An Analytical Approach to Enhance the Capacity of GSM Frequency Hopping Networks with Intelligent Underlay-Overlay

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Abstract— **Intelligent Underlay Overlay (IUO) scheme is one of the most cost effective solution for capacity enhancement of Global System for Mobile Communication (GSM). However, the overall gain from this type of complex architecture depends on how efficiently it is designed and available radio resources are utilized. This paper proposes a step by step process to design IUO in order to optimize the gain. Here, the network configurations are determined analytically and a traffic model is developed to estimate the traffic distribution among different layers of IUO cell. Equations for frequency reuse in each layer are derived and Frequency Hopping (FH), Power Control (PC) and Discontinuous Transmission (DTX) are integrated. Effect of various parameters on cluster sizes is studied. It is found that for some cases it is better to utilize the advantages from FH rather than IUO when these features are combined. Several factors are taken into consideration during design phase like co-channel cells, super area coverage, traffic distribution, ratio and speed of moving vehicles, blocking probability intended by operator etc. Finally an IUO cell is designed which shows 41.42% capacity enhancement over normal cells having similar features and resources.**

Index Terms—**Carrier to interference ratio (C/I), Frequency Hopping, Global System for Mobile Communication (GSM), Grade of Service (GoS), Intelligent Underlay Overlay, Cluster Size, Signal to Interference Ratio (SIR).**

I. INTRODUCTION

Despite of limited spectrum, GSM cellular system has met tremendous growth over the past years and the demand for radio resources is continuously increasing. Several techniques have been explored to enhance the system capacity like cell splitting, reuse partitioning, sectorisation, intelligent underlay overlay (IUO), hierarchical cell structure etc [1]-[6]. In IUO the available frequencies are divided into super and regular layer frequencies. Super frequencies which form the under layer are heavily reused and enhance the capacity. The over layer is formed by regular frequencies which is used throughout the cell and provides the coverage. Since only frequencies have to be redistributed and no additional base station (BS) sites are required IUO can be implemented with minor investment. Furthermore, existing network features like discontinuous transmission (DTX), frequency hopping (FH), power control (PC) can be integrated to achieve higher capacity gain. However, it is necessary to efficiently distribute the limited radio resource among different layers and utilize available network features in order to obtain optimum capacity gain.

Several works on IUO can be found in literature. A comprehensive description of IUO functionality is given in [2], [6]. It has been theoretically shown in [8-9] that, how capacity gain can be obtained if Underlay-Overlay scheme is used. In [2], [11], [12] IUO was modeled and analyzed with a GSM network simulator CAPACITY. Enhancement up to 35% was found in [11] and up to 50% was obtained in [12]. However the model incorporated sectored cells and the ratio of moving and non moving mobile stations (MS) was not considered. Since the stationary users will not urge for intra-cell handover as much as moving users, this ratio has a significant impact on overall blocking. The results found in [11] shows that the capacity gain is decreased from 35% to 26% percent for high speed MS. In [7] the performance of IUO was analyzed by assuming a continuous time Markov chain model. A design method was proposed in [13] to implement IUO based on simulation tool NPS/X. However, the required cluster size of each layer was not considered. As the operators

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have limited spectrum these cluster sizes play a vital role in design process.

It can be seen from above that most of the analysis are done based on computer simulation rather than analytical methods. Analytical methods are useful in reducing computational time, simulation effort and more practical for implementing dynamic algorithms. In this paper we propose an analytical method to design IUO according to available resources and operator's demand. To avoid potential deadlock condition where all the channels in regular layer are occupied while some channels in super are free, the super layer area is largely varied by varying the cluster size of super and regular layer. Moreover, the cluster sizes are calculated not only taking into account the co-channel cell's super area coverage but also the traffic distribution. Thus more realistic design can be achieved.

The rest of the paper is organized as follows. Section II describes the origin and operation of IUO. Section III describes the design steps. Section IV explains the traffic model and assumptions. Section V gives cluster size calculation and results at various cell conditions. Section VI studies the effect of different parameters. Section VII compares the results and integrates improvements. Last of all conclusion is given in Section VIII.

II. Origin and Functionality of IUO

A. Origin

At first, IUO concept was introduced by Nokia Telecommunications and network operator CSL from Hong Kong [2]. The idea behind this is reuse partitioning which is presented in [4], [5]. Intra-cell handover between two layers of different reuse partitions forms the underlay-overlay design. In the primary stage of underlay-overlay networks, the decision of intra-cell handover was triggered by measuring signal strength and/or distance between MS to BS [14], [16]. The main disadvantage was ambiguity in determining threshold signal levels at which the handover should take place. It is because every location in each cell has its own radio path properties. In case of IUO, handover decision takes place by measuring C/I (carrier to interference ratio) experienced by the mobile stations. This allows the network operators to determine a more generalized threshold level at which the intra-cell handover should take place.

B. Principles of IUO

In IUO, a mobile station always starts on a regular frequency and constantly evaluates if C/I ratio is above a threshold. If the calculated C/I ratio is higher than a predefined C/I good threshold, the mobile is hand over to one of the super frequencies. If there is no available super frequency, the MS stays in the regular frequency but continues trying to enter the super layer. When 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. Hence usually a non moving vehicle will not try for intra-cell handover and there will not be any direct inter-cell handover from super to a neighbor cell. Regular layer frequencies can be occupied by any mobiles throughout the cell thus it provides the coverage while the super layer enhances the overall capacity. In Figure 1 an IUO cell has been depicted where super layer users are extended from center to $cov.R$. Here, R is the cell radius and cov is the coverage factor of super layer.

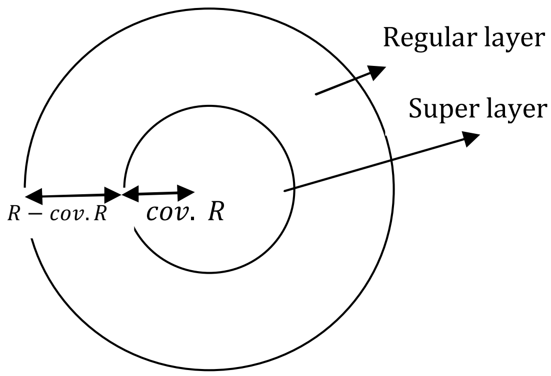


Figure 1. IUO cell

III. Design procedure

To design an IUO cell the following steps are taken. In the beginning, total available frequency and Grade of Service (GoS) intended by operator is acquired. The traffic distribution among different layers of cell and cluster sizes at different coverage factors is determined. For certain offered traffic and super frequency allocation corresponding hard blocking is calculated. Then the offered traffic is increased and the whole process is repeated until the blocking probability is equal to given GoS. When this condition is satisfied, the network configuration for maximum gain provides the optimized IUO design. It is mentionable that in this paper traffic distribution is assumed as uniform distribution which is not true in the practical case. So, the suitable coverage factor will be that factor in which maximum gain will be achieved but deadlock conditions will not arise. The design processes are summarized in Figure 2. Details of the implementation of these steps are described in subsequent sections.

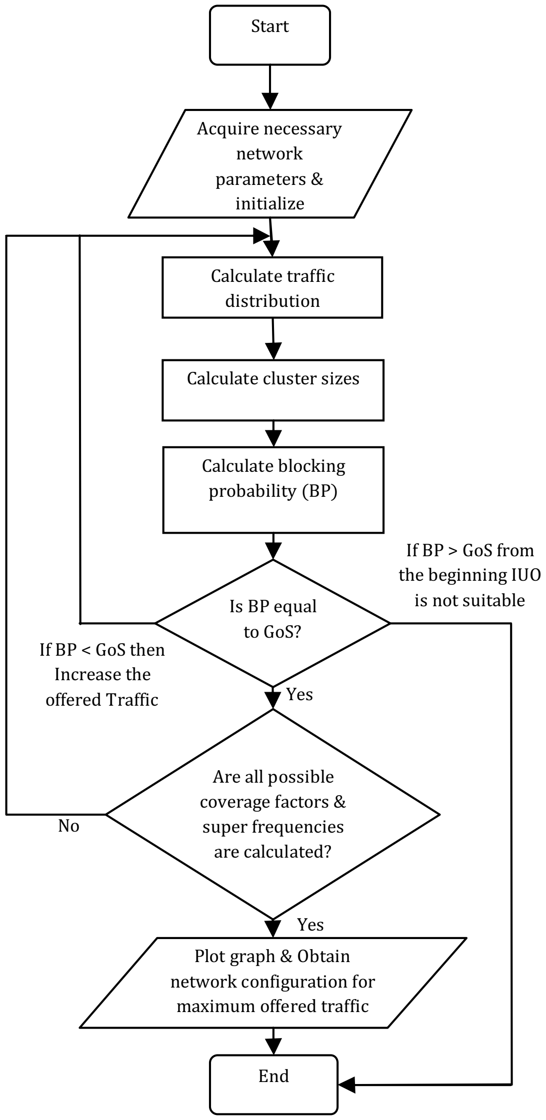


Figure 2. Design flow of IUO

IV. TRAFFIC DISTRIBUTION MODEL & ASSUMPTIONS

A model is developed to analytically estimate the traffic distribution in an IUO cell. We utilize the fact that for certain amount of offered traffic, call arrival rate will be equal to the sum of call termination rate and call blocking rate. Thus an equilibrium state will appear and solving the system of nonlinear equations which evolves for this condition, the carried traffic in each layer can be found. At optimized design super channels will be occupied before all channels in the regular layer become busy. And when super layer channels become busy most of the moving vehicles with good C/I will reside in the regular channels but try to access super layer from there. Several assumptions are made to make the analytical approach simpler. Call transition rates of Table I between super and regular layer and assumptions related with transition rates are taken from [7]. The assumptions for this model are,

