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The Channel Capacity of a GSM Frequency Hopping Network with Intelligent Underlay-Overlay

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Abstract — **In this paper a complete step by step method is described to increase the capacity of Global System for Mobile Communication (GSM) using the Intelligent Underlay Overlay(IUO) with frequency hopping and Discontinuous Transmission (DTX). The IUO splits the available frequencies into two layers, super and regular. Super layer frequencies have tighter reuse factor and can be accessed by only mobile stations (MS) having good C/I ratio while the regular frequencies can be used by MS's throughout the cell. The most promising work of this paper is that C/I ratio (hence reuse factor) is obtained by considering the first tier co-channel cells are also using IUO network structure. Analysis is performed by taking some default parameters into account shows that capacity enhancement up to 31 percent can be obtained with respect to a normal frequency hopping network.**

Index Terms — **Carrier to Interference Ratio (C/I), Discontinuous Transmission (DTX), Global System for Mobile Communication (GSM), Grade of Service (GOS) and Intelligent Underlay Overlay (IUO).**

I. Introduction

At present, increasing the capacity of the cellular network with limited resources (like available spectrum or number of base stations) is one the most crucial problem for the network operators. The general approach towards increasing the capacity with limited spectrum is cell splitting, sectoring, hierarchical cell structure like micro and pico cells [1, 2], or multiple reuse patterns with frequency hopping [3]. But most of these involve additional network elements like base stations or transmission network-which costs a lot. The most desired solution is to increase the capacity with minimal investment while maintaining the quality of service (QoS). There are two possible solutions may be mentioned here such as Frequency hopping (FH), and Intelligent underlay overlay (IUO) which was first proposed by Nokia Telecommunications [4]. The idea behind IUO is to partition the channels into two groups with different frequency reuse factors. The MS's having good C/I ratio (better than a predefined threshold) will be assigned to the frequencies with tighter reuse factor which eventually enhances the capacity. The other frequency group with normal reuse factor provides the coverage. Several design methods have been proposed for the IUO. Some are well suited for networks without frequency hopping [4, 5, 7, 8]. In some papers, analysis was done by taking predefined value of reuse partitioning and channel assignment strategy [7, 9, 10]. Though the C/I ratio was considered in [5, 8, 10, 11] it was not a function of co-channel cells super area coverage factor. In this paper, an analytical approach has been taken considering that the C/I ratio is a function of super area coverage factor and carried traffic in co-channel cells. Hence, dynamic channel assignment strategy for a given Grade of Service (GOS) can be obtained. In analysis, it is also assumed that the network is large, homogeneous with symmetric traffic and using frequency hopping. At last the IUO model is compared with a normal cell considering some default parameters for performance evolution.

II. Principle of Intelligent Underlay Overlay (IUO) Scheme

The principle of IUO is that, the available radio frequencies are split in two groups, a super layer and a regular layer frequency group. The super frequencies are meant for the mobile stations with a good C/I, while the regular frequencies can be used by all MS's. A mobile station always starts on a regular frequency, because the C/I ratio of the call is not yet known. If this calculated C/I ratio is higher than a predefined C/I good threshold, the mobile is allowed to enter one of the super frequencies. If there is no available super frequency, the MS stays in the regular group but continue trying to enter the super layer. In the same way while the mobile station is already using a super frequency, it is continuously evaluated whether the C/I ratio is less than so called good C/I ratio, in that case the MS is handover to the regular frequencies. The IUO algorithm doesn't distinguish moving or non moving vehicles. It considers that a non moving vehicle will not try for handover while the moving vehicles will. And there will not be any direct handover from super to a neighbor cell. The handover rate from super to regular or regular to super are calculated in [7] considering the speed of MS, the coverage factor of the super layer, the radius of the cell, the probability that the MS will move in a direction to increase or decrease the C/I ratio.

III. Modeling assumptions

A model is considered for the analysis. The assumptions taken for modeling is described here,

- A single cell is taken into considerations for the sake of simplicity. It is also considered that the amount of incoming handover is equal the amount of outgoing traffic from the cell. However the model kept the opportunities to consider this. It is advised that in the practical case it should be considered.
- The source of traffic is uniformly distributed throughout the cell.
- For a particular coverage factor same reuse factor is considered for all the super layer frequencies.
- Number of super channel is SC and regular channel is RC. Any time the amount of occupied channel in regular layer is R_{reg} and occupied channel of regular but residing in the super is R_{sup}. The number of super channel occupied is Sup.
- The ratio of moving MS is Rmv.
- The moving MS are assumed to move uniformly in a random direction with a velocity Vms
- New call arrival rate is assumed to be a Poisson process with arrival rate .
- The total incoming handover rate is λ_h and outgoing is $R_{reg}.\mu_{hout}$
- The time needed to calculate the C/I ratio is exponentially distributed with mean $\frac{1}{\mu_{cal}}$.
- The call holding time is assumed exponentially distributed with mean $\frac{1}{\mu_t}$.
- The channel dwell time is exponentially distributed with mean $\frac{1}{\mu_{hout}}$.
- The time needed for a moving vehicle to move from a super to regular area or regular to super is exponentially distributed random variable with mean value $\frac{1}{\mu_{sup-reg}}$ and $\frac{1}{\mu_{reg-sup}}$ which is given in [7]

IV. Equilibrium model

The model described here utilizes the fact that for certain amount of traffic in the super and regular layer, the sum of call termination rate and call blocking rate (GOS given by the operator) will be equal to call arrival rate. Hence at maximum traffic carrying condition there will be an equilibrium state. Channel allocation and suitable coverage factor will be calculated from there. From fig 1, we find the maximum carried traffic for blocked call rate B,

$$\lambda.cov + Rreg.\mu_{reg-sup} - Rsup.\mu_t - Rsup.\mu_{cal} - B.\lambda.cov - Rsup.\mu_{sup-reg} = 0 \quad (1)$$

$$\lambda.(1-cov) + \lambda_h + sup.\mu_{sup-reg} + Rsup.\mu_{sup-reg} - Rreg.\mu_{reg-sup} - Rreg\mu_t - Rreg\mu_{hout} - B\lambda(1-cov) = 0 \quad (2)$$

$$Rsup.\mu_{cal} - sup.\mu_{sup-reg} - sup.\mu_t = 0 \quad (3)$$

Solving equation 1, 2, and 3 $Rreg, Rsup$ and sup can be found.

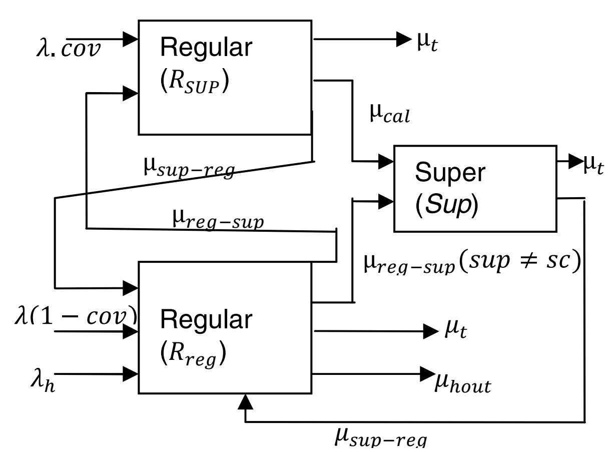

Fig 1. Equilibrium model of IUO cell

TABLE I
TRANSITION RATE [7]

Event	Rate
New Call in regular layer	$(1-cov).\lambda$
New call in super layer	$cov.\lambda$
Incoming handoff	λ_h
Good SIR calls	$R_{sup}\mu_{cal}$
Super to regular	$sup.\mu_{sup-reg}$ $R_{sup}.\mu_{sup-reg}$
Soft blocking	$sup.\mu_{sup-reg}$
Regular to super	$R_{reg}.\mu_{reg-sup}$
Call terminating	$R_{reg}.\mu_t$ $R_{sup}.\mu_t$ $sup.\mu_t$
Outgoing handoff	$R_{reg}.\mu_{hout}$

V. DESIGN PROCEDURE

The design procedure is described with the flow chart in fig 2.

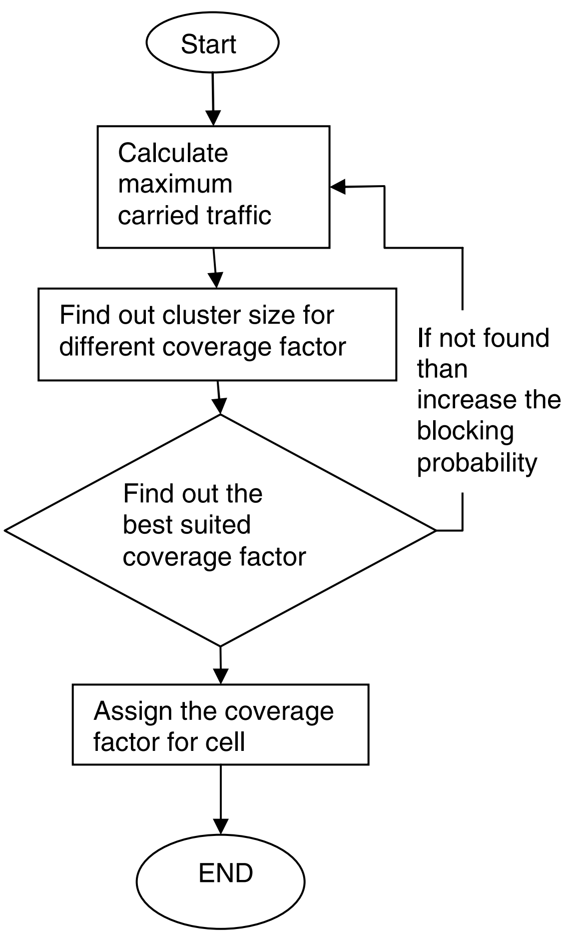

Fig. 2. Design procedure with flow chart

A. Calculation of traffic

The maximum traffic can be calculated from section IV. Here it is noticeable that *sup* =SC. All the other values are different for different cells and can be estimated by field measurement.

B. Cluster size

It is assumed that the users are uniformly distributed, hence the probability that a user using a slot in a carrier in a frequency hopping network is uniformly distributed [12]. In a simple cell this distribution of user is extended over the area with radius 0 to R. In a model like IUO and coverage factor cov distribution will take place in two different areas. For super the users are distributed from 0 to cov.R. In case of regular layer a fraction of regular layer user $Rsup$ resides in super layer area. And the other are distributed in regular layer area $Rreg$. So the average interference power present in BTS due to super frequency user sup in j th cell will be [11].

$$E[Y_j] = \frac{S}{\pi(cov.R)^2}\int_0^{cov.R}\int_0^{2\pi}\left(\frac{r}{d_j}\right)^{\alpha} E\left[10^{\frac{\zeta}{10}}\right] rdrd\varphi$$

And for regular frequency user $(Rsup + Rreg)$ this will be a conditional case as the frequency hopping takes place. So the average interference power will be

$$E[Y_j] = \left(\frac{R_{sup}}{R_{reg}+R_{sup}}\right).\frac{S}{\pi(cov.R)^2}$$

$$.\int_0^{cov.R}\int_0^{2\pi}\left(\frac{r}{d_j}\right)^{\alpha}.E\left[10^{\frac{\zeta}{10}}\right].rdrd\varphi +$$

$$\left(\frac{R_{reg}}{R_{reg}+R_{sup}}\right).\frac{S}{\pi(R-cov.R)^2}\int_0^{cov.R}\int_0^{2\pi}\left(\frac{r}{d_j}\right)^{\alpha}.$$

