Optimal Almost Blank Subframe (ABS) density in Long Term Evolution (LTE) to serve cell edge users and ensuring optimal throughput of the network

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M. Tech 2017-19, IIT Madras

***Abstract*—In Long-Term Evolution (LTE)- Advanced heterogeneous cellular networks the user offloading is done via macro, micro, pico and femto- tier architecture. Owing to the high cross-tier interference from the macro to picocells in the co-channel deployment, there needs to be a harmonious optimisation of Almost Blank Subframes (ABSs) released by the macro Base Station with the offloading of the users. In this paper we discuss the optimisation of the ABS density to facilitate the cell edge users and simultaneously ensuring an optimal throughput of the entire LTE network. In addition, a heuristic algorithm is proposed that aims at predicting the optimal ABS density based upon the current load and expected data rate of the users in the network. Multiple simulations of the proposed algorithm were undertaken and a detailed comparison with the ones existing was carried out.**

***Keywords*—LTE, heterogeneous cellular network, macro/ pico base station, user equipment, cell edge users and Almost Blank Subframes.**

I. Introduction

Heterogeneous LTE network comprises of multiple layers of networks of different cell sizes. A cell is based on the coverage area of a base station(BS), commonly referred as Node B (eNB), where it can communicate with a mobile user equipment(UE) over the radio frequency (RF) link. A UE operating near the edge of the cell suffers from distance-dependent path losses of the power transmitted by eNB. As a result, cell-edge users often experience the lowest data throughput within the cell. In a classical macrocell architecture cell splitting was initially used to cater for the increased load, but it was observed that such cell splitting lead to high implementation cost and a colossal increase in the hand off when a User Equipment(UE) shifted from one cell to other. Later on, new heterogeneous networks were developed that a mixture of a variety of base stations like high power macro and low power pico nodes. The macro Base Station(BS) covers a wide area whereas the pico BS which cover a relatively smaller area are conventionally used in hot spots to reduce the transmitter-to-receiver separation and enable better spatial reuse of the frequency. In addition, they also ensure the offloading of the traffic from the macro layer. Along with the pico base stations there are other low power base stations in the heterogeneous LTE network such as micro-Nodes, femto-Nodes and relays-Nodes which can also be deployed in different settings. These kind of mixed heterogeneous deployments have several drawbacks as well like it can lead to Inter-Cell Interference (ICI) owing to the frequency reuse in various kind of similar cells, which also called as unity frequency reuse [5], [7].

There is a full duplex communication between the eNB and the UE in a LTE network. The transmission of the data from the eNB to the UE is called down-link transmission and the vice-verse is the up-link transmission. The study in the paper are related only with the down-link channel of the LTE network architecture. A Resource Element (RE) is the smallest time-frequency unit for down link transmission, which is one symbol on one sub-carrier. A group of 12 contiguous sub-carriers in frequency and one slot in time form a Resource Block (RB). The data is allocated per User Equipment (UE) in units of RB. A RB spans over 12 consecutive sub-carriers at a sub-carrier spacing of 15kHz, and 7 consecutive symbols over a slot duration of 0.5 msec. A guard interval is also appended to each symbol which is called as Cyclic Prefix. Thus, a RB has 84 resource elements (12 sub-carriers x 7 symbols) corresponding to one slot in the time domain and 180kHz (12 sub-carriers x 15kHz spacing) in the frequency domain. The size of a RB is the same for all bandwidths; therefore, the number of available physical RBs depends on the transmission bandwidth. As the CP is present between each symbol in a similar manner a guard band of 20kHz is present between two consecutive channels of RBs.

Inter-Cell Interference Coordination (ICIC) is a type of technology which is designed in the LTE network to reduce the interference created by two or more cells, specially the interference in the pico cell UE form the associated macro eNB. LTE signal has two components the time domain and frequency domain, hence the interference occurs in both these domains.In Time Domain, one way to reduce the interference is by making a cell (e.g, serving cell) to stop transmitting at a certain sub frame so that other cell (e.g, a femto/pico cell) can transmit the signal during that period. But, sometimes completely stopping the signal transmission causes some issues. So it is recommended to transmit the signal at a very low power. These very low power sub frame are called 'Almost Blank Sub frames (ABS)'. Due to high interference from the associated macro eNB to the cell edge users of a pico eNB leads to a high drop in the Signal to Interference Noise Ratio(SINR) of these UEs. This has a cascading effect in decreasing the data rate received by the cell edge users in a LTE network. To compensate for the same each pico eNB requests additional RBs from their respective macro eNBs which are also called as ABS density. In case of multiple pico cells in a single macro cell architecture a the macro BS needs to meet the optimal ABS density to satisfy the requirement of all cell edge UEs of its pico cells. Selection of optimal ABS density can be undertaken via algorithms which select either maximum, minimum or average ABS density demand among requirements from all its pico eNBs. Based on literature survey and simulations several trade off were observed in these existing algorithms; like providing maximum ABS density lead to maximum wastage of RBs. Simultaneously allocation of minimum of all ABS requirement to each pico eNBs lead to maximum blockage. Better results were observed on allocation of average of all ABS densities of pico cells to each pico eNB by the macro BS. It is pertinent to mention that each macro eNB while meeting the requirement of ABS density of its associated pico BS(for satisfying the requirements of cell edge users) has to ensure that it meets the optimal requirement of all UE within the macro cell as well.Further, based upon the load in the entire LTE network each macro BS has to optimally decide a solution to satisfy all users in macro as well as the pico cell whilst ensuring high throughput of the entire network, for which it decides which UE to offload for meeting the optimal solution globally. Here we are trying to propose a heuristic algorithm that predicts the optimal ABS density for the entire LTE network based upon the present loading conditions.

II. System Model

The system that we considered as a model for our simulations and research is a typical heterogeneous LTE network comprising of 19 macro eNB. Further, each macro eNB contains 2-4 pico eNB.The macro cells follow a hexagonal shape for maximum coverage and each pico eNB is having a circular shape.(Fig. 1) Throughout our paper and research we have assumed that every macro eNB and pico eNB use same frequency(i.e called unity frequency reuse), further the users are assumed to follow a uniform distribution. Along with the uniform distribution the data rates of the have been kept as 128kbps, 256kbps, 512kbps or 1Mbps and the number of users in each of these profile is in the ratio 4:3:2:1. The assumptions and the parameters for designing the peculiar architecture have been tabulated at Table I.

The expected SINR values of the pico cell edge users, macro users and pico users was calculated based on the undermentioned formula for SINR:

$$SINR = \frac{\frac{Pw(Tx\ power\ of\ Pico\ BS\ in\ watt)}{d^2(d\ is\ distance\ of\ UE\ in\ km\ from\ Pico\ BS}}{\Sigma\frac{Pm(Tx\ power\ of\ Macro\ BS\ in\ watt)}{d^2(d\ is\ distance\ of\ UE\ in\ km\ from\ Macro\ BS} + \sigma^2} \quad (1)$$

For decreasing the complexity an removing of trivial values in all our cases we have not taken the interference between two pico cells.For segregation of users into cell center and cell edge user in a pico cell we have classified all users whose SINR values(in dB) are less than zero(0) as cell edge users.In addition to this for further refinement of the selection of cell edge users two points in a pico cell were selected which had SINR values zero(0) and one being closest to the macro eNB and the other farthest from macro eNB.The average of the distance of these two points was selected as the radii separating cell center and cell edge users.