i. The network is large, homogenous. A single cell is taken into considerations where the source of traffic has uniform distribution in respective layers.
ii. The ratio of moving MS is Rmv and they move uniformly in a random direction with a velocity Vms
iii. Regular layer and normal cell frequencies consist of 7 TCH while super frequencies are of 8 TCH. One slot in regular frequencies is kept for BCCH. Number of super channel per cell is Ns and regular channel is Nr
iv. Carried traffic in super frequencies are sup and regular frequencies are $Rsup + Rreg$ where $Rsup$ is residing in super area.
v. New call arrival rate is assumed to be a Poisson process with arrival rate λ. The channel dwell time is exponentially distributed with mean $\frac{1}{\mu_{hout}}$
vi. The total incoming handover rate is Poisson process λ_h and outgoing rate is $R_{reg}.\mu_{hout}$. It is assumed here that the aggregate incoming handover traffic is equal to outgoing traffic and has same characteristics. However, these values can be obtained from database during practical implementation.
vii. The time needed to calculate the C/I ratio is exponentially distributed with mean $\frac{1}{\mu_{cal}}$
viii. It is shown in [7] that the soft blocking has minor effect on overall blocking rate. When offered traffic is large soft blocked traffic is very small compared to $Rreg$ and it is ignored during cluster size estimation.
ix. 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 $\frac{1}{\mu_{reg-sup}}$
x. Considering all layers, the call holding time is assumed to be exponentially distributed with mean $\frac{1}{\mu_t} = Th$

Various transitions take place among different portion of the cell is depicted in Figure 3. Due to hard blocking B which is the intended GoS not all offered calls will be served. As the number of channels in super layer is kept limited, not all good traffic will be able to access the super layer. The blocking of this good traffic is given by $E(Ns, Rsup.\mu_{cal}.Th)$ where $E(a,b)$ is the Erlang blocking probability for b traffic offered to a number of channels. The parameter $Rsup.\mu_{cal}$ can be thought of as Poisson distribution as the carried traffic $Rsup$ is multiplication of effective Poisson arrival rate and exponential call holding time. The governing equations of the system are,

$$\lambda.cov.(1-B) + Rreg.\mu_{reg-sup} - Rsup.\mu_t - Rsup.\mu_{cal}.\left(1-E\left(Ns, Rsup.\mu_{cal.}Th\right)\right) - Rsup.\mu_{sup-reg} = 0 \quad (1)$$

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

$$Rsup.\mu_{cal}.\left(1-E\left(Ns, Rsup.\mu_{cal.}Th\right)\right) - sup.\mu_{sup-reg} - sup.\mu_t = 0 \quad (3)$$

Solving equation 1, 2, and 3 simultaneously, traffic distributions among super and regular layer can be found.

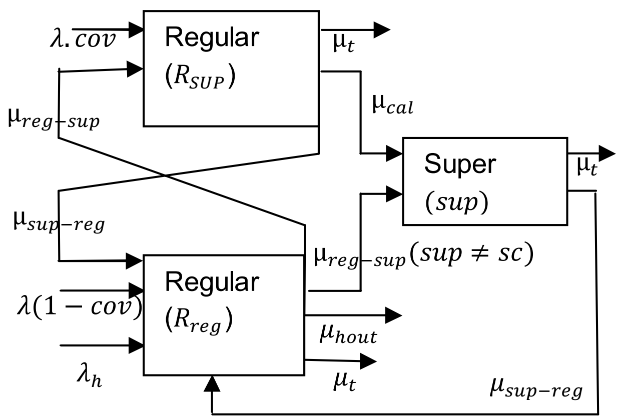


Figure 3. Traffic behavior in IUO

TABLE I.
TRANSITION RATES [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. CLUSTER SIZE CALCULATION

It is mainly the C/I i.e. received Signal to co-channel Interference Ratio (SIR) which limits the frequency reuse thus determines the cluster size. Cluster sizes of conventional normal cells are given in [15]. In this paper we derived the equations for cluster size of IUO cell based on that. As this paper focuses on generalizing a design method for IUO, omnidirectional BS antenna is considered here. However, in case of sectorised cells the calculation of SIR can be obtained by same way as derivations are obtained here. During SIR computation, the following assumptions are made

i. FH (frequency hopping) and PC (power control) are applied.
ii. Discontinuous transmission (DTX) with voice activity factor μ is introduced.
iii. Traffic distribution of regular layer is obtained from section IV.
iv. GSM radio link is able to combat the effect of fast fading by means of its channel coding, bit interleaving, channel equalization and signal processing sub-systems.
v. The radio channel is subjected to log-normal shadow fading and path losses.

A. Cluster sizes for Uplink transmission

Let's consider a MS occupying an area da (Figure 4), at a distance r from BS. Power transmitted by the MS

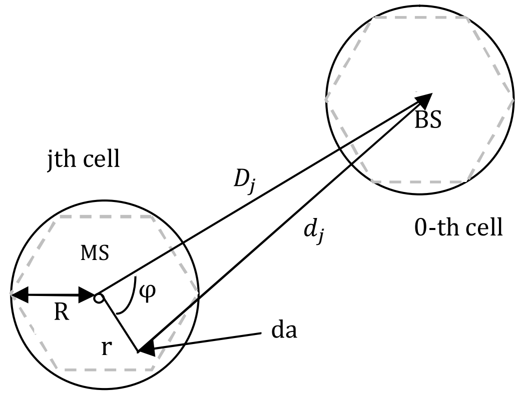


Figure 4. A MS in the *j*th cell interfering with the zeroth BS in uplink transmission

is P_T such that received power at jth BS is S. So,

$$P_T = Sr^{\alpha}10^{-\lambda_j/10}$$

Here, α is the path loss exponent (dB) and λ_j is the shadowing random variable for path r. This power causes interference at the zeroth BS. The actual interference depends on the distance d_j between the MS and zeroth BS where,

$$d_j = \sqrt{(D_j{}^2 + r^2 - 2D_j r cos\varphi)}$$

Hrere, $D_j$is the distance between co-channel cells and proportional to cluster sizes.

The interference due to the MS in the *j*th cell is,

$$I_j = P_T d_j^{-\alpha} 10^{\lambda_0/10}$$

If λ_0 is shadowing random variable in path d_j, Substituting P_T we get,

$$I_j = S\left(r/d_j\right)^{\alpha} 10^{\zeta/10}$$

Where $\zeta = (\lambda_0 - \lambda_j)$.

In a special architecture like IUO the distribution of MS is different for MS in super and in regular layer. Super layer users are uniformly distributed from 0 to $cov.R$ as shown in the Figure 5.

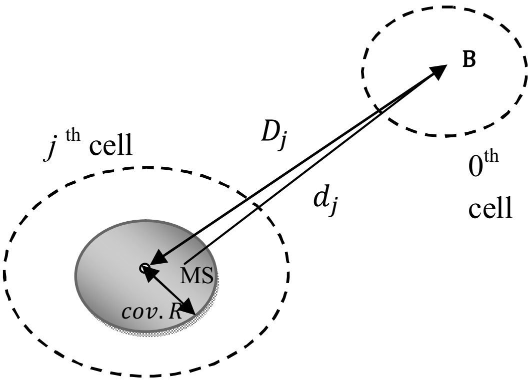


Figure 5. A MS in the super layer (*j*th cell) interfering with the zeroth BS

Now, the probability that a MS will be using a time slot in a carrier f_i is equal to $f(a)da$. Where $f(a)$ is the probability distribution function (PDF) and since users are uniformly distributed it will be equal to $1/\pi(cov.R)^2$ [17]. The network incorporates FH hence the average interference power present in 0th BS due to super frequency traffic sup in *j*th cell will be

$$E[Y_j] = S\iint_{Cell\ area}\left(\frac{r}{d_j}\right)^{\alpha} E\left[10^{\frac{\zeta}{10}}\right] f(a)da$$

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

Where E $[10^{\zeta/10}]$ is calculated by the following equation

$$E\left[10^{\zeta/10}\right] = 1.023exp\left(\frac{\sigma ln(10)}{10}\right)^2\frac{\sqrt{2}\sigma}{(4\pi\sigma^2)^{1/2}}$$

$$\int_{-4-\sqrt{2}\sigma ln10/10}^{2-\sqrt{2}\sigma ln10/10} exp\left(-\frac{x^2}{2}\right)dx$$

and da substituted by $rdrd\varphi$. Assuming six co-channel neighbors, the SIR at the 0th BS for uplink transmission will be the ratio of received signal and sum of all interfering signals. Thus,

$$S/I = \frac{S}{\mu\sum_{j=1}^{6} E[Y_j]} \quad (4)$$

In case of regular layer, a portion of regular layer traffic $Rsup$ resides in super layer area and the rest of them $(Rreg)$ reside in regular layer area as shadowed in Figure 6.

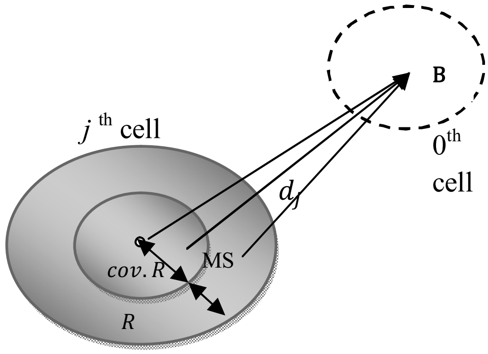


Figure 6. A MS using the regular frequency and interfering with the zeroth BS. It might reside in super area or outside of it

So the average interference power will be a joint distribution of both segments with conditional probability of channel occupation. The probaility of of a call ongoing in super area is $\left(\frac{R_{sup}}{R_{reg}+R_{sup}}\right)$ and regular area is $\left(\frac{R_{reg}}{R_{reg}+R_{sup}}\right)$ Hence the average interference power will be,

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

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

$$\left(\frac{R_{reg}}{R_{reg}+R_{sup}}\right)\cdot\frac{S}{\pi(1-cov^2).R^2}\int_{cov.R}^{R}\int_0^{2\pi}\left(\frac{r}{d_j}\right)^{\alpha}.$$

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

The SIR can be found from equation 4

B. Downlink transmission

The amount of power transmitted by BS is determined by the location of MS in that cell. Thus SIR on the downlink is both dependent upon the location of an MS in j^{th} cell and loacation of MS in 0th cell which are occupying the same frequency. For conventional normal cells depicted in Figure 7. Let, the distance between a cell site and the apex of hexagonal cell is R. The average transmitted power of j^{th} BS will be,

$$P_{jnor} = \frac{2S}{R^2}\cdot\int_0^R r_j^{\alpha+1}10^{-\lambda_j/10}dr_j$$

MS is interfered by jth BS of jth cell. Hence the average interference at location (r,φ) of 0th cell is

$$I_{jnor} = P_{jnor}10^{\lambda_0/10}d_j^{-\alpha}$$

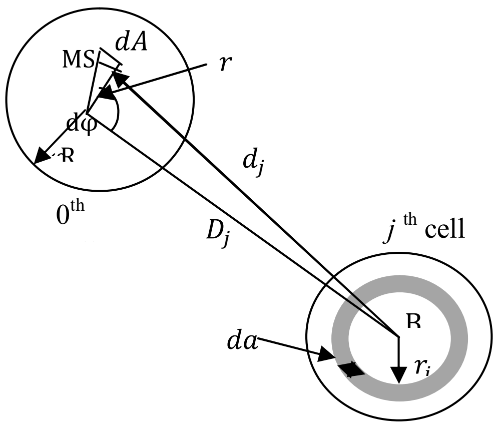


Figure 7. BS in the j^{th} cell interfering with the zeroth MS

Due to frequency hopping,

$$\mathrm{E}\left[I_{jnor}\right] = \frac{2S}{R^2}.\int_0^R r_j^{\alpha+1} d_j^{-\alpha} E[10^{\zeta/10}]dr_j$$

And average interference throughout 0th cell is,

$$E\left[\gamma_{jnor}\right] = \int_0^R \int_0^{2\pi} \mathrm{E}\left[I_{jnor}\right] \frac{1}{\pi R^2} r d\phi dr$$

For normal cell the cluster size is approximatly 7 for 12dB threshold as given in [15]. In this paper the equations for calculating cluster sizes hence reuse factor of super and regular layer are derived. As described before super layer users in IUO are no longer distributed from 0 to R but from 0 to $cov.R$. So, the average transmitted power is,

$$P_{jsup} = \frac{2S}{cov^2 R^2}.\int_0^{cov.R} r_j^{\alpha+1} 10^{-\lambda_j/10} dr_j$$

And, the average interference power is

$$\mathrm{E}\left[I_{jsup}\right] = \frac{2S}{\pi cov^2 R^2}.\int_0^{cov.R} r_j^{\alpha+1} d_j^{-\alpha} E[10^{\zeta/10}]dr_j$$

The average interference for super layer is,

$$E\left[\gamma_{jsup}\right] = \int_0^{cov.R} \int_0^{2\pi} \mathrm{E}\left[I_{jsup}\right] \frac{1}{\pi cov^2 R^2} r d\phi dr$$

For regular layer, some of the traffic is in super area while the others are in regular area. So the average transmitted power,

$$P_{jreg} = \frac{2S}{R^2} 10^{-\lambda_j/10}.[\frac{R_{sup}}{cov^2\left(R_{reg}+R_{sup}\right)}.\int_0^{cov.R} r_j^{\alpha+1}\, dr_j + \frac{R_{reg}}{(1-cov^2).\left(R_{reg}+R_{sup}\right)}\int_{cov.R}^{R} r_j^{\alpha+1}\, dr_j]$$

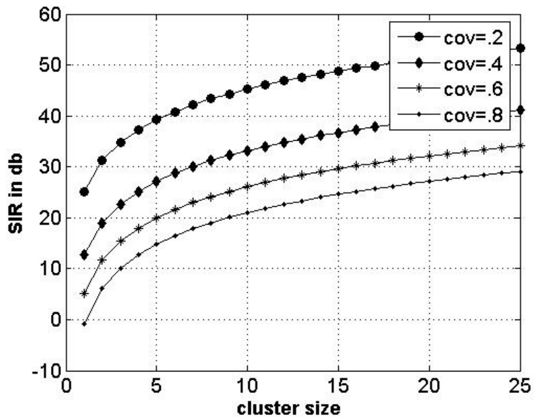


Figure 8. Downlink SIR versus cluster size of super layer for different super area coverage factor

