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Higher Order Horizontal Sectorisation Gains for 6, 9, 12 and 15 Sectored Cell Sites in a 3GPP/HSPA+ Network

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***Abstract*—Horizontal antenna sectorisation has been used within all generations of cellular radio networks to improve both the coverage and capacity of such networks. This paper evaluates the potential coverage and capacity gains of sectorisation through extensive simulation and real world trials of deployments of higher order horizontal sectorisation (3, 6, 9, 12, and 15 sectors) when applied to a 3G/HSPA+ network. Simulation results are presented for idealized homogenous networks based upon a standardized 3GPP HSPA/LTE network model in order to find the theoretical downlink capacity gains and the optimum horizontal antenna beamwidth to maximize capacity without significantly reducing coverage and other cellular network Key Performance Indicators. Further simulations have also been performed to assess the potential gain seen within Telefonica UK's central London 3G/HSPA+ network and these results have also been verified using live network field results from the deployment of six sector sites into Telefonica UK's network. Finally trial results from the deployment of what is believed to be the industry's first fifteen sector 3G site are presented showing further gains are possible well beyond six sectors per site.**

***Index Terms*—3GPP, Antennas, Cellular networks, Directional antennas, Higher order sectorisation, HSPA.**

I. Introduction

For many years antenna sectorisation has been seen as a key technique to improve both the coverage and capacity of cellular networks [1], [2] with most cellular networks typically employing three sectors per cell site (Fig. 1). The reason behind three sectors per cell site is mainly due to the fact that three sectors per cell site works well with the concept that the idealized cellular network is a tessellation of hexagonal cells as well as the limitation of cellular antenna technology at the time of its introduction. However in reality modern cellular networks are not based upon a perfect hexagonal grid of cell sites and nor do the sectors of each cell site perfectly tessellate

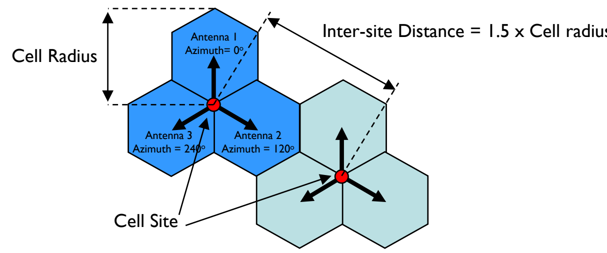

Fig. 1. The theoretical tessellation of three sector sites in a cellular network

with one another. Cell sites are typically deployed at high vantage points within the network to provide wide area coverage (e.g. existing TV/radio transmission towers), in areas of high traffic density (e.g. downtown areas / shopping malls) or at locations where the cellular operator may have favorable rental terms with the site provider. Therefore since cellular networks do not follow a perfect hexagonal grid, three sectors per site is really an arbitrary value and higher sector counts are possible and as will be shown in this paper yield significant capacity and coverage benefits for a 3G/High Speed Packet Access+ (HSPA+) network.

There have been a number of key papers considering higher order horizontal sectorisation mainly for WCDMA cellular networks based upon earlier versions of the WCDMA standard and prior to the introduction of HSPA. In [3] the authors mainly consider the effect of three fixed antenna beamwidths of 90°, 65° and 33° on the capacity and coverage for three, four and six sector WCDMA sites (it should be noted that within this paper we define the antenna beamwidth as the angle between two points either side of the antenna bore sight having 3 dB lower gain than the bore sight gain - also often referred to as the half-power beamwidth of the antenna). As with all previous papers found on the subject no reason is given why these particular beamwidths should be the ones used for the different sector counts. A homogenous network simulator is used with even traffic spreading to generate the results and it is proposed that six sectors, with each sector utilizing a 33° horizontal antenna beamwidth gives the best coverage and capacity for the configuration studied. The paper also presents a theoretical uplink calculation for the sectorisation gain for a sector count greater than six but only for the three fixed antenna beamwidths considered. The paper concludes that the gains determined from the simulations suggest a six sector capacity gain of 1.72 for a 6x33° site configuration over a 3x65° configuration.

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Reference [4] considers the performance of three, six, nine and twelve sector sites for an IS-95 based CDMA network. Here real sector coverage measurements are taken from a smart antenna on the roof of a building located in typical European city. These measurements are then imported into a network simulator consisting of a network of only seven sites (a test site and a single tier of "ghost" sites generating the surrounding interference). Simulation results presented suggest a six sector capacity gain of 1.52, a nine sector gain of 2.59 and a twelve sector gain of 2.67 over the capacity of a standard three sector site. These gains also assume the non-ideal overlap seen from the field measurements collected.

In [5] again the antenna beamwidth is considered as an important factor in the capacity of three and six sector WCDMA sites, however once again only fixed beamwidths of 33^o, 65^o and 90^o are considered. Simulations are performed on a homogenous network configuration of ten sites, but with a non-uniform traffic distribution. Simulation results suggest a six capacity sector gain of 1.8 for the $6x33^o$ site configuration over a standard $3x65^o$ site configuration.

References [6], [7] consider the impact of angular spread (the effect of local scatters around the antenna increasing the effective beamwidth of the antenna) on the capacity gains of three, six and twelve sector sites and use a homogeneous 19 site network simulation setup very similar to that proposed by 3GPP in [8] but with a 3 km inter-site distance. Traffic is spread uniformly across the simulation area and capacity gains over a three site configuration ($3x63^o$) of 1.8 and 3 are reported for the $6x35^o$ and $12x20^o$ configurations respectively. A 5-10 % reduction in the capacity gains is suggested because of sector overlap caused by angular spread in a typical multipath environment such as an urban area.

Reference [9] considers higher order sectorisation gains in both homogenous and real network deployments. The homogenous network simulation results with a uniform traffic distribution suggest a six sector capacity gain of 1.86 and a twelve sector gain of 3.24 over three sectors, again fixed antenna beamwidths of 65^o, 33^o and 16^o were assumed for the three, six and twelve sector site configurations respectively. Real network simulations (undertaken for a central Stuttgart network) are performed with just a central set of five out of 134 sites being upgraded from three to six sectors and therefore the paper considers six sectors more as a single site hot spot solution rather than a network wide capacity upgrade. Only three and six sector configurations were considered with the six sector sites providing on average a capacity gain of 1.8 over the previous three sector configuration. The results also suggest that the soft hand over (SHO) overhead remains very similar for both three and six sector deployments since the roll off of the gain of the narrower beam antenna deployed for the six sector configuration is sharper and therefore whilst there are more cell boundaries between adjacent sectors for the six sector sites, the area of equal Common Pilot Indication Channel (CPICH) powers between sectors is also reduced.

Finally reference [10] is the only reference found to date that considers the potential gains of higher order sectorisation for Long Term Evolution (LTE). The simulations performed are based upon the 19 site 3GPP homogenous network model defined in [11] using idealized antenna patterns also specified in [11]. A fixed antenna beamwidth of 70^o is assumed for the three sector site configuration and beamwidths of 35^o, 40^o, and 45^o are assumed for the six sector site configurations with the 40^o, and 45^o beamwidths being used to model the effect of angular spreading on a 35^o beamwidth antenna. The simulation results suggest a six sector network capacity gain of 1.88 ($6x35^o$) over a network deployed using three sector sites ($3x70^o$) and an standalone site six sector gain of up to 2.1 for individual hotspot sites upgrade from three to six sectors.

In summary previous work indