A Cognitive Cell-level Resource Allocation Scheme for LTE

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Abstract— The 3GPP Long Term Evolution (LTE) is targeted to support 100 Mbps in downlink and 50 Mbps in uplink with single layer transmissions in 20 MHz bandwidth. This requires frequency reuse factor to be unity in multi cell scenario by which an unacceptable Inter Cell Interference (ICI) will occur especially at cell edge regions. While providing higher throughputs an intelligent Cell-level resources (frequency bands and allowable transmit power over those bands) Allocation method should come up to mitigate the ICI, This paper attempts this issue by proposing an opportunistic cell- level resource allocation scheme for LTE by using cognitive radio principles which we call Cognitive Cell-level Resource Allocation (CCRA).

I. INTRODUCTION

The emerging advanced wireless cellular networks (IEEE 802.16m, LTE etc.) are supposed to be spectrally efficient and provide mitigation of Inter Cell Interference (ICI) or keep it within a specified level. In order to achieve high spectral efficiency, there are so many schemes proposed for the allocation of Radio Resources (frequency bands and allowable transmit power over those bands) at cell level. The significant proposals are: Fractional Frequency Reuse (FFR), Soft Fre-quency Reuse (SFR), and their traffic load adapted versions [6], [7]. In this paper, we propose an opportunistic based Cell level Resource allocation scheme which we call as Cognitive Cell level Resource Allocation scheme (CCRA). The FFR and SFR schemes suffer mainly from: ICI, lower spectral efficiency and the cell edge user throughput. The spectral efficiency can be increased by using their adapted versions with respect to cell load at the cost of computations (prediction of cell load etc.) and the requirement of a strong coordination among adjacent base stations. But the complete ruling out of ICI cannot be possible in these schemes. Our proposed scheme will solve all those problems which are faced by FFR and SFR schemes at the cost of periodic measurement of adjacent cell interference by the mobile terminals and Base station, and fusion of the multiple measured interference information gathered by the base station.

This paper is explained with reference to the 3GPP Long Term Evolution (LTE) standard which uses OFDMA as its air interface of the downlink (SC-FDMA for uplink). These schemes can also be extended with minor modifications to IEEE WiMAX standards which are also uses OFDMA as its air interface (for both uplink and downlink).

In LTE, a radio frame consists of 10 subframes. Each sub frame is duration 1ms in which two physical slots will be present and each physical slot of 0.5ms consists of 6 or 7 OFDM symbols that depends on the cyclic prefix length (4.7 and 16.7 μs are defined in the standard). In frequency domain, each physical slot is divided in to Physical Resource Blocks (PRBs) of 12 sub carries x 6 or 7 OFDM symbols [8]. So the cell level resources in LTE will be the number of PRBs and the maximum allowable transmit power over these resource blocks. A sample resource chart or map of a given cell will be allocated PRBs and the respective power levels as shown in figure 1.

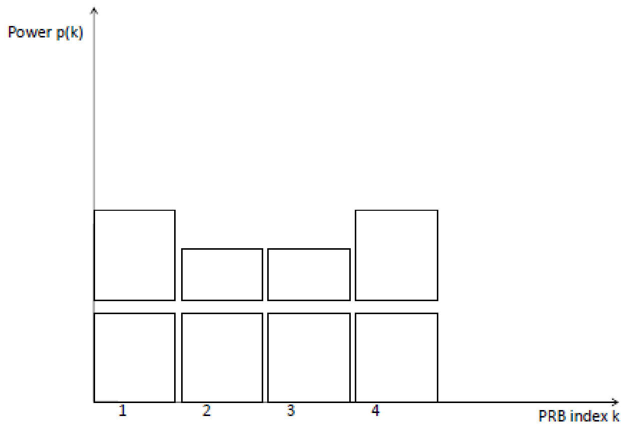

Figure 1: A sample resource chart

II. FFR AND SFR SCHEMES

A. The Fractional Frequency Reuse (FFR)

This scheme differs the full frequency reuse (in which, all the PRBs in the resource chart can be used by every cell at the same power level) by dividing the cell coverage area in to two parts as cell center and cell edge regions and allocating some of the total PRBs and same positioned in the resource chart with the lowered power level for all the cells in the given service area. Then remaining PRBs will be allocated with the given reuse factor for the cell edge regions at high power level to all cells. In the adaptive version of this scheme, the ratio of the PRBs for cell center and cell edge is adaptive according to the cell center and cell edge users' traffic arrival patterns. These schemes suffer mainly with low spectral efficiency. Because only a part of the total allocated spectrum is used with reuse factor one and remaining part of it is used with a given reuse factor which is greater than one.

B. The Soft Frequency Reuse (SFR)

Unlike FFR, this scheme can allocate all PRBs to every cell in the sense that: first it will allocate the bandwidth for each cell with the reuse factor of 3 (for example) at high power level. After this allocation, initially each cell gets only one third of the total bandwidth. Then the remaining bandwidth will be used at low power level in each cell. A cell can use high power level bandwidth for cell edge users and the low power level bandwidth for cell center users. This scheme is spectrally more efficient than the FFR scheme. But the ICI in this scheme is much more than in the FFR scheme [1], [2].

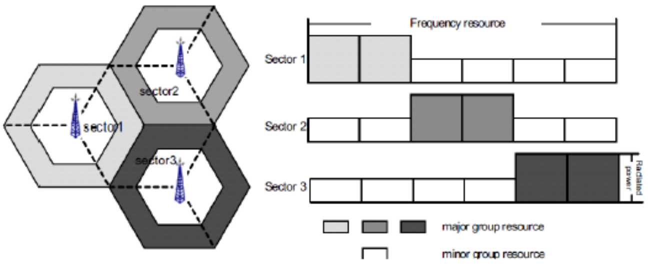

Figure 2. Cell planning model and Power allocation over frequency band in SFR scheme. [1]

III. COGNITIVE RADIO

A cognitive radio can typically use the spectrum of a primary user as a secondary user. A cognitive radio measures the interference power in a given frequency band caused by the primary user of that band. If the measured interference power in a primary band is less than a certain threshold, then it will use that band for its transmission purposes. However it has to vacate that band whenever the primary user of that band suddenly comes up. To do this, a system monitors the band currently in use in between its transmissions by creating a silence (no transmission) period in that band intermittently. This sensing mechanism is 'in-band sensing 'as opposed to 'out-of-band sensing 'which is performed on the bands which are currently not in use for cognitive radio transmission.

If a cognitive radio senses the primary user's presence in the outside of its coverage circle and that primary user can tolerate some interference from that cognitive radio transmission, then the cognitive radio can use that primary user's frequency band for a given tolerable interference power at the primary user's receiver by estimating the Maximum Interference Free Transmit Power (MIFTP) which is the maximum allowable transmit power by that cognitive radio by which it will not create harmful interference (i.e., co-channel interference will not exceed a given value) to that primary user. By knowing the location of the primary user and received signal strength from that primary user transmission, the MIFTP can be estimated for a given tolerable interference power at the primary user receiver [3], [4] by a cognitive radio.

In the case of cellular networks since a base station knows the location of its adjacent base stations, by giving this information to its associated mobile terminals, they can easily estimate the MIFTP by measuring the received signal strength (or interference) from the adjacent base station over a given frequency channel or band. In this proposed scheme we will apply these cognitive radio principles to solve the cell-level resource allocation problem in LTE.

IV. A COGNITIVE CELL LEVEL RESOURCE ALLOCATION SCHEME (CCRA)

In this proposed scheme, a Base station (eNodeB) will command its associated mobile terminals to measure the interference through sensing and estimate MIFTP (since the location of an adjacent base station is fixed and known, the MIFTP can be estimated) in each group of 12 contiguous subcarriers (equal to the PRB length in the frequency domain) of all useful subcarriers. In return, users will send their estimated MIFTP over each PRB in frequency domain to the base station. Then the base station will fuse this collection of information to find appropriate transmission power over each PRB by which a prescribed ICI can be achieved. By doing this base station can make a resource chart or map in which each PRB will have the transmission power level that is declared by it with the fusion of collected MIFTP information over all PRBs. In this negotiated resource chart, if a PRB's transmit power level is low which means that, in the adjacent cell that PRB is used at high transmit power level. Similarly, if a PRB's transmit power level in the resource chart is high, it means that the corresponding PRB in the adjacent base station cell is used at low transmit power level. Once the resource chart is obtained by a base station, the base station can use it for user level resource allocation purpose in its own cell until any request is comes from other adjacent base station (s). In the worst case, the obtained resource chart may have a few number (or zero) of PRBs with low transmission power level. But if with this resource chart the base station cannot serve enough number of its cell edge users then the base station can send a request to the adjacent base station through X2 interface to decrease the power level over some number of PRBs. This proposed scheme can be employed in two forms: one is at a low degree of complexity (version-1) and the other is at a high degree of complexity (version-2).

A. Version-1 of the proposed scheme

The estimated MIFTP value over each PRB can be quan-tized in to only two values, 'low 'and 'high '. So we will get the resource chart with PRBs at low or high transmis-sion power levels. Then this scheme will be converted into opportunistic version of Soft Frequency Reuse (SFR) as if an adjacent cell's base station is not using high transmission power over some PRBs then the negotiated resource chart after the fusion process in the current cell will have those PRBs at high transmission level, then the current base station can use those PRBs for cell edge users. It may so happen that, the negotiated resource chart is inappropriate to serve cell edge users for a given required edge user throughput and the other base stations are not responding to the sent request to decrease power level over some resource blocks (this may happen in the case where the other adjacent cells also have a higher number of cell edge users), then a fairness feature may such that each cell's base station satisfy its cell edge user throughput may be introduced. For that purpose, we propose to put a limit on the number of PRBs for each cell to use at high power level. If the estimated resource chart through sensing has only a few number of high transmission power level PRBs which cannot serve the edge users' arrival traffic for a given required cell edge user throughput then it counts the number of PRBs over which transmission power can be high and if that number is less than the threshold number of PRBs over which transmission power can be high, then it sends the request to other adjacent base stations to decrease the power level over a given number of PRBs. when a base station receives that request, it decrease the transmission power over those PRBs exceeding the threshold number. It takes no action if the number of high-power users is within the threshold. Ones the resource chart is prepared as per the proposed scheme, based on the received Channel Quality Indicator (CQI) users will be categorized into two sets: one is cell center user set and another is cell edge user set as a low CQI user can be presumed as a cell edge user and a high CQI having user can be presumed as the cell center user. Then allocate high transmission power level PRBs to cell edge users if present, otherwise allocate to cell center users if required.

B. Version-2 of the proposed scheme

In this version we allow the transmission power level over each PRB as estimated by the MIFTP. Then we may have a distinct number of power levels over the PRBs in the resource chart. In this version after having the resource chart through sensing, we schedule the users frst in time domain for every subframe as per their required QoS. Then we send this resource chart to the scheduled users to estimate their channel quality indicator (CQI) over this negotiated PRBs chart. Then the mobile terminal's estimated CQI report, in the form of modulation scheme and code rate over each PRB will be sent back to the base station. Through these collected CQI reports, resources (PRB, power level, modulation scheme, and code rate) will be allocated to the time scheduled users by applying our proposed 'User-level Resource Allocation (URA) 'shown in Fig. 3 which better suits with our proposed 'Cell-level Resource Allocation (CRA) 'scheme. In the proposed URA, the Proportion Fair (PF) algorithm [5] is used to solve the contention between equal priority users. For example, after the negotiation of the resource chart and users' estimated CQI according to that chart, the base station will have a CQI table as shown below. For simplicity we have shown the chart for four users for four PRBs and the code rate is ignored.

When we apply the proposed URA algorithm to CQI table given in Table 1, in the first iteration, our algorithm will allocate PRB4 to U 3. In the second, third and fourth iterations, PRB3, PRB1, and PRB2 to U1, U2 and U4 will be allocated respectively.

Table 1: A Sample CQI report sent by four users to base station over four PRBs

Users	PRB-1	PRB-2	PRB-3	PRB-4
U 1	QPSK	Zero	QPSK	Zero
U 2	16QAM	16QAM	16QAM	QPSK
U 3	Zero	zero	Zero	QPSK
U 4	16QAM	16QAM	16QAM	64QAM

```
Load the CQI table.
While (any user without a PRB
allocated is present)
{
Prioritize the users according to
the lowest number of nonzero CQI PRBs.

If (the high priority user has only
one nonzero CQI resource block)
{
If (other equal high priority
users have same nonzero CQI PRB)
{
Apply 'Proportional Fair'
algorithm over them for that PRB.
}
Else
{
Allocate that nonzero CQI PRB.
}
}
Else
{
Allocate one of the nonzero CQI
PRB's which gives a better throughput
than the other PRBs.
}
 After the allocation, reprioritize
 them by putting zero on the scheduled
 PRB for all users.
}
```

Figure 3: Proposed User-level Resource Allocation (URA)Scheme

V. SIMULATION STUDIES

The Version-1 scheme is simulated in MATLAB. Average throughput per cell is compared with the SFR scheme in two cases: (1) the cell load is kept constant at 10 packets per millisecond where each packet can consume one Schedule Block (SB) and the ratio of cell edge users and cell center user *(e/c)*'s increases from 5% to 50% in steps of 5%. (2) *e/c* kept constant at 1/3 and the cell load increases from 6 packets per millisecond to 24 packets per millisecond in steps of 2 packets per millisecond. Both comparisons are shown in figures 4 & 5 respectively.

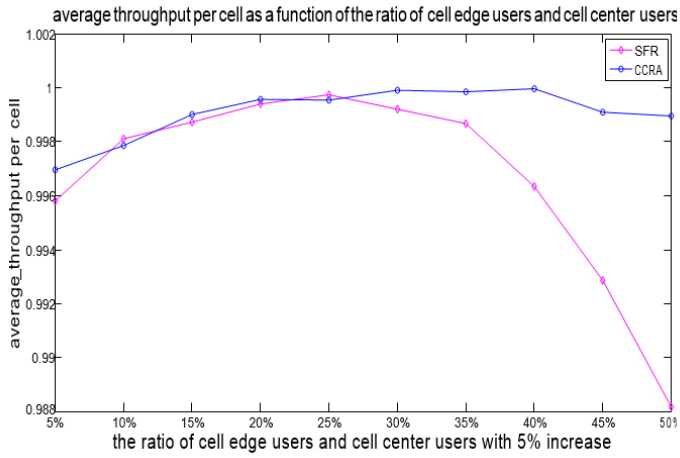

Figure 4: Comparisons of CCRA with SFR for constant cell load with the variable ratio of edge users and center users

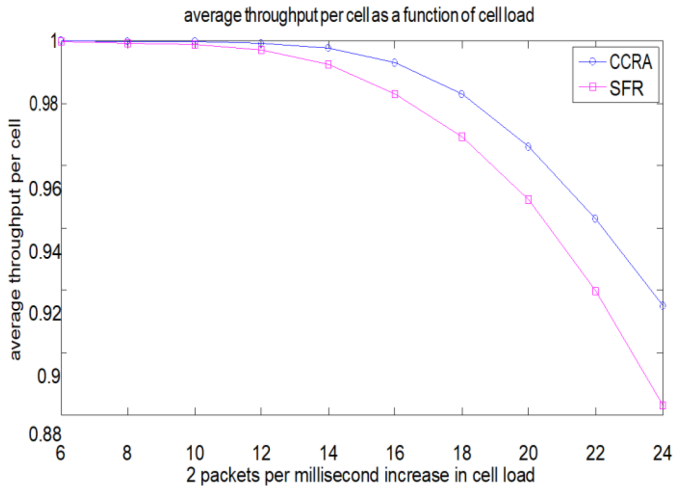

Figure 5: Comparisons of CCRA with SFR for the constant ratio of edge users and center users with variable cell load

A base station should serve its users equally without de-pending on their locations (cell center and edge regions) so for a given cell load, the average throughput per cell should be constant for all the e/c values. From Fig. 4 it can be observed that our proposed scheme make the average throughput per cell almost constant as increasing the *e/c*. But with the SFR scheme the average throughput per cell is decreased with the increasing value of the e/c. And from Fig. 5 it can be observed that CCRA gives better average cell throughput with the increasing cell load while the *e/c* kept at 1/3 value. compared to cell center region and hence reuse 3 must be used for the users located far away from base station.

I. CONCLUSIONS

Since eNodeBs are not connected to a centralized body (such as RNC in WCDMA) in LTE, it is difficult to allocate resources at Cell-level as per traffic load. In our proposed scheme, a cell's base station can attain the resources au-tonomously by measuring the interference from base station of adjacent cells and estimating MIFTP. Through this scheme, a highly loaded cell can get sufficient resources from its lightly loaded neighbor cells without going to co-ordinate with them. With the proposed scheme the temporal variations in the arrival traffic load could not create 'spectrum scarcity 'and 'spectrum underutilization 'problems. In version-2 of our scheme we have proposed a User-level Resource Allocation (URA) which suits with our proposed Cell-level Resource Allocation Scheme (CRA). The proposed scheme allows the high transmission power level PRBs opportunistically by a base station so increased spectral efficiency can be obtained. In version-2, our scheme allows the base station to use the exact MIFTP (which is obtained for a given ICI) level over each PRB there by it mitigates the ICI. The problem with SFR and FFR that, as the ratio of cell edge users and cell center user's increases, then the overall throughput will go down because the allocated bandwidth for cell edge users is fixed. But with our proposed scheme that we have shown in results that for moderate loads, the overall through put is almost constant with our scheme as compared to SFR scheme.

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