \phi)|_{max}}\right) \quad \ldots (19)$$

Where β is function representing radiation pattern of antenna as function spherical co-ordinate angles θ and ϕ. For practical purposes the denominator of Eq. (19) can be approximated by product of half power beam widths ψ_h and ψ_v in horizontal and vertical plane. So Eq. (19) can be approximated as

$$D = \frac{4\pi}{\psi_h \psi_v} \quad \ldots (20)$$

In cellular system the desired vertical beam width of antenna is around $\frac{\pi}{18} = 10^o$ and horizontal beam width depends on the number of sectors per site e.g. for three sectors and six sectors, beam width of around 70^o and 35^o are usually used respectively. If we define α as factor determining the overlap between the adjacent sectors, we can write horizontal beam width as function of S as $\psi_h = \frac{\alpha\pi}{S}$. Then Eq. (20) can be written as

$$D = \frac{72S}{\alpha\pi} \quad \ldots (21)$$

Normal value is $\alpha = 1.1$. To achieve a desired EIRP in the coverage area, less transmission power P_t will be required for antennas with higher gains i.e.

$$EIRP = \xi D \times P_t \quad \ldots (22)$$

If P_d is the power required to acheive required $EIRP_d$ with an ominidirectional antenna

$$P_d = EIRP_d \frac{1}{\pi\xi} \quad \ldots (23)$$

Then the variable circuit power per sector for desired $EIRP_d$ can be written in dB as

$$P_v^s = 10\, log_{10} P_d^s - 10\, log_{10}\left(\frac{4\xi^s S}{\alpha\psi_v^s}\right) + 10\, log_{10} \gamma^s \quad \ldots (24)$$

Similarly, the variable circuit power on a RS can be written as

$$P_v^r = 10\, log_{10} P_d^r - 10\, log_{10}\left(\frac{4\xi^r}{\psi_v^r}\right) + 10\, log_{10} \gamma^r \quad \ldots (25)$$

Putting in Eq. (24)-(25) to in Eq. (18) and

$$P = log_{10}\left(\sum_{s=1}^{S}\left\{P_f^s + \alpha\left(\frac{\gamma^s \psi_v^s P_d^s}{4\xi^s S}\right)\right\} + \sum_{r=1}^{R}\left\{P_f^r + \frac{\gamma^r \psi_v^r P_d^r}{4\xi^r}\right\}\right) \ldots (26)$$

Fig. 1& 2 plot variable power consumptions and total power consumptions respectively. $\gamma^s = \gamma^r = 1$ is assumed because we are considering full load scenario. Antenna efficiency of commercial antennas is used. i.e. $\xi^r = \xi^s = .6$, $P_f^s = 15W$ with $P_f^r = 0.5P_f^s$ due to reasons explained in [10]. It is important to note that, variable power consumption does not increase with number of sectors. This is because the additional gain due to higher directivity of sectorized antennas cancels out the additional power required to transmit on sectors.

Figure 2, shows that power consumption per site increases more rapidly with the increase in no. of RS than in no. of sectors per site. This is mainly because each RS has an omnidirectional antenna, so there is no compensating factor as in case of sectors.

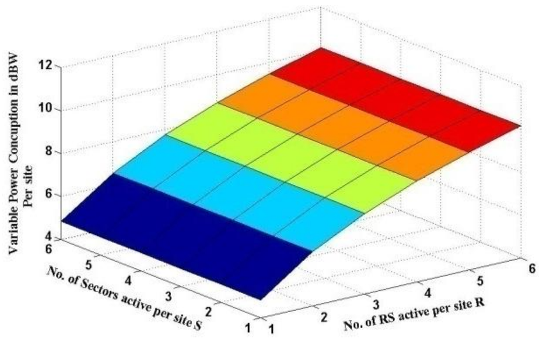

Figure 1: Variable power consumption per site

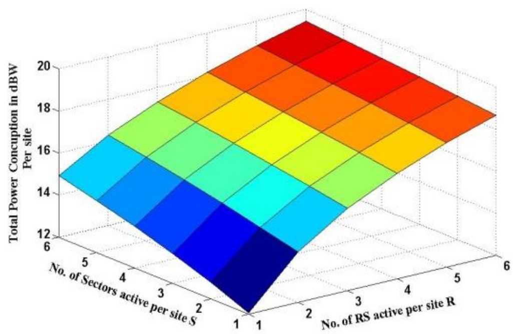

Figure 2: Total power consumption per site

By putting Eq.(13) and (26) in (17),we can define $\eta(\mathrm{F,S,R})$ as

$$\eta = \frac{\rho_{\mathrm{MF}}\left(\sum_{s=1}^{S}\left\{P_f^s + \alpha\left(\frac{\gamma^s\psi_v^s P_d^s}{4\xi^s S}\right)\right\} + \sum_{r=1}^{R}\left\{P_f^r + \frac{\gamma^r\psi_v^r P_d^r}{4\xi^r}\right\}\right)}{\sum_{\mathrm{L}=0}^{\mathrm{L}}\left(\mathrm{MCE}_l \times \frac{\mathrm{A}_l}{\mathrm{A}_t}\right) \times \rho_{\mathrm{FR}}} \quad \ldots (27)$$

V. Results and discussion

Figure 3-4, show the normalized values ε, ζ, and η worked out through Eq(13),(16) & (27). The values of Eq. (14) to be used in (13) are evaluated through extensive system level simulations for all FRD's listed in Fig 3 & 4. Table 2 summarizes the simulation parameters used. For the ease of plotting on same scale, value of each metric in Fig 3-4 is normalized by its maximum for both cellular and relay enhanced cellular network respectively. These two graphs form the solution space for the problem in Eq. 7. Before we explain the use of this solution space for our SO-FRD framework it is important to highlight some interesting tradeoffs we can observe among the performance metrics or optimization objectives in Fig.3 as well as Fig. 4. Fig. 3 shows that FRD=1 is optimal w.r.t. energy efficiency, but has suboptimal spectral efficiency and worst fairness. Compared to FRD=1, in FRD=2 spectral efficiency and fairness both improve but at the expense of more energy consumption. FRD=3 provides some gain over FRD=2 in terms of spectral efficiency as well as energy efficiency but at a heavy expense of fairness and so on. In Fig. 4 it can be seen that relays bring in an additional factor in this tradeoff. First fact to notice is

Table 2: 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
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 [11] for micro, macro and
LOS to NLOS breakpoint	300m

that of FRD's without RS. This is mainly due to the fact that RS has low fixed power consumption compared to BS (see Fig.1& 2). Secondly, fairness of FRD with relays in general is much better than FRD's without relays. The reason behind this is that these are users at the cell edge which receive very low rate compared to cell center users due to poor SINR and hence bring unfairness in FRD without Relays. Whereas, with RS active at cell edge, these deprived users now come at par with cell center in terms of data rate hence a boost in fairness. But nothing comes without a cost to pay and it can be seen by comparing Fig. 3 & Fig.4 that the cost for the improvement in fairness and energy efficiency is being paid in terms of significant loss in spectral efficiency, in general in FRD with RS. Detailed discussion on the tradeoff between fairness and spectral efficiency is scope of our future work. In context of this paper, the important observation is that no single FRD strategy is optimal in all the three performance metrics simultaneously. In other words no single FRD can meet all objectives together. Rather each FRD is optimal in a particular sense. This is where SO-FRD provides a useful solution.

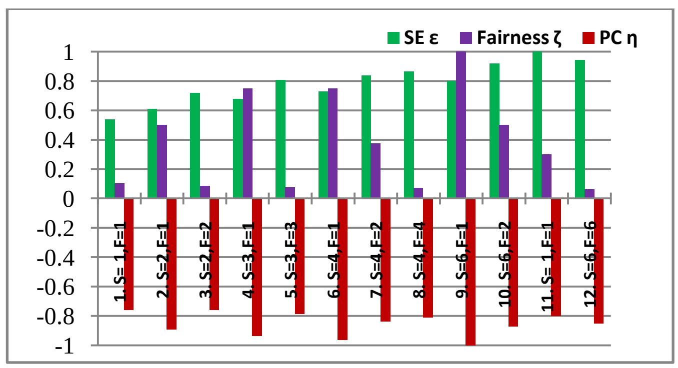

Figure 3: ε, ζ, and η normalized by their respective maximum value in conventional cellular OCN

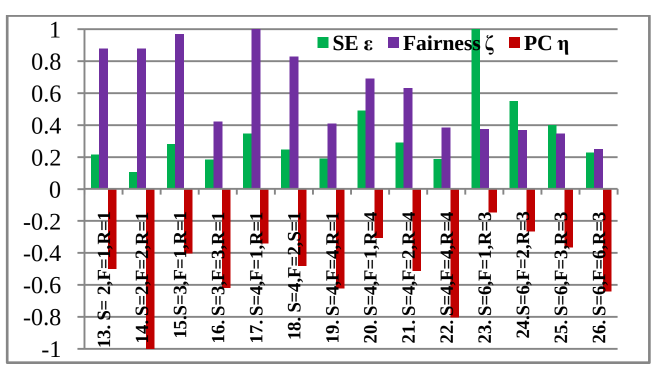

Figure 4: ε, ζ, and η normalized by their respective maximum value in relay enhanced cellular OCN

As explained in III.C, depending on the current system requirements, SO-FRD framework will select an appropriate utility i.e. either Eq.(8) or Eq.(12). Then it will set the parameters to reflect the priorities of desired objectives. If the FRD, that optimizes the utility, in the provides solution space, is not already system's current FRD mode, system will switch to this FRD. On next trigger of poor performance e.g. blocking, or poor fairness, or power shortage alarm, system will repeat same process to go to the new FRD mode which is optimal to achieve target objectives under system's newly changed state.