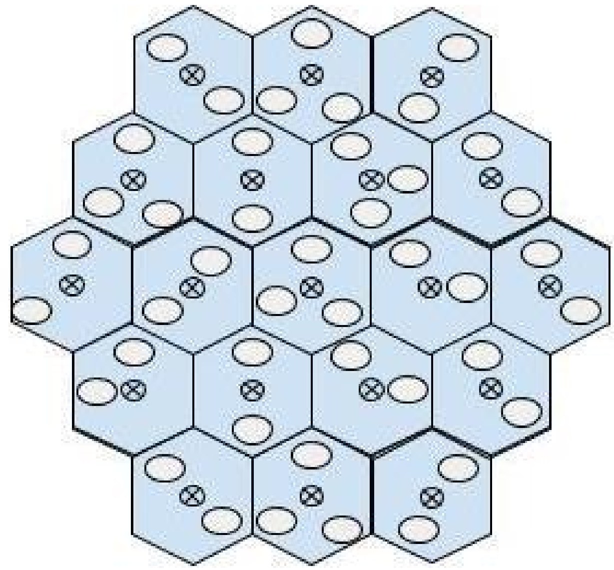

Fig. 1: Overview of Architecture

TABLE I: Parameters and assumptions

Total no. of Macro cell	19
No. of pico cell per macro cell	3-4
Noise (σ)	-174 dBM/hz
Path Loss (pico) in dB	140.1+36.7log10(d)
Path Loss(macro) in dB	128.1+37.6log10(d)
Carrier frequency	2 GHZ
System Bandwidth	10 MHZ
Pico cell radius	100m
Macro cell radius	750m
Pico BS transmit power	30 dBm
Macro BS transmit power	46 dBm
(γ) RSRP threshold	To select cell edge users
Frame size	10 ms
Sub frame size	1 ms
Channel size	180 Khz
Guard band size	20 Khz
User distribution	Uniform
No. of RBs per sub frame	2
Total no. of symbols per RB	84
Actual no. of symbol used per RB	70
Number of MBS users per MBS	30-60
Number of PBS users per PBS	20-40

III. Problem Statement

The objective of this report is to identify the optimal Almost Blank Sub-frame (ABS) in Long Term Evolution (LTE) frame in order to serve the cell edge users without significantly affecting the throughput of cell center users and thereby ensuring efficient throughput of the entire heterogeneous LTE network.

IV. Approaching Problem

The identification of the optimal ABS was progressed by carrying out the undermentioned tasks in a phased manner

A. Identification of expected number of users in the cell edge region

The cell edge users were calculated based on the SINR value. Using the given SINR and the expected data rate of the cell edge users was found out which was used to identify the required number of Resource Blocks (RBs) for cell edge users.

B. Selection of ABS density by the MBS.

The total RBs(ABS density) required by all pico eNB for providing services to its cell edge users was calculated based on the existing algorithms Min,Max and Average.

C. Identifying optimal ABS density for enabling MBS/PBS to on-load/offload the users

The existing algorithms(Min,Max and Average) had several drawbacks like it was observed that the selection of maximum ABS density lead to maximum wastage of RBs whereas allocation of minimum of all ABS requirement to each pico eNBs lead to maximum blockage of users.

D. Results and analysis

Comparison of the proposed algorithm with the existing ones.

V. Solution

A. ABS density calculation

For every pico cell inside a macro two points, one farthest(at r2 distance) and one closest(at r1 distance) from the macro eNB were selected such that the SINR value at that points is zero(0). The distance of these two points from the pico eNB were used to obtain an average separation(R) of all points inside a pico cell having zero (0) SINR. This separation distance was used to classify the users as all users inside this were taken as cell center users and the rest as cell edge users.