$$E\left[10\,\frac{\zeta}{10}\right] rdrd\varphi$$

Here d_j is the distance between MS in j th cell and BTS. It

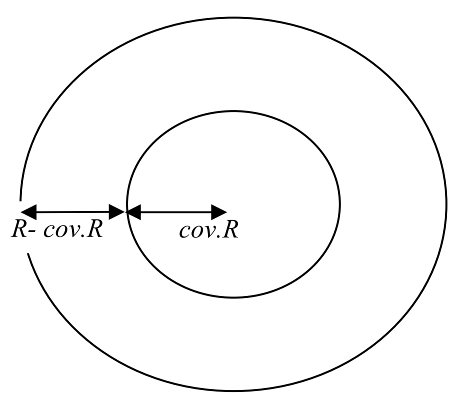

Fig. 3. IUO cell

is a function of cell radius, coverage factor cov and cluster size. Now, the C/I ratio at the BTS for uplink transmission (assuming reciprocity) will be,

$$C/_I = \frac{S}{\mu \sum_{j=1}^{6} E[\gamma_j]}$$

Where µ is the voice activity factor (VAF), which allows discontinuous transmission (DTX) to include in the model. To model the IUO for the worst case we considered here VAF=1. For various coverage factors cov and to maintain a minimum level of C/I ratio which is predefined by operator, we will get different cluster size. However, in the case of co-located overlay and underlay cell, Broadcast Control Channel (BCCH) is carried by a regular frequency [4], hence, this BCCH should be kept clean as much as possible. It is the next problem to allocate frequency to super and regular layer so that none them is allocated more or less with respect to expected carried traffic.

C. Optimization

First the required number of frequency is estimated considering for a given GOS. The frequencies are allocated considering that regular layer frequencies consist of 7 TCH, and super layer consist of 8 [7].Then a graph is plotted for required total frequency vs. offered traffic. From the curve a minimum point can be achieved which best fulfills the offered traffic and power management.

VI. Analytical Result

To observe the practical outcome of the proposed model, we analyzed a cell with some default configurations. The objective is to provide adequate frequency for super and regular layer. If there is not enough frequency, to the GOS has to be increased or the available frequency should be increased which is not desired or cost effective. The default parameters are presented in Table 2 and the results are analyzed in subsequent graphs.

TABLE 2
ANALYSIS ASSUMPTION PARAMETERS

Parameters	Values
Call holding time	80sec.
Cell radius	3km
Ratio of moving MS	50%
Speed of moving MS	50km/hr
The path loss exponent,	4
The standard deviation of shadow fading,	8
Voice activity factor, µ	1
Blocked call rate, b	5%
Threshold level	12db

The resultant graphs show that for different values of cov the C/I ratio for MS in super frequencies decreases as the cov increases.

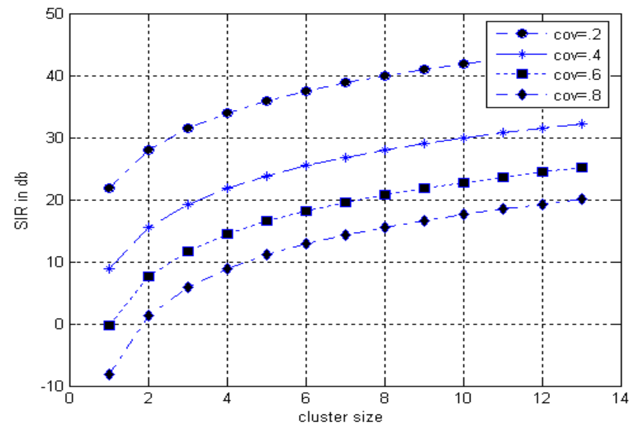

Fig. 4. Uplink SIR versus super layer cluster size at different super area coverage factor