For the sake brevity, we will explain operation of SO-FRD framework using results of relay enhanced OCN only. If FRD schemes without relay are also included the process will essentially remain the same only the search space will become larger.

Fig.5 plots utility υ for four sets of different objective priorities. With equal priority of all three objectives, we can see FRD=23 in Fig 5, is optimal choice. When, spectral efficiency has highest priority i.e. 80%, and fairness and energy efficiency has lower and equal priorities of 10% each FRD=23 is again optimal. On the other hand, when fairness has highest importance i.e. 80%, and spectrum and energy efficiency have lower and equal priorities of 10%, FRD=17 becomes optimal state. When energy efficiency is most important target with 80% importance factor, and fairness and spectral efficiency are lower priorities with importance of just 10%, SO-FRD framework will switch the system to FRD=20.

Fig.6 plots $\boldsymbol{\tau}$ for three different set of target values of the three objectives each having same priority i.e $\lambda_1 = \lambda_2 = \lambda_3 = \frac{1}{3}$. First case (blue) represents the scenario when system wants spectral efficiency and fairness both be closes to their optimal values 100% but have some flexibility in energy efficiency. In this scenario So-FRD frame work will switch to FRD=23. In second case (red), power is need to closest to optimal, followed by spectral efficiency followed by fairness. Now the FRD=24 is the optimal state. In the last case (green), when fairness need to be closest to optimal, followed by spectral efficiency, followed by energy efficiency, 14 is the optimal state to be switched to.

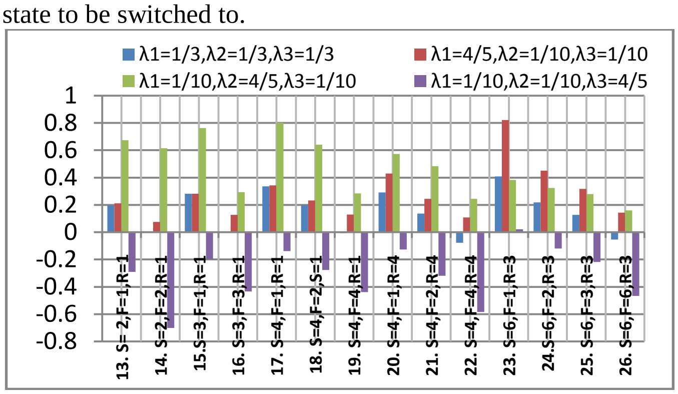

Figure 5: Utility υ for different type of objective priorities

VI. Conclusions

In this paper we proposed SO-FRD which can switch to an optimal FRD modes to cope with changing spatiotemporal dynamics of the system. This framework can be implemented on each site independently, as it does not require explicit signaling and cooperation among sites. This is because the triggers required for FRD state change are mostly local observations at site level e.g. blocking, low data rate, or large difference among data rates of users within the coverage of that site, or power consumption rate etc. This makes this framework highly scalable. Furthermore, once the solution space is worked out, operation of SO-FRD is so simple that it can run fast enough on each BS independently to cope with even short time scale dynamics as well.

Our future work will focus on enhancing this framework with additional features from MAC layer like scheduling, and PHY layer like beam forming, to cope with very short scale dynamics like channel variations, shadowing and user mobility.

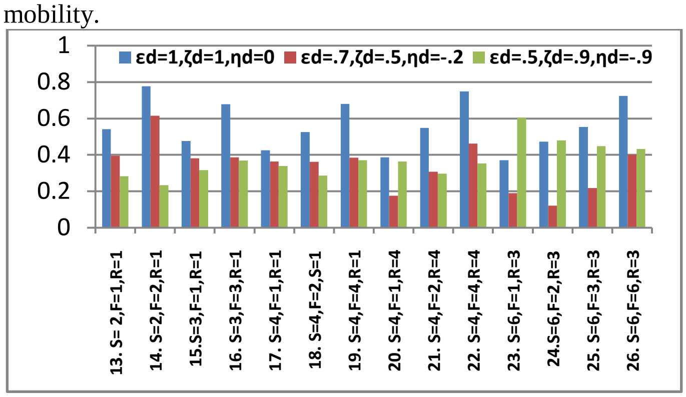

Figure 6: Utility $\boldsymbol{\tau}$ for three different sets of specific target values with same priority among them i.e. $\boldsymbol{\lambda_1 = \lambda_2 = \lambda_3 = \frac{1}{3}}$

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