By euclidean distance formula

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{2}$$

Here (x1,y1) and (x2,y2) are the co-ordinates of macro eNB and co-ordinates of pico eNB in the plane respectively. Hence, their separation can be calculated using equation (3).The values of r1 and r2 can be obtained using the equations (3) and (5) and finally R can be obtained by (7)

$$SINR = \frac{P_w/r_1^2}{P_m/(d - r_1)^2} = 1 \tag{3}$$

$$r_1 = \frac{\sqrt{P_w} * d}{\sqrt{P_m} + \sqrt{P_w}} \tag{4}$$

$$SINR = \frac{P_w/r_2^2}{P_m/(d + r_2)^2} = 1 \tag{5}$$

$$r_2 = \frac{\sqrt{P_w} * d}{\sqrt{P_m} - \sqrt{P_w}} \tag{6}$$

$$R = \frac{r_1 + r_2}{2} \tag{7}$$

Expected number of cell edge user(Ne) can be obtained from the formula:

$$N_e = \frac{N_p(R_p^2 - R^2)}{R_p^2} \tag{8}$$

Where Np is the number of pico cell users, Rp is the radius of the pico cell and R has been obtained from (7). The expected SINR of cell edge user can be obtained by:

$$SINR_e = \frac{S_1 + S_2 + S_3 + S_4 + S_5 + S_6}{6} \tag{9}$$

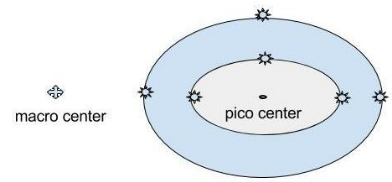

Fig. 2: * denotes point where SINR is calculated

Where S1,S2,S3,S4,S5,S6 are the point at the cell edge region of pico cell as depicted in Fig 2. Expected SINRe that can be calculated using (9), we can obtain expected number of bits contained per symbol(Be) from II, thereafter number of bits contain by per RB(Br) was calculated:

$$B_r = B_e * 70 \tag{10}$$

Here we are assumed that out of 84 symbols only 70 symbols were used(84 symbol contain by per RB). Then expected number of RBs required by cell edge users were calculated

$$ABS_d = \frac{N_e * (4 * ud_1 + 3 * ud_2 + 2 * ud_3 + 1 * ud_4)}{10 * B_r} \tag{11}$$

TABLE II: MCS (MODULATION & CODING SCHEMES)

MCS	Modulation	Code Rate	SINR threshold [dB]	Efficiency [bits/symbol]
MCS 1	QPSK	1/12	-6.50	0.15
MCS 2	QPSK	1/9	-4.00	0.23
MCS 3	QPSK	1/6	-2.60	0.38
MCS 4	QPSK	1/3	1.00	0.60
MCS 5	QPSK	1/2	1.00	0.88
MCS 6	QPSK	3/5	3.00	1.18
MCS 7	16 QAM	1/3	6.60	1.48
MCS 8	16 QAM	1/2	10.00	1.91
MCS 9	16 QAM	3/5	11.40	2.41
MCS 10	64 QAM	1/2	11.80	2.73
MCS 11	64 QAM	1/2	13.00	3.32
MCS 12	64 QAM	3/5	13.80	3.90
MCS 13	64 QAM	3/4	15.60	4.52
MCS 14	64 QAM	5/6	16.80	5.12
MCS 15	64 QAM	11/12	17.60	5.55

ABSd is the ABS density and ud1,ud2,ud3 and ud4 are the data rate of four different type of users, which are in the ratio 4:3:2:1. The ABSd for all the pico in the given architecture were calculated.

B. Proposed algorithm for calculating optimal ABS

The proposed algorithm took into consideration the blockage and the wastage parameters while deciding optimal ABS density.As per the existing algorithms of Min, Max and Average it was observed that the maximum wastage was observed in case of assigning Maximum ABS density while allotment of minimum ABS density lead to maximum blockage. It was heuristically decided that the optimal ABS density(M) would be at the minimum value of the curve obtained by multiplying blockage(B) by wastage(W) which is Y given by the equations below:

$$Y = -(W\% * B\%) \tag{12}$$

The primitive step for obtaining the optimal ABS density was to sort the demands by all pico in the system in an increasing order. We assumed Di as the demand of the i-th pico eNB in a macro eNB, M the optimal ABS density and N the total no. of pico cells in the system. For calculating the optimized ABS density(M) we differentiate Y w.r.t to M and obtain a value for M(will be an integral value as it is ABS demand of a pico). It was further assumed that this requirement of M will be for the pico at k-th position and $1 \leq k \leq n$. For this value of M at k-th position the Wastage will be zero(0) for all pico cells which have ABS density requirement more than M; which will lie from k+1 $\leq i \leq n$. Similarly, the values of Blockage will be zero(0) for all pico cells which have ABS density requirement less than M; which will lie from $1 \leq i \leq k$. The wastage(W) and blockage(B) can be calculated as below:

$$W = \sum_{i=1}^{k} \frac{M - D_i}{M} \tag{13}$$

$$B = -\sum_{i=k+1}^{n} \frac{D_i - M}{D_i} \tag{14}$$

$$Y = -\sum_{i=1}^{k} \frac{M - D_i}{M} * \sum_{i=k+1}^{n} \frac{D_i - M}{D_i} \tag{15}$$

$$Y = -(k - \sum_{i=1}^{k} \frac{D_i}{M}) * ((n-k) - \sum_{k+1}^{n} \frac{M}{D_i}) \tag{16}$$

$$\frac{dY}{dM} = -\frac{(n-k)}{M^2} \sum_{i=1}^{k} D_i + k \sum_{i=k+1}^{n} (\frac{1}{D_i}) \tag{17}$$

$$\frac{dY}{dM} = 0 \tag{18}$$

$$M^2 = \frac{(n-k)\sum_{i=1}^{k} D_i}{k \sum_{i=k+1}^{n} (\frac{1}{D_i})} \tag{19}$$

$$M = \sqrt{\frac{(n-k)\sum_{i=1}^{k} D_i}{k \sum_{i=k+1}^{n} (\frac{1}{D_i})}} \tag{20}$$

At this point we propose that the value of k will be based on the Median of the ABS requirements of the pico cells; that means that M will be the optimal ABS density requirement and it shall lie near to the median of the values of the ABS requirements. The optimal ABS obtained using this algorithm was found to be better than the ones obtained by using existing algorithms Min, Max and Average. The results of all were calculated and have been shown in the results and analysis.

C. *Throughput calculation of the system*

As we know that throughput is the amount of the data transferring in the channel per second. One of the goal of our algorithm was to increase the system throughput and the throughput(Th) for our case was the number of bits transferred in the channel per frame(10ms) which can be calculated using the undermentioned equation:

$$Th = \sum_{ep \in satisfied\ pico\ UE} B_{ep} * t_{sc} + \sum_{em \in satisfied\ macro\ UE} B_{em} * t_{sc} \tag{21}$$

B_{ep} and B_{em} are the expected number of bits in one RBs in pico and macro cell. The values for both can be calculated using (10) where t_{sc} is the total number of sub carrier in 10ms frame and can be calculated as follows:

$$t_{sc} = (\frac{BW}{BW_{ch} + BW_{gb}}) * 10 \tag{22}$$

As we know that there are total 10 frames of 1ms each and bandwidth(BW) of each channel is 180Khz(BW_{ch}) with 20Khz(BW_{gb}) guard band between two channels.

VI. Results and Analysis

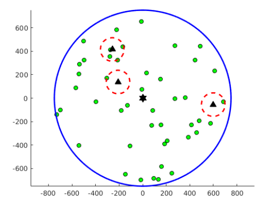

Fig. 3: One of the simulated instance having 3 pico cells inside a macro cell

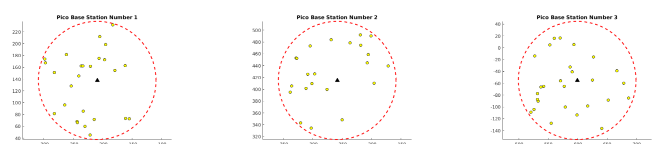

Fig. 4: Corresponding pico of the above macro

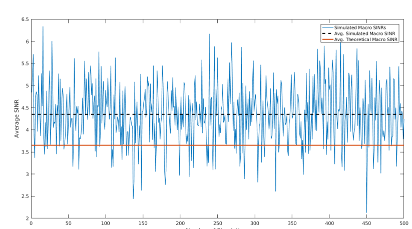

Fig. 5: Comparison of simulated v/s average SINR of macro Base Station

Based on the inter base distance between each macro eNB and pico eNB, macro cells and pico cells were generated randomly. As a uniform distribution was assumed throughout the system architecture we populated the entire scenario by

