Capacity Improvement and Congestion Control of WCDMA Network Using Dual Cell and Two Co-Siting Sectorization Technique

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Abstract
Presently, a good number of users with communication gadgets usable with second generation (2G) and third generation (3G) Wideband Code Division Multiple Access (WCDMA) accessible networks are prevalent especially in developing countries. These networks experience congestion, interferences and poor Quality of Service (QoS) due to the large number of users with limited available spectrum. Cell sectorization scheme of 3-sector (120^0) commonly used in Base Transceiver Station (BTS) can be employed to improve the WCDMA 3G cellular network capacities with dual cell sectoring model of 3-sector 2-120^0 applied to multi-band combiner strategy for co-siting multiple WCDMA networks. This model can further enhance the system capacity with less inter-cell and intra-cell interference and improved handoff. A Users Multiple Sector Sharing Algorithm (UMSSA) was introduced into the Dual cell model to provide seamless congestion control mechanism. Simulations was carried out using MATLAB and MPLAB(C++ Programming) to investigate the performance of the proposed scheme and the result showed that in a six co-channel channel cell; co-channel interference reduced from 2 to 1 with increased in capacity of at least 52% without increase in sectorization and handover factors as against existing cell sectoring models.

Keywords: WCDMA, 3G, Sectorization, Dual Cell Sectoring, Co-Siting, Multi-band Combiner

1.0 Introduction

The multiple access technology for First Generation (1G), Second Generation (2G), Third Generation (3G), Fourth Generation (4G) and Fifth Generation (5G) networks are Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Orthogonal FDMA (OFDMA) and Non-Orthogonal Multiple Access (NOMA) respectively. 2G and 3G cellular communication networks use circuit switching with enhanced voice communication while 4G and 5G uses packet switching with enhanced data communication which is very promising for Internet of Things (IoT) and other data services (Dai et al., 2018; Mir and Kumar 2015 and Cimini et al., 1996).

There are good numbers of users with communication gadgets usable with 2G and 3G only especially in developing economies. These users experience exhaustion of the cellular capacity of the Wideband Code Division Multiple Access (WCDMA)-3G network leading to congestion, interferences and poor Quality of Service (QoS). To improve the user base, various techniques have been employed to enhance network capacity ranging from cell splitting which is limited with cost of building new cell sites, frequent handoff, etc., to cell sectoring which drawbacks include cost of antenna deployment and more handoff and microcell zone which is more useful on highways only (Alam et al., 2013; Ohaneme et al, 2018 and Abbasi et al, 2015).

1.1 WCDMA Cell Sectorization Scheme

WCDMA system model was originally deployed in each sector in conventional cell sectoring scheme in either of 3-sectors (120^0), 4 sectors (90^0), six sectors (60^0) or twelve sectors (30^0) to increase the cellular system capacity. In this scheme, softer handover are practicable in the systems operation but multiple handoff process impact negatively on the network especially with 4, 6 and 12 sectors network. The architecture of conventional cell sectoring and a 6 co-channel cells are shown in figures 1 and 2 (Haque et al, 2011; Alam et al., 2013; Abbasi et al, 2015 and Ohaneme et al, 2018).

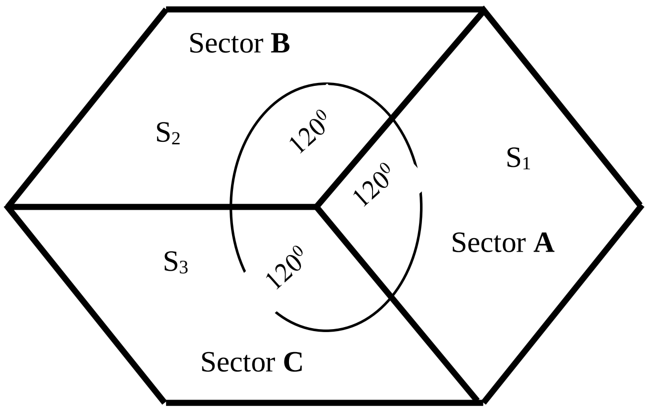

Figure 1: Architecture of cell sectoring scheme

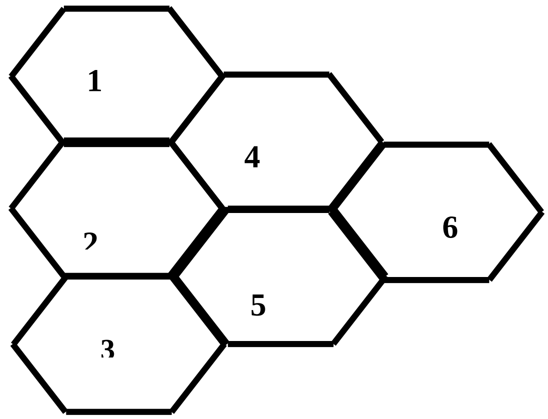

Figure 2: Six co-channels cells

The capacity of WCDMA system is basically determined by signal to noise ratio or mostly said E_b/N_o (Bit energy to effective noise power spectral density) and by the processing gain of the system. The processing gain is defined as the ratio of the spreading bandwidth of the system to the data bit rate for the selected application i.e. voice, data & multimedia etc. The interference is already included in the noise power spectral density and it can be self-interference, co-channel interference and multi-access interference.

The expression for WCDMA model was derived by assuming that there are K number of users accessing the network using the same frequency simultaneously and each user has a personal PN code sequence. Now, if P_s is the signal power, W is the bandwidth of spreading (PN) code sequence, R_b is the data bit rate; E_b is the energy per bit, N_o is noise power spectral density, n is thermal noise, then energy per bit can be written as (Singla and Saxena, 2011 and Ohaneme et al, 2018):

$$K = 1 + \frac{1}{\alpha}\left(\frac{P_G}{E_b/N_o}\right) - \frac{n}{P_s x \alpha} \qquad (1)$$

Where α is the voice activity factor and P_G is the processing gain.

The speech codec in UTMS (that is voice over UTMS) employs the Adaptive Multi-Rate (AMR) technique. The Multi-rate codec is a single speech codec with eight source rates: 12.2 (GSM-EFR), 10.2, 7.95, and 7.40 (IS-641), 6.70 (PDC-EFR), 5.90, 5.15 and 4.75kbps. Release 5 contains enhancement of AMR technology with clear voice and audio quality which support data rate of 6.6kbps to 23.85kbps (Salonem et al., 2002).

A cell sectoring scheme of 3-sector (120^0) commonly used in Base Transceiver Station (BTS) in Nigeria to improve on WCDMA 3G cellular network capacities was investigated and a dual cell sectoring model of 3-sector 2-120^0 was proposed to further improve on the system capacity with less inter-cell and intra-cell interferences and improved handoff.

2.0 Dual Cell Sectoring Model

WCDMA technology is a form of multiple access scheme used in radio based cellular network to provide interface through which multiple voice call users access the network simultaneously. In an attempt to reduce users' calls congestion and increase capacity of a 3G cellular system, dual cell sectoring can be employed. The concept of the model was based on assigning the Mains Sector as WCDMA 2 (that is 3G B) and Auxiliary Sector as WCDMA 1 (3G A) where two of the same cellular communication systems share one Base Transceiver Station (BTS). In a single cell site (that's BTS) configuration, this concept could be designed in two ways: option 1: without integrating a selector hardware and software, sequential communication transceiver is activated for Mains and Auxiliary sectors. When Mains is active, it receives calls until it gets to the maximum designed threshold before the Auxiliary sector is initialized to transmit and receive user's calls. Less acceptable congestion calls are received by Sector B (S_2 and S_5) and Sector C (S_3 and S_6) for the case of Sector A(S_1 and S_4), and vice versa. Option 2: when a selector is embedded in the system, subscriber can choose to route calls to either WCDMA 1 or WCDMA 2 as both mains and auxiliary systems are active at the same time. More acceptable congestion calls are accepted as Sector A (S_1) can also route its excess calls to Sector A (S_4) , Sector B (S_2 and S_5) and Sector SC (S_3 and S_6) and vice versa. Both option 1 and 2 were applicable in the UMSSA, however option 1 was used in simulation and modeling.

Consider a three sector network of 2-120^0 per sector providing interface to mobile users' accessing the BTS simultaneously and make the following assumptions;

i. Sector A (S_1), Sector B (S_2) and Sector C (S_3) as the Mains Sectors (cell) operating with higher frequency channel, and
ii. Sector A (S_4), Sector B (S_5) and Sector C (S_6) as the Auxiliary Sectors (cell) operating with lower frequency channel.

The developed dual cell sectorization architecture as shown in figure 3 has S_1 and S_4, S_2 and $S_{5,}$ and S_3 and S_6 respectively to share the same cell.

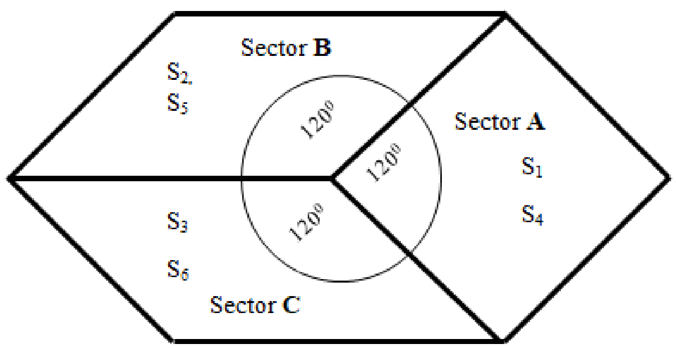

Figure 3: Architecture of Dual Sectorization Model

2.1 Co-Siting Multi-Band

Co-siting multi-band is where multiple BTS services can be funneled into a single feeder cable that runs up to the tower to the antennas. These services combine multiple transmitted signals (TXs) and divide received signals (RXs) and can be split away from the cable directly beneath the antennas. Various Combinations exist: Cross-band Coupler, Same band Combiner (SBC), Low-Loss Combiner and Hybrid Combiners. Most combiners are designed with the features to either share a common feeder and share common antenna (e.g. antenna-directional- antenna) or share a common feeder and share a different antenna (e.g. antenna-Multiband-antenna, Twin-beam -antenna).

Using diplexer cross-band coupler concept, two 3G co-cell site can be combined to form one cell site, thus, from equation 1, the expression for capacity (that is the number of users) of WCDMA system deploying sectored antenna where each user accesses the network at the same frequency and each user has its own PN code, considering figure 3 and applying the concept in equation 1, the new number of users as for mains K_m and auxiliary channels K_a with azimuth angle $\llcorner\theta_m$ and $\llcorner\theta_a$ respectively, the sum of number of users accessing the two-WCDMA cellular system denoted by $K_{m,a}$ in a single cell site per sector configuration is given by (Singla and Saxena, 2011 and Ohaneme et al, 2018);

$$K = K_{m.a} = \left(1 + \frac{1}{\alpha}\left(\frac{P_{G1}}{E_b/_{N_o}}\right) - \frac{n}{P_s x \alpha}\right) \llcorner\theta_m + \left(1 + \frac{1}{\alpha}\left(\frac{P_{G2}}{E_b/_{N_o}}\right) - \frac{n}{P_s x \alpha}\right) \llcorner\theta_a \qquad (2)$$

Introducing channel spacing in order to avoid/reduce co-channel intra-interference, the processing gain of individual WCDMA system and its carrier frequency were set differently in values as;

$$P_{G1} = \frac{W_1}{R_1} \quad (3)$$

$$P_{G2} = \frac{W_2}{R_2} \quad (4)$$

Substituting the values of (3) and (4) into (2) gives:

$$K = K_{m.a} = \left(1 + \frac{1}{\alpha}\left(\frac{\frac{W_1}{R_1}}{E_b/_{N_o}}\right) - \frac{n}{P_s x\alpha}\right) \llcorner\theta_m + \left(1 + \frac{1}{\alpha}\left(\frac{\frac{W_2}{R_2}}{E_b/_{N_o}}\right) - \frac{n}{P_s x\alpha}\right) \llcorner\theta_a \quad (5)$$

Where W_1 and R_1 are the bandwidths and data rates of the mains WCDMA 1 cellular systems while W_2 and R_2 are the bandwidth and data rate of the auxiliary WCDMA 2 cellular system.
From equation 5, for the number of user accessing various sectors of the mains and the auxiliary cellular networks, equation 5 can be rewritten as:

$$K_{m.a} = K_{m1} + K_{m2} + K_{m3} + K_{a1} + K_{a2} + K_{a3} \quad (6)$$

Where $K_{m1}, K_{m2} and\ K_{m3}$ are the users capacity for the Mains sector while $K_{a1}, K_{a2}\ and\ K_{a3}$ are the users capacity for Auxiliary sector.
Now, consider a situation where mobile users accessing both Mains sector and auxiliary sectors have more users more than the designed system capacity leading to congestion (call blocking) and take the acceptable congestion calls X as $x_1, x_2, \dots, x_N, x_5\ and\ x_6$ for sectors S_1, S_2 and S_3, S_4, S_5 and S_6 respectively. Then, take the capacity of each cell (sectors) that operates below the designed threshold as ξ_{m1}, ξ_{m2}, and ξ_{m3} for Mains sectors and ξ_{a1}, ξ_{a2}, and ξ_{a3} for auxiliary sectors respectively. A 6 by 5 set of "if case codebook" were formed for each users thereby giving them access to route their calls even if the calls were initiated at a congested sector in the 2-120^0 (six sectors) as shown in Users Multiple Sector Sharing Algorithm (UMSSA) for Two-WCDMA cellular systems (figure 4).

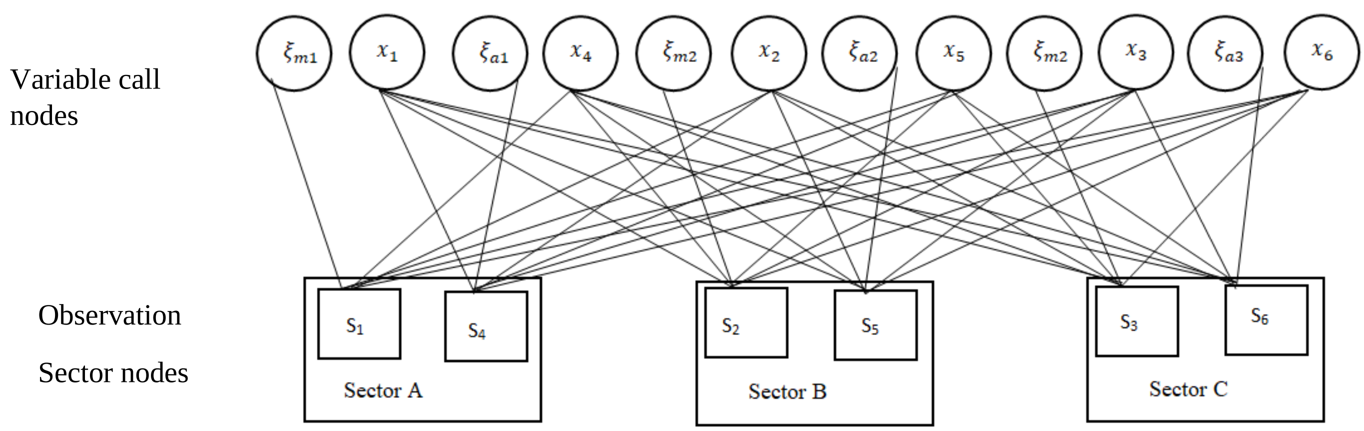

Figure 4: UMSS Algorithm with Two-WCDMA cellular Systems Configuration in Dual Cell Sectorining.

UMSS Algorithm Step1 : Sector A (S_1 and S_2)

i. S_1 WCDMA network receives subscribers calls within ξ_{m1} capacity $i.e\ K_{m1} < 1$
ii. When K_{m1} maximum threshold is reached, $K_{m1} = 1$, route users call to S_4,
iii. S_4 WCDMA network now receives subscribers calls within ξ_{a1} Capacity $i.e\ K_{a1} < 1$
iv. When K_{a1} maximum threshold is reached, $K_{a1} = 1$, and subsequently;
v. If $K_{m1} > 1$ and $K_{a1} > 1$, that is when both S_1 and S_4 operates above its threshold denoted as ξ^I_{m1} and ξ^I_{a1}respectively leading to overall user's congestion call X^I

vi. Compare/check if any of S_2, S_3, S_5 and S_6 operates below/within $\xi_{m,a}$ with acceptable user's congestion call denoted by X of x_2, x_3, x_5 and x_6 respectively, if available then receive $X^I$from (v) until when X space is exhausted, then drop the remaining X^I.

vii. Ignore (vi) actions, after comparing and observe that $K_{m2} > 1$,$K_{m3} > 1$, $K_{a2} > 1$ and $K_{a3} > 1$ and drop the X^I users.

These processes were equally taken for Sector B (S2 and S_5) and Sector C (S_3 and S_6) respectively, where the X is positive integer $x_1 + x_2 + \cdots + x_N$.

Relating the equation 6 with DCS UMSS algorithm, the capacity of the two-WCDMA cellular systems with acceptable congestion calls is given as:

$$K_{m,a} = \xi_{m,a} + X \qquad (7)$$

From equation 7, the number of acceptable user's congestion call can be known by subtracting various values of the system when it is operating below the optimal capacity from the maximum designed threshold of the individual system, hence from equation 7, the value of X can be gotten using;

$$X = K_{m,a} - \xi_{m,a} \qquad (8)$$

Where X is the total value of user's acceptable congestion calls in WCDMA systems in Mains and Auxiliary sectors configuration.

Estimating the overall user's congestion call, X^ι in the system, subtract the optimal capacity of the system, equation 6, from the capacity of the system operating above its optimal capacity for the various sector configurations;

$$X^\iota = \xi^\iota_{m,a} - K_{m,a} \qquad (9)$$

Determining the non-acceptable user's congestion call (Call droppedD_c), subtract the values of acceptable user's congestion call from the overall user's congestion call;

$$D_c = X^\iota - X \qquad (10)$$

Percentage of user's dropped calls in the two-WCDMA system using DCS configuration is given as;

$$\% \; of \; D_c = \frac{X^\iota - X}{X^\iota} x \; 100 \qquad (11)$$

Percentage of the acceptable user's congestion call in the system would be gotten by subtracting the values of equation 11 from 100%.

Hence, the total number of users accessing the WCDMA 1 and WCDMA 2 in a single cell site using DCS model can be determined using equation 7, while the acceptable user's congestion calls, non-acceptable user's congestion (dropped calls) and the overall user's congestion calls in this cellular network can be calculated using equations 8, 10 and 9 respectively.

3.0 System Design Considerations

Figure 5 shows the overall block diagram of congestion control for Dual Cell Sectorization, with various assumptions of the simulation parameters as stipulated in table 1. From figure 5:

i. CCMU (Central Call Microcontroller Unit): To channel entire calls coming from mobile user's smartphones or other gadget to MCMU and ACMU

ii. MSMU (Mains Sector Microcontroller Unit): To handle calls of the higher frequency channel and when its threshold is reached, route the excess calls to the CTMMU only when the ACMU threshold is equally met.

iii. ASMU (Auxiliary Sector Microcontroller Unit): Handles calls for lower frequency channel. It starts operation only when the MCMU threshold is reached.

A diplexer cross-coupler combiner is used for combining the wide range of the two frequency spectrum. It shares a common feeder cable and shares common directional antenna in-use at the conventional cell site.

Note: Either Mains or Auxiliary sectors can chose/interchange to be of high or low frequency channel. In this design, Mains is on low frequency channel while auxiliary is on high frequency channel

iv. CTMMU (Call Traffic Management Microcontroller Unit): Manages calls for different cells (sectors). Its reroutes calls from any congested to non-congested cell.

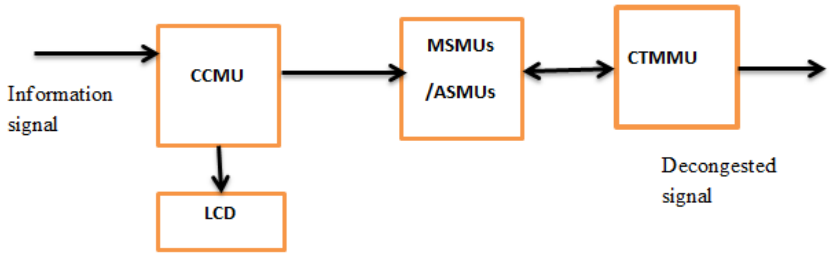

Figure 5: Overall block diagram of Traffic Management for Dual Cell Sectorization

Table 1: Simulation Parameters for single cell site deployment of WCDMA 1 and WCDMA 2 using Dual Cell Sectoring Configurations with directional antenna

Circuit Demonstration Parameter using MPLAB(C++ Programming)			**Graphical Demonstration site DCS using MATLAB**	
S/N	Materials / Component selection	Number required	Parameters	Values
1	Laptop	1	Sector	2-120^{0}sectors
2	Proteus Software	Installed	path loss Model for the experimental testbed	$L_p(d) = 75 + 31log(D)$
3	MPLAB software	Installed	Eb/No	2dB
4	PICKIT3 software	Installed	Systems Bandwidth W1, W2	4.781MHz, 5MHz
5	PIC16F648A	3	Carrier Frequencies F1, F2	1900MHz, 700MHz
6	PIC16F873A	1	Voice Activity Factor	0.434
7	Number of sector	3-dual sectors (6)	Date rate R1, R2 for voice users	12kps
8	Antenna Concept	Directional antenna	Inter-cell interference	0.1
9	Crystal Oscillator	4MHz	Shadow Fading	6dB
10	Diplexer Cross-Coupler Combiner	DB-X-CBC-7-17	Number of users for WCDMA1/WCDMA2	481/460 users

3.1 WCDMA 1 and WCDMA 2 in a single cell cite using DCS Configurations

In integrating WCDMA 1 and WCDMA 2 voice service in a single cell site using dual cell sectorization, the parameters as indicated in table 1 were used in circuit and graphical demonstrations respectively;

a) Circuit Demonstration for DCS-UMSSA Mechanism

The capacity of the various WCDMA systems in DCS configuration varies at regular time intervals. To evaluate the performance of the scheme and its effect on congestion control, from figure 6, consider at a given time 1400hours GMT, 12/5/2021) where the number of users accessing the WCDMA 1 and WCDMA 2 networks goes beyond the designed threshold for a Mains sectors (S_2 and S_3) and Auxiliary sector (S_6) respectively while at the same time Mains sector (S_1) and Auxiliary sector (S_4 and S_5) were below the thresholds, the following can be deduced:

i. The number of overall user's congestion call
ii. The user's acceptable congestions call
iii. Call drop (that's non-acceptable user's congestion call
iv. Percentages of user's acceptable and user's non-acceptable congestion call

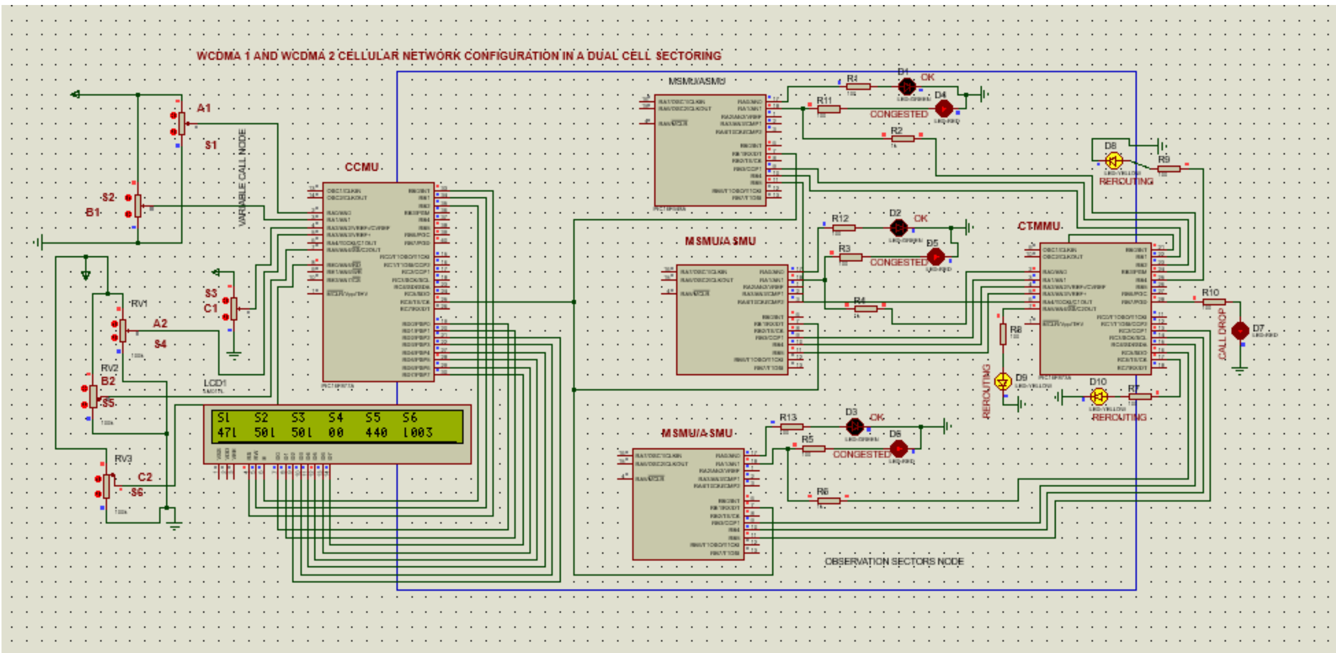

Figure 6: WCDMA 1 and WCDMA 2 Cellular Network using DCS in a single cell site operating above its optimal capacity with drop calls.

Parameter

$\xi_{m1} = 471\, users, \xi^{\iota}_{m3} = 501\, users, \xi^{\iota}_{m2} = 501\, users, \xi_{a1} = 0\, calls, \xi_{a2} = 440\, users$

$\xi^{\iota}_{a3} = 1003\, users$ (12)

i. Estimating the overall congestion calls for mains and auxiliary using equation 9 as:

$X^{\iota} = \xi^{\iota}_{m,a} - K_{m,a}$

$X^{\iota} = (\xi^{\iota}_{m2} - K_{m2}) + (\xi^{\iota}_{m2} - K_{m2}) + (\xi_{a3} - \xi^{\iota}_{a3})$