So the total average interference is,

$$\mathrm{E}\left[I_{jreg}\right] = \frac{2S}{R^2}.E\left[10^{\zeta/10}\right].[\frac{R_{sup}}{cov^2\left(R_{reg}+R_{sup}\right)}.\int_0^{cov.R} r_j^{\alpha+1}\, d_j^{-\alpha} dr_j + \frac{R_{reg}}{(1-cov^2).\left(R_{reg}+R_{sup}\right)}\int_{cov.R}^{R} r_j^{\alpha+1}\, d_j^{-\alpha} dr_j]$$

And the average is,

$$E\left[\gamma_{jreg}\right] = \frac{R_{sup}}{\pi(cov.R)^2\left(R_{reg}+R_{sup}\right)}.\int_0^{cov.R}\int_0^{2\pi} \mathrm{E}\left[I_{jreg}\right].rdrd\phi + \frac{R_{reg}}{\pi(1-cov^2)\left(R_{reg}+R_{sup}\right)R^2}.\int_{cov.R}^{R}\int_0^{2\pi} \mathrm{E}\left[I_{jreg}\right]rdrd\phi$$

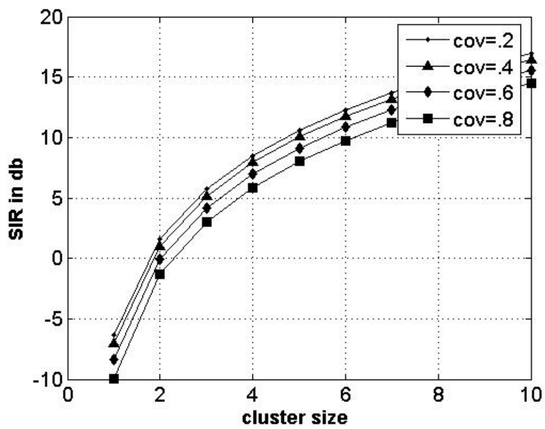


Figure 9. Downlink SIR versus cluster size of regular layer for different super area coverage factor

From Figure 8 it is found that the cluster size for super layer at SIR threshold 12dB is within 4 which represents tighter reuse factor than the normal cell. But for the regular layer which has characteristics like normal cell the cluster size is almost 7 as found from Figure 9. The default network parameters used during cluster size estimation are given in Table II. Regular and super layer traffic can be obtained from section IV.

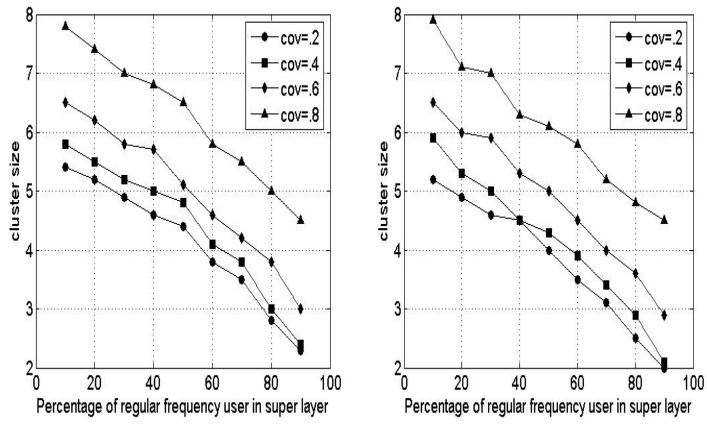
TABLE II.
ANALYSIS ASSUMPTION PARAMETERS

Parameters	Values
Call holding time	80sec.
Cell radius	3km
Ratio of moving MS	50%
Speed of moving MS	50km/hr
The path loss exponent, α	4
The standard deviation of shadow fading, σ	8
Voice activity factor, μ	1
Grade of Service, B	5%
Threshold level	12db
Available frequency spectrum	15 MHz

VI. Effect of Variation of Different Parameters

A. Varying percentage of regular frequency user in super layer

If the percentage of regular frequency user in super layer is increased, cluster size of regular layer decreases as depicted in Figure 10. As regular frequency user in super area increases, FH gives better advantage by averaging the interference power. It is shown in section VII that increasing the number of heavily reused frequencies which is the mechanism of IUO doesn't mean the capacity will also increase. So there must be a tradeoff between them.

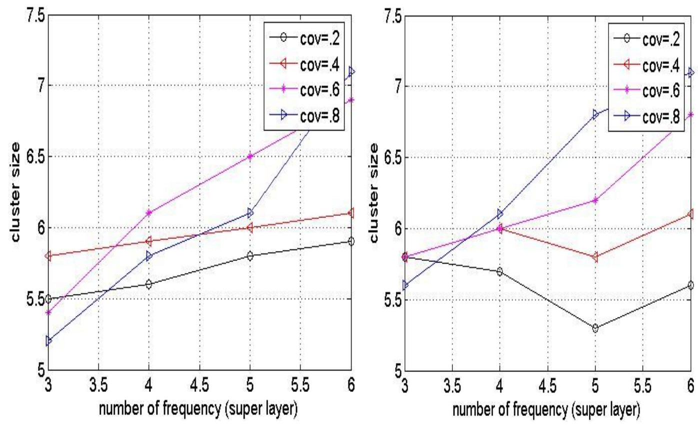


(a) (b)

Figure 10. Cluster size of regular layer for different percentage of regular frequency user in super layer (a) at uplink transmission & (b) at downlink transmission.