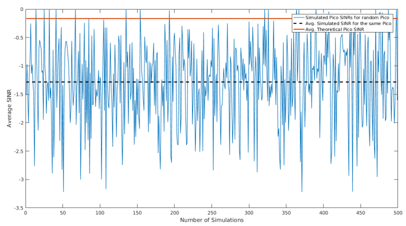

Fig. 6: Comparison of simulated v/s average SINR of pico Base Station

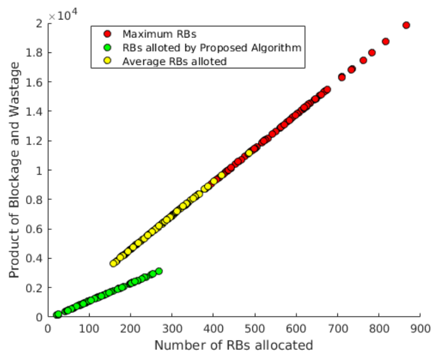

Fig. 7: Verification of optimality of proposed algorithm

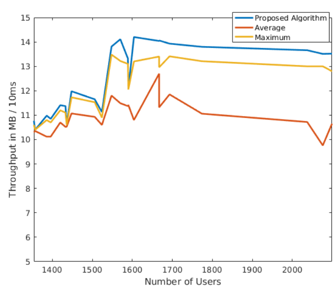

Fig. 8: Throughput comparisons of Avg, Max and proposed

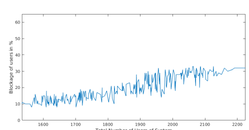

Fig. 9: Blockage for proposed algorithm wrt load

generating the UE in the cells for formulating test cases of our algorithm and comparison with existing ones. An instance of a macro cell having 3 pico cells inside it shown in 3 and all the three pico cells with their UE inside that macro are depicted in 4. A comparison of the theoretical with the practical results was undertaken for a total of 500 simulations and the results for the same are depicted in the figures 5 and 6. The graphs depict that the practical average SINR in case of the pico as well as the macro cells lie very close to the theoretical values which was established post a total of 500 simulations. After obtaining the optimal ABS density using our proposed algorithm we compared the total system throughput; to establish that the proposed algorithm was better than the existing Max and Average; we compared their system throughput values. It was observed that the system throughout was found to be highest at various loading conditions(shown in Fig 8). The blockage of the users with respect to loading conditions was checked later on (Fig 9)and the blockage was found to increase with the loading of the network/architecture.

VII. Conclusion

In the paper we calculated the expected number of users in the cell edge region. The SINR values and data rate for them were calculated based on which we were able to find the RBs required for them. Thereafter, we made the macro eNB smart enough to offer the optimal ABS density to its pico cells after analyzing the ABS density of all of them. We further compared the existing Min, Max and Average algorithms with our proposed one and found out that it gave better results. The optimal ABS values lie somewhat near to the median of all the ABS densities but as we have taken integral values it shifts from the median value as well. The optimal ABS density plays a key role here as it makes the macro eNB to decide to give or not to give sufficient RBs to a pico cell with the sole aim to increasing the system throughput in the overall scenario.

Acknowledgment

The authors would like to thank Prof. *C Siva Ram Murthy* for his guidance and mentor ship. He has not only aided in increasing our knowledge of the subject but have illuminated us with all the latest development. Further, the authors would like to make a special mention to supervision and direction provided *Mr. Vijeth J K* without which successful completion of the research would not have been possible.

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