Substituting the values gives,

$X^{\iota} = (501 - 481) + (501 - 481) + (1003 - 460)$

= 20 + 20+543

= 583 users

ii. Acceptable user's congestion calls

Using equation 8, the values of acceptable congestion calls is given as:

$X = K_{m,a} - \xi_{m,a}$

$X = (K_{m1} - \xi_{m1}) + (K_{a1} - \xi_{a1}) + (K_{a1} - \xi_{a1})$

Putting the values gives;

$\gamma = (481 - 471) + ((460 - 0) + (460 - 440)$

= 10 + 460 + 20 = 490 users

iii. Call drop (non-acceptable user's congestion calls) from equation 10:

$D_c = X^{\iota} - X$

Since $X^{\iota} > X$, congestion is present, inserting the values gives;

$D_c = (583 - 490\ )users$ that is 93 users.

Percentage of call drop is gotten from equation 11 as:

$\%\ of\ D_c = \frac{X^{\iota}-X}{X^{\iota}}\ x\ 100\ \ = \frac{93}{583}$ x 100 = 15.95 %

iv. Percentage of acceptable user's congestion calls is 100-15.95 = 84.05%

With overall user's congested calls of 583 users in some sectors and 490 users spaces idle in other sectors, 490 users from congested sector was rerouted to non-congested sector. Thus, with this concept of DCS scheme, supposedly blocked user's calls in a congested sector at a given time are rerouted to non-congested sector which improves the capacity and reduces interference in the wireless network system.

4.0 Results and Discussion

4.1 Graphical demonstration of Voice over UTMS

From figure 7, the number of users (i.e. system capacity) verse Inter-cell Interference factor in WCDMA network using dual cell sectoring is shown with decrease in inter-cell interference for six co-channel cells. For cell splitting configurations, the co-channel interference remains six, while that of 120^0 cell sectoring (120^0 that is 3 sectors) and dual cell sectoring ($2\text{-}120^0$ that is 6-sectors), the co-channel interferences decreases to 2 and 1 respectively.

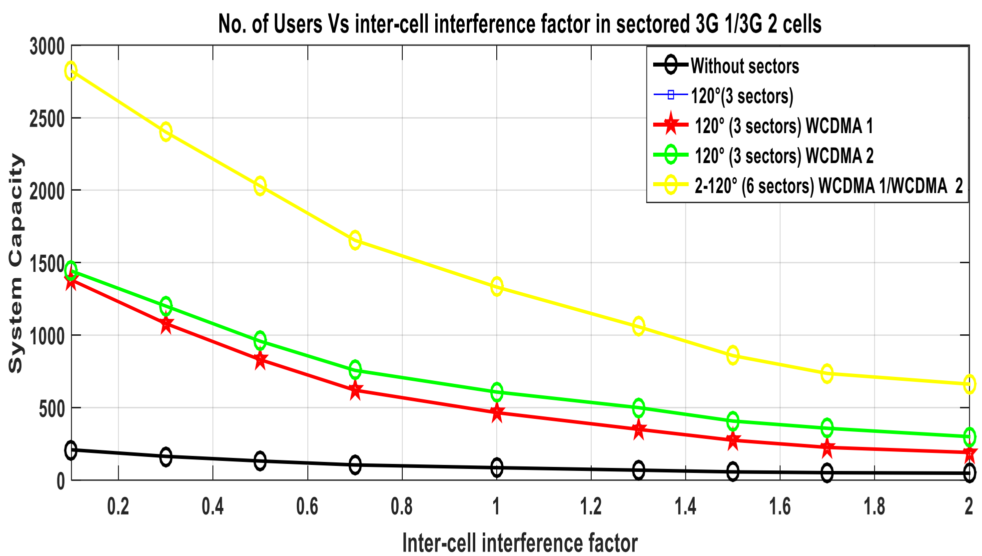

Figure 7: System Capacity vs. Inter-cell Interference in Co-Siting of two WCDMA Networks Using Dual Cell Sectoring Configuration

Figure 7 above showed the number of users (that's system capacity) verse Inter-cell Interference factor in WCDMA networks using dual cell sectoring. This graph highlight the increase/decrease in inter-cell interference for a six co-channel cells. Inter-cell interference occurs when a cell interferes with other cell. In multi-cell configurations, the outer cell can reduce cell capacity in WCDMA networks. To achieve increase in number of users, the inter-cell interference needs to be small.

Figure 4 shows that for a cell splitting configurations (without sector), for a six co-channel cells, the co-channel interference remains six, while that of 120^0 cell sectoring (120^0 that's 3 sectors) and dual cell sectoring ($2\text{-}120^0$ that's 6-sectors), the co-channel interferences decreases to 2 and 1 respectively.

