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Capacity Expansion methods for live GSM Network- an overview

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Abstract— **The increase of subscriber base and attractive marketing strategies has resulted in high traffic channel congestion and demands proportional capacity expansions. Techniques such as carrier addition, cell splitting, aggressive frequency reuse pattern, micro cells for hot spots, realizing dual band networks and halfrate are available to support increase in traffic of live GSM network. A comparative study of suitability of these methods for different traffic requirement is discussed**

***Keywords*— congestion, frequency planning, Traffic**

I. Introduction

GSM (Global system for Mobile communication) has met with tremendous growth over the past years and the demand for radio resources is continuously increasing. In spite of mobile operator's priority for deployment of 3G network worldwide, GSM networks are still enjoying a period of sustained growth. Two factors determine 2G network Success: traffic and Quality of Experience (QOE). Traffic refers to the number of subscribers a network can support and QOE refers to network performance and reflects the quality of the whole network, including wireless access, transmission and core network architecture. At present, GSM networks are expanding because of increase in number of subscribers. Increase in subscriber level will results in increase in Traffic level, which in turn demands the network expansion in order to maintain the required level of Quality of Service (QOS). Many methods are available in the literature to expand the GSM Network such as Carrier Expansion, Cell splitting, Aggressive Frequency reuse pattern, micro cells for hot areas, realizing dual band networks and Halfrate [1]. The objective of this paper is to review the different methods available for capacity expansion of live GSM network.

II. Capacity Expansion methods

The RF loss call drop (radio link failure call drop), Handover failure call drop and LAPD call drops are the common types of call drops that can be quantized from Base station subsystem (BSS) of GSM network.

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A. *Carrier Expansion and Cell Splitting:*

Carrier expansion (transceiver addition) directly increases the number of carriers in a cell and Cell splitting results in increase in number of sites after reducing the coverage of legacy sites. The carrier expansion would be the first step to support increase in traffic in the network. The carrier expansion is made by adding additional TRMs (Transceiver modules) to the congested BTS (Bases Transceiver stations) sites and assigning clean or unused frequencies to the added carriers without altering the frequency plan of neighboring non congested sites. If the number of subscribers continues to increase and the available channels are already assigned, the cell splitting technology can be used to meet the requirements. The relationship in capacity between cell splitting and subscriber addition can be expressed as shown in equation (1).

$$Tn = 4n\ T0 \qquad (1)$$

Where, Tn indicates network capacity after "n" times of cell splitting and T0 represents network capacity before cell splitting.Equation (1) is applicable to the case where a cell is split into four smaller cells according to 1:4. According to 1:4 splitting, after each spitting, the coverage radius of the BTS falls by a half, and the transmitted power of the BTS should decrease by 12 dB, while the number of BTSs increases to four times of the original. The cell splitting will results in increase in inter cell handover and demands the software up gradation in the BSC (Base station controller). The maximum allowed split times 'n' depends on the site location and the capability of the system for processing inter-cell handovers[2]. If cell splitting is performed, a new coverage and frequency plan will be required to ensure inter cell interference is kept to a minimum [3]. The cost of installing new hardware (Transceiver and BTS) and devising new frequency and coverage plan is considerable. As per the results from the live network, the ratio of traffic demand in the busiest hour to the quietest hour is almost 20 to 1 [4]. Therefore it is vital for an operator to ensure that their resources (both hardware and spectrum) are utilized to their full potential. The Dynamic cell Sizing and cell load sharing are the alternative approaches found in the literature to overcome the limitations of cell splitting. In dynamic cell sizing, the size of any given congested cell is dynamically controlled within a layer of hierarchical cells. The advantage of dynamic cell sizing includes; the flexibility that could be brought into the network, borrowing of neighboring resources as and when required and capacity gain. The Ericson has come up with an optional solution called Cell load sharing (CLS) feature in its Base station Controller Software which is designed to redistribute traffic load between neighboring cells. The efficiency limits are defined by setting range of key parameters, actual network

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capacity, size and number of congested and uncongested cells [5]

B. Frequency Reuse Pattern

Frequency reuse is a commonly used technique in GSM networks to use the same frequency to cover different areas. There must be an appropriate distance (co-frequency reuse distance D=sqrt (3FRF)*R) between the areas that use the same frequency and meet the requirement of co-frequency interference ratio and adjacent frequency interference ratio as per ETSI specification (C/I ≥ 9 dB and C/I -9 dB.). The GSM adopts many frequency reuse patterns (FRF) such as 4x3, 3x3, 2x3, 1x3 and 1x1. All frequency reuse patterns divide the limited frequencies into several groups to form a cluster of frequencies for allocation to adjacent cells for use as shown in figure.1 to figure 3. The comparison of different FRP w.r.t to Quality and Capacity is shown in Table 1. The Quality relation has been derived using D=sqrt (3FRF)*R where R is the radius of the cell and D is the frequency reuse distance. The Capacity column in the Table 1 is derived assuming any 30 frequencies with the operator. From the Table 1, it can be concluded that more capacity could be achieved by reducing the cluster size and compromising the quality.