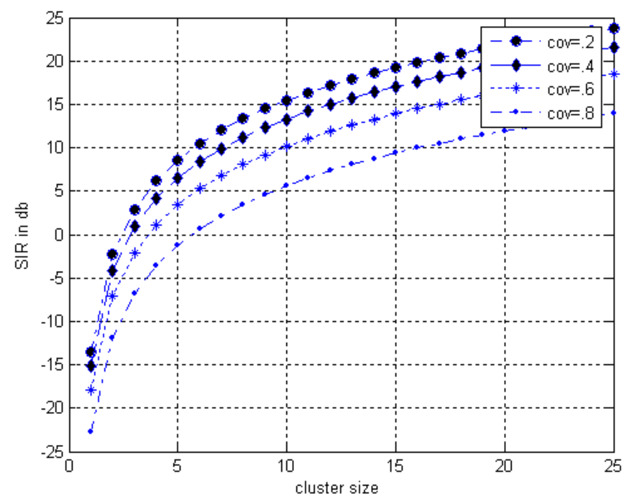

Fig. 5. Uplink SIR versus regular layer cluster size at different super area coverage factor

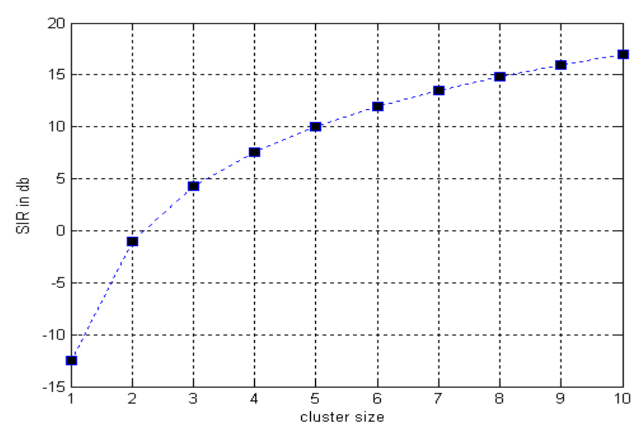

Fig. 6. Uplink SIR versus cluster size for a normal cell

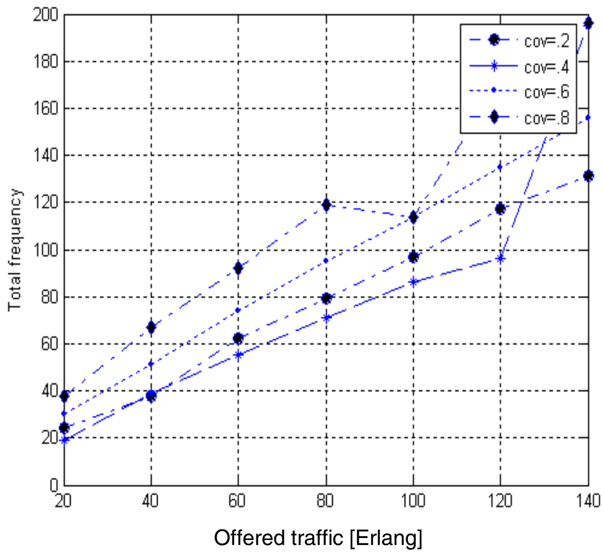

Fig. 7. Total channel versus offered traffic for different super area coverage factor

The same result for regular is obtained. Hence the cluster size increases as cov increases. This was expected because as the cov increases more and more MS spread throughout the cell. Hence the MS comes into more vicinity to neighbor co-channel BTS, hence the interference power increases thus the C/I decreases. Another thing is that different number of frequencies is required to meet the GOS for different cov. A careful observation is necessary before allocating frequencies. A handoff between the amounts of simultaneous subscriber served in a cell and the number of frequencies available to operator is to be considered. Performance improvement will depend completely upon the efficient partitioning of available frequency and maintaining the minimal threshold of C/I at the same time. By assuming lost call cleared system, it is seen that the capacity is increased up to 31% with respect to the FH GSM network. If the cluster size is not taken some discrete values like 3,7,12 $(i^2 + ij + j^2)$ etc, more enhancement can be found.

VII. Conclusion

This paper focused on designing Intelligent Underlay Overlay (IUO) scheme and optimization of capacity without compromising the Quality of Service of a cellular network. The analysis results characterize the effect of IUO on the performance of a cell as a function of the coverage factor, offered traffic, the mobility of MSs, QoS and GOS. The proposed model indicates that significant capacity enhancement can be achieved with increased complexities of frequency partitioning and network optimization.

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