Figure 8 shows the number of simultaneous 12Kps users verse handover factor in WCDMA networks using dual cell sectoring. The overlapped cell can lead to an extra power hence introducing soft handover factor (H) in the WCDMA cells. The value of H in WCDMA can be a factor to increase the number of users. Conventionally, Increasing H and changing values of sectorization, the simultaneous 12kps voice user's increases.

Figure 8 also shows that the new scheme witnessed increase in the number of simultaneous 12 Kbps voice users without changing the value of sectorization. Since, $S_1$and S_4, S_2 and S_5, and S_3 and S_6 shares Sector A, B and C respectively, a decrease in handover factor is noticed especially when a second BTS would have been built to accommodate the auxiliary sectors.
For example, if H value is 2dB, then for a 3 sectors 120^0, the number of simultaneous users will be 1380 but for 2-120^0 (6 sectors) that is Mains (1443) and Auxiliary (1380), thus, the total number of 12kps simultaneous voice users will be 2783; thereby leading to 52% increase in the capacity while maintaining 120^0 sectorization. This equally reduces the rate of handover that would have been occasioned by building another 120^0 sectored network cell site by 52%.
Note that from both figures 7 and 8, line Auxiliary is covered by the conventional cell sectoring (with 3 sectors) as both were designed with the same 1380 user's capacities.

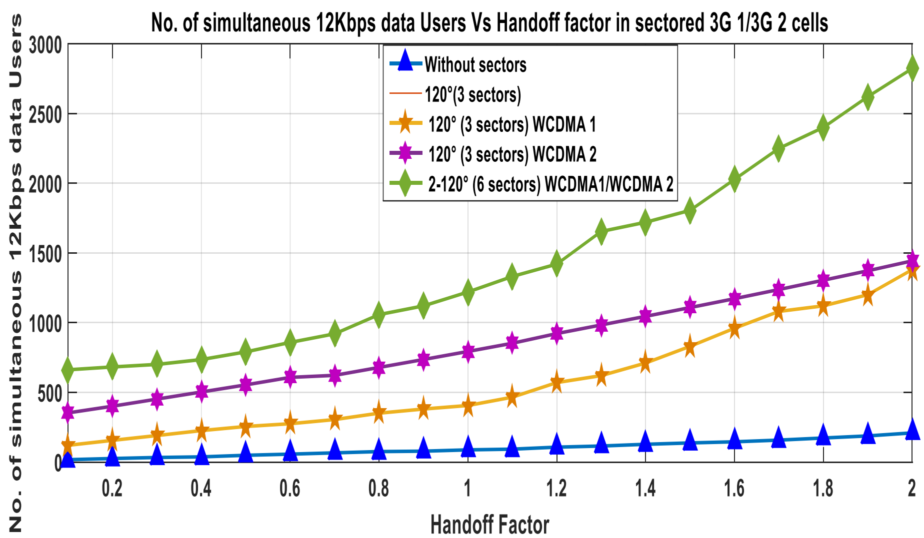

Figure 8: System Capacities vs. Handover in Co-Siting of two WCDMA Networks Using Dual Cell Sectoring Configuration

Conclusion

Traditional cell sectorization and cell splitting play key roles in improving third generation (3G) networks with other cellular network capacities to meet growing number of subscribers. Conventional approach has drawbacks which include frequent handoff, inter-cell and intra-cell interferences, cost of antenna deployment and cost of building new cell sites. To mitigate the challenges posed by the cell sectoring and cell splitting and provides more to access users, the cell sectoring was investigated and a dual cell sectoring model with Users Multiple Sector Sharing Algorithm (UMSSA) was introduced.

It was observed from the developed dual cell sectorization model that higher numbers of users were added to the scheme with improved congestion control mechanism and less handover. Comparing the existing cell sectoring with the developed model, the six co-channel cells, has interference reduced from 2 to 1 with increased in capacity of at least 52%.

With the UMSSA, the model demonstrated that with circuit (at 1400hours GMT, 12/5/2021) the number of users accessing the WCDMA 1 and WCDMA 2 in single cell site goes beyond the designed threshold for Mains sectors (S_2 and S_3) and Auxiliary sector (S_6) respectively while at the same time Mains sector (S_1) and Auxiliary sectors (S_4 and S_5) were below the thresholds. From the overall user's congestion calls of 583user's, the non-acceptable user's congestion call reduced to 15.95% paving way to acceptable user's congestion call of 84.05%, thereby immensely improving the 3G wireless network capacity.

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