1) Aggressive Frequency Reuse Pattern (AFR)

If network capacity cannot be improved through cell splitting, aggressive frequency reuse (AFR) pattern can be used to improve band utilization. Common AFR patterns are Multiple Reuse Pattern (MRP), 1 x 3 (or 1 x 1) multiplexing technology and Concentric Cell. The 1x3 or 1x1 FRP are normally used along with the frequency hopping to compensate the degradation in S/I.

2) Multiple Reuse Pattern (MRP)

The MRP technology divides the whole frequency band into a BCCH band and a TCH band that are mutually orthogonal [6-8]. Each segment of carrier serves as an independent layer. Frequencies at different layers adopt different reuse patterns and the frequency reuse becomes increasingly closer layer by layer. Assuming any 30 frequencies with the operator, the capacity and quality improvement using MRP planning is discussed in this section. The BCCH frequency needs to be planned giving importance to coverage and quality. The TCH frequency planning is more concerned with supporting large capacity. The MRP planning is done for the assumed set of ARFCN (Absolute Frequency Channel Number) and is shown in Table 2. From the Table2, the configuration of Site A is $S_{4/4/4}$. The Frequency reuse Factor can be calculated by averaging all the FRP used in planning.

$$\text{FRP}=\frac{12+9+6+3}{4}=7.5 \qquad (2)$$

$$\text{D}=\sqrt{3FRF}*R=\text{D}=\sqrt{37.5}*R=4.74\text{ R} \qquad (3)$$

In the live GSM network, all the TRX will not be occupied all the time and therefore practical interference will be lesser than theoretical interference. Thus MRP method of frequency reuse will result in larger capacity sites and also maintains the quality.

C. Concentric Cell Technology

In concentric cell technology, a common cell is divided into two areas: outer layer and inner layer, also known as overlay and underlay. The coverage of the outer layer is the traditional cell, while the coverage of the inner layer is around the BTS. The available frequencies are divided into super and regular layer frequencies. Super frequencies which form the under layer are heavily reused using FRP such as 3x3,2x3 or 1x3 and enhance the capacity. The over layer adopts the traditional 4x3 FRP which is used throughout the cell and provides the coverage. The common control channel (BCCH Frequency) must belong to the outer layer. Figure 5 shows the structure of Concentric cell.According to the implementation mode, the concentric cell is divided into common concentric cell and intelligent underlay overlay (IUO). The major difference between these two types of concentric cell lies in the transmission power of the inner layer and the handover algorithm between the inner and outer layers. The transmission power of the inner layer of a common concentric cell is usually lower than that of the outer layer to reduce the coverage, increase the distance ratio, and meet the requirement of co-frequency interference. The handover between the inner layer and outer layer of a common concentric cell is usually based on the power and the distance. In case of IUO, transmission power of the inner layer (because the frequency adopts the closer reuse pattern, this layer is called super layer) of the IUO is completely the same as that of the outer layer (conventional layer) and the IUO handover algorithm is based upon C/I.

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 [11]. For a common concentric cell, the transmitted power of the inner layer is low and cannot easily absorb the traffic indoors, so the efficiency of the frequency is not high. The actual capacity increases about 10-30%. For IUO, the transmitted power of the inner layer is not changed, it can absorb the indoor traffic, and it can absorb the capacity flexibly for handover based on quality. Therefore, the actual capacity increases greatly by about 20-40%. [12].

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A detailed description of IUO functionality is available in [1]. The increase in capacity gain of 35% was found in [13] and an enhancement up to 50 %was shown in [14]. In [11], a traffic model was developed to estimate the traffic distribution among different layers of IUO cell. After integrating Frequency hopping, power control and discontinuous transmission (DTX), a capacity enhancement of 41.2 % was achieved in IUO cell over normal cells having similar features and resources.

D. Micro cells

Micro cell are used to provide coverage to blind areas in the network and to solve the problem of traffic overflow in hot spots. The concept of micro cells and its implications towards capacity expansion in cellular network can be found in literatures [15]. During the initial phase of the network rollout, operator will give importance to coverage based planning as subscriber base will be less. This is achieved by configuring large cells called macro cells, may be sectorized with adequate signal to interference ratio (S/I). As the subscriber base increases, the network is expanded by methods such as carrier expansion, cell splitting and Aggressive Frequency Reuse Pattern (ARP). When all these methods fail to satisfy increasing teletraffic loading, Microcells are introduced.[16].