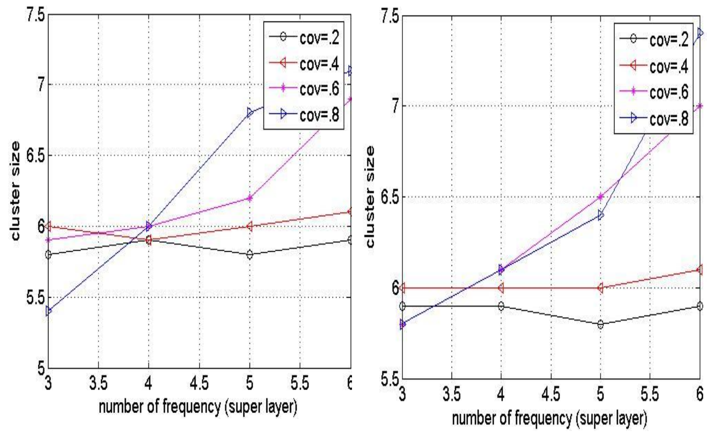
B. Varying speed and ratio of moving vehicles

The ratio and speed of moving MS has significant impact on cluster size. The effects of these parameters are shown in Figure 11-12 using downlink transmission. If the speed and ratio of moving MS increases, the regular layer user in super area also increases. Hence the cluster size usually decreases. But increasing the number of super frequency means fewer regular frequency users in super area which increases the cluster size of regular layer.



(a) (b)

Figure 11. Cluster sizes at .5 ratio of moving vehicles and speed is (a) 3km/h & (b) 50km/h



(a) (b)

Figure 12. Cluster sizes at .2 ratio of moving vehicles and speed is (a) 3km/h & (b) 50km/hr

VII. Performance Comparison

A: Performance of IUO

We compared the performance of IUO cell with a normal cell that has same resources and network features. The default parameters taken during design process are given in Table II. The blocking probability is calculated in terms of hard blocking and assuming lost calls cleared (LCC) system. Erlang B formula is applied for estimating the capacity of normal cell for a given GoS. The blocking probability for IUO is estimated according to equations derived in [10]. Super frequencies per cell are assumed with minimum three frequencies (in order to allow frequency hopping) to maximum six frequencies (to avoid potential deadlock conditions). And the regular frequency per cell $n_{regular}$ is calculated by,

$$n_{regular} = \lfloor (N - n_{super} \times S_{reuse})/R_{reuse} \rfloor \qquad (4)$$

Where N is the total number of frequency, n_{super} is super frequency per cell, S_{reuse} and R_{reuse} is super layer and regular layer reuse factors respectively. All cluster sizes are obtained by method described in section IV-V and considering downlink transmission. Cluster sizes are usually discrete values which satisfy the equation $M = (i^2 + ij + j^2)$ as described in [1]. By assuming minimum 12 db SIR it is found that maximum 70 Erlang traffic can be accommodated in conventional normal cell with 15 MHz and 5% blocking probability. For different configurations of IUO the maximum offered traffic at 5% blocking probability is plotted in Figure 13.

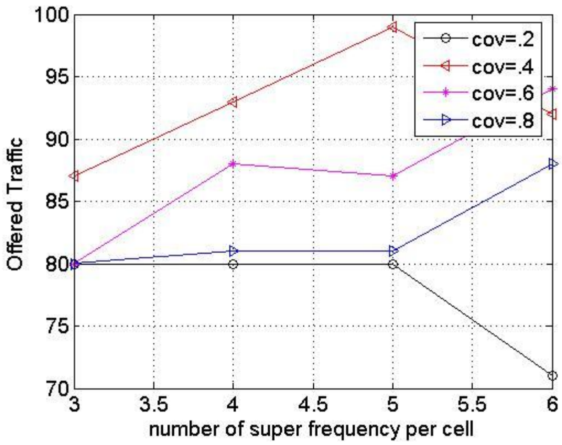


Figure 13: Offered traffic vs. allocated super frequency

It can be seen from above figure that, at .4 coverage factor and 5 frequencies allocated in super layer a maximum offered traffic of 99 Erlang can be accommodated with 5% blocking. So 41.42% capacity gain is achieved here. The graph represents some characteristics of IUO that increasing the number of super frequency doesn't mean it will also increase gain and too much or too high coverage factors can also degrade the performance. The tradeoff between advantages from FH and advantage from tighter reuse of super frequencies can be optimized by plotting this kind of graphs and taking the maximum points. However, as the gain is function of all parameters like available frequency spectrum, offered traffic, speed and ratio of moving MS, minimum threshold level, blocking probability etc. the enhancement will vary as per network operators' requirements, resources and traffic characteristics.

B. Improvement

It is proposed in [11] and shown in [2], [12] that changing some functionality of IUO can improve the performance more. These are direct access to super layer and reserving one or more time slot of regular frequency for super to regular layer handover. In direct access to super layer users with good SIR can access the super layers frequencies directly. Here, after the mobile is switched on it won't be necessary to go into super layer through regular frequencies but MS's will be assigned super frequencies when SIR is above threshold. To allow these modifications in traffic distribution few things have to be changed during design of IUO. Now $\lambda.cov$ arrival rate will be offered to super layer. The hard blocking model for direct access to super layer is given in [2] from which the blocking probability has to be calculated. In equation 4, ceiling function was used hence there is possibility of having some extra channels which were not taken into account during performance evaluation. These extra channels can be dynamically allocated and reserved for super to regular layer handover.

VIII. CONCLUSION

In this paper we propose a design method of IUO to optimize the overall capacity gain. Advance network features FH, PC and DTX are integrated. We developed a traffic model to consider co-channels cell's traffic distribution during design phase. Equations for estimating the cluster sizes of different layers are derived. Effects of various parameters are studied and it is found that sometimes it is better to utilize the advantages from FH rather than IUO when these features are combined. The design process proposed here considers this tradeoff. Several other factors like co-channel cells super area coverage, intended blocking probability, available spectrum of network operator, speed and ratio of moving vehicles etc are also considered. Finally an IUO cell is designed and performance is compared with normal cell which shows significant capacity enhancement. The network configurations and IUO performance are obtained analytically i.e. without using any network simulators so that dynamic configurations can be easily achieved. Analysis with timed Petri net of the scenarios developed here is considered for the future work.

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REFERENCES

[1] Theodore S. Rappaport "Wireless Communications Principles and Practice", Second edition, Prentice Hall India, 2004.
[2] Thomas Toftegaard Nielsen and Jeroen Wigard "Performance Enhancements In A Frequency Hopping GSM Network", Kluwer Academic Publishers, 2002
[3] Pedro Assunção, Rui Estevinho and Luis M.Correia. "Assessment of Cellular Planning Methods for GSM" *Proc. of the 12th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* San Diego, CA, USA 2001
[4] J. Zander, "Generalized Reuse Partitioning in Cellular Mobile Radio" *Proc. of the 43rd IEEE Vehicular Technology Conference,* Secaucus, NJ, USA, 1993
[5] S. Papavassiliou, L. Tassiulas, P. Tandon, "Meeting QoS Requirements in Cellular Network with Reuse Partitioning" *IEEE Journal on selected areas in Communications*, 1994
[6] Timo Halonen, Risto Aalto, Esa Tuovien "Increasing the Capacity of a Cellular Radio Network", *US Patent 6985736 Issued* on January 10, 2006.
[7] Khalid Begain, Gergo Istvan Rozsa, Andras Pfening, Miklos Telek, "Performance Analysis of GSM Networks with Intelligent Underlay-Overlay", *Proc. of the Seventh International Symposium on Computers and Communications,* 2002
[8] V. Wille, S.M. Irons, A.J. King "Capacity Increase in Cellular Radio Networks Using Intelligent Underlay Overlay" *proc. of tenth international conference on antennas and propagation,* 1997
[9] V. Wille, S.M. Irons, A.J. King "capacity increase in cellulair radio networks using existing base station sites" *IEE Colloquium on Propagation Aspects of Future Mobile Systems,*1996
[10] Y. K. Ling, J. Elling, T. Toftegrad Nielson, "Capacity of Intelligent Underlay and Overlay Network", *Proc. of the IEE Colloquium on Advanced TDMA Techniques and Applications,* 1996.
[11] T. T. Nielsen, J. Wigard, P. Morgensen, "On The Capacity of a GSM Frequency Hopping Network with Intelligent Underlay-Overlay", *Proc. of the VTC Phoenix*, Arizona, USA, May 1997
[12] J. Wigard, T. T. Nielson, P. H. Michaelsen, P. Mogensen " Improved Intelligent Underlay-Overlay Combined With Frequency Hopping" *Proc. of the 8th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* Helsinki, Finland 1997
[13] Jie Tian "Modelling the TRX Configurations for Intelligent Underlay-Overlay Radio Networks" *proc. of 8th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* 1997
[14] Kumaran, Krishnan, Whitling, P. Alfred "Method for Designing Underlay-Overlay Networks for Mobile Wireless Communication." *European Patent EP 0993210B1 issued* on January 30, 2002
[15] Raymond Steele, Chin-Chun Lee, Peter Gould "GSM, CDMA1, and 3G Systems", Jhon Wiley & Sons Ltd, 2001.
[16] William C. Y. Lee, "Mobile Cellular Telecommunications Systems", McGraw-Hill, 1989
[17] Sheldon M. Ross "Introduction to Probability and Statistics for Engineers and Scientists", Third Edition, Elsevier Academic Press, 2004.

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