Microcells are realized as an isolated single cell rather than clusters to accommodate teletraffic hot-spots. The micro cellular base station antennas are usually located at some 6-9m height and attached to walls or mounted on the roofs of low buildings. Macrocellular sectors will oversail the microcellular clusters, providing the coverage in microcellular radio dead spots and assisting handovers when candidate microcells have no available channels[17]. There are two approaches for assigning the frequencies to the microcells; reuse the same frequencies between microcells and the macrocells or partition the available frequency band such that macrocells and microcells have their own unique set of frequencies. The spectral efficiency of both frequency shared and frequency partitioned arrangements for microcells under different cluster size were evaluated by Robincombs etal [16] and found that partitioned arrangement was found to be two to three times more efficient.A 10-30 percent of capacity improvement has been shown in [18] by deploying of microcells in hot spots.

E. Dual Band Network for Capacity Expansion

The GSM 900MHz band is apparently insufficient to meet the capacity requirements of heavy-traffic area inspite of using capacity expansion techniques such as carrier expansion, cell splitting and Aggressive frequency Reuse Pattern. The use of dual band network will be an alternative solution for capacity expansion. The 1800 MHz band is discussed in this section to configure network for dual band operation.

The GSM900 network and the GSM1800 network are the same in network structure, voice coding, modulation technology, and signaling procedures, but are different in frequency range, radio propagation feature, feeder loss, and coverage range. The frequency resource of 1800 MHz is abundant than 900 MHz which reduces the capacity pressure effectively. GSM 900MHz can be configured to guarantee the network function (coverage) and 1800MHz is used for extracting actual traffic.The dual band network of the same manufacturer can use the co-bcch technology to save one CCCH**.** The radio parameters which defines the relationship between the GSM900 system and the GSM1800 system (for example, networking mode, traffic flow direction, handover relationship, and priority) need to be properly adjusted in order to improve the dual band network quality and capacity [19]. The dual band network of the same manufacturer can use the co-bcch technology to save one CCCH.

F. Half Rate

Traffic channel (TCH) in GSM can carry user speech or data which can be either in full-rate (TCH/F-13kbits/s) or half-rate (TCH/H-5.6kbits/s) channel mode. When TCH/H is in use, one timeslot may be shared by two connections thus doubling the number of connections that can potentially be handled by a TRX and, at the same time, the interference generated in the system would be halved for the same number of connections. TCH/H channels are interleaved in 4 bursts instead of 8 as the TCH/F, but the distance between consecutive bursts is 16 burst periods instead of 8[20]. GSM Half rate (HR) offers enhanced capacity over the air interface-corresponding to the proportion of mobiles within a coverage area that support half rate technology. The GSM enhanced full rate (EFR-12.2 kbits/s) codec provides substantial improvement over the GSM full rate and half rate codecs was introduced in GSM phase 2. It provides wireline quantity in error-free conditions and also in the most typical channel error conditions. In terms of link performance, the channel coding used with the original HR codec Provides equivalent FER robustness to one of the EFR codecs.[xx]. However, when the quality of the voice (mean opinion score (MOS)) is taken into account, there is a large difference between EFR and HR. Considering the error-free HR MOS performance as the benchmark MOS value, the EFR codec is roughly 3 dB more robust. that is, for the same MOS value, the EFR codec can support double the level of interference. On the other hand, HR connections generate half the amount of interference (3 dB better theoretical performance). Therefore HR has a network performance similar to that of EFR, in terms of speech quality outage. The details of simulation results are available in [20] and do not consider speech quality or HW utilization and cost. The use of HR has an associated degradation in speech quality since HR speech codec has a worse error-free MOS. In other words for the good-quality FER samples, the speech quality of EFR would be higher than that of HR. The market perception of degradation in speech quality by HR codec was the reason for less deployment HR codec in the GSM network. The introduction of AMR (Adaptive multirate) will undoubtedly boost the use of HR channel mode since the speech codecs used in this mode are a subset of the ones used in the FR channel mode; so, with an efficient mode adaptation algorithm

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there should not be substantial MOS degradation when the HR channel mode is used. AMR can support a tighter reuse pattern because of its robust codecs. If 100 percent AMR penetration could be achieved, service providers can expect up to a 70 percent capacity gain [18].A detailed performance study of the AMR half-rate codec in GERAN networks was performed by R. Mullner et al [21] and results show that a significant capacity gain can be achieved in the networks with relaxed 4x3 and 3x3 frequency re-use planning. It was found that the Dynamic half-rate assignment can nearly double the capacity in 4x3 and 3x3 re-use networks at quality degradation lower than 0.5 MOS[21].

III. Summary remarks

To improve network capacity, operators can introduce methods such as Carrier Expansion, Cell splitting, Aggressive Frequency reuse pattern, micro cells, dual band networks and Halfrate. The carrier expansion could be done in a smaller scale for the case of non uniform distribution of traffic in the network without disturbing the frequency plan of the existing network The cell splitting solution requires hardware expenditure and maintenance cost but it can return 100 percent capacity increase. The factor that has the greatest influence on cell capacity is Aggressive Frequency reuse. Three common methods are MRP, 1x3 Frequency reuse and Concentric. Implementing tight frequency reuse by using MRP with frequency hopping in GSM has been proven to be an efficient way to increase the radio network capacity with minimal costs for a network operator. The Microcells could be realized to expand capacity at hot spots or to cover small dead spots in the radio network. for the hot spots areas could be provided by using microcells. If additional spectrum is available then dual band operation would be the best choice for extracting heavy traffic with an additional hardware expenditures and site management. GSM HR capable mobiles are widely available due to the introduction of HR codes in early phase of GSM standard and therefore Halfrate could be a viable option for high density areas.

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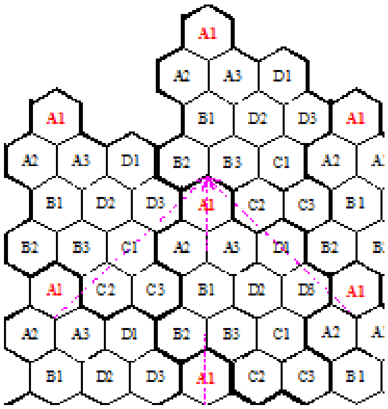

Figure. 1 4x3 FRP

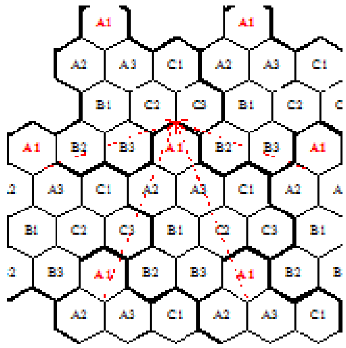

Figure. 2 3x3 FRP

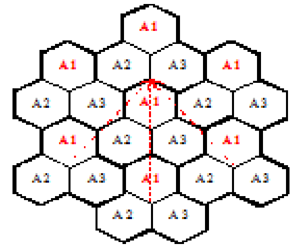

Figure. 3 1x3 FRP

TABLE I. COMPARISON BETWEEN DIFFERENT FRP

Sl. No.	FRF	Quality	Capacity	S/I
1	4x3	6R	$S_{3/3/2}$	18 dB
2	3x3	5.2R	$S_{4/3/3}$	13.3 dB
3	1x3	3R	$S_{10/10/10}$	9.43 dB

TABLE II. MRP PLANNING ASSUMING ARFCN FROM 1 TO 30

Carrier		A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3
BCCH	4x3	1	2	3	4	5	6	7	8	9	10	11	12
TRX1	3x3	13	14	15	13	16	17	18	16	19	20	21	19
TRX2	2x3	22	23	22	23	24	25	24	25	26	27	26	27
TRX3	1x3	28	28	28	28	29	29	29	29	30	30	30	30

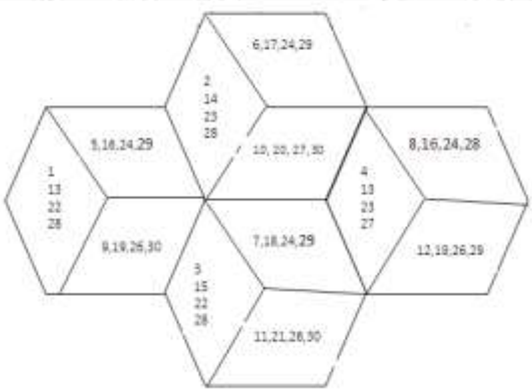

Figure 4. Schematic Diagram MRP Carrier Configurations

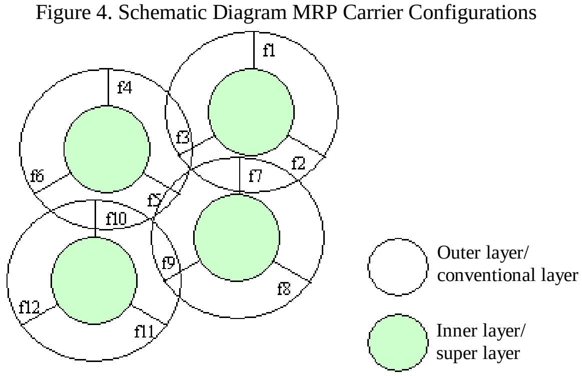

Figure 5. Schematic Diagram Concentric cell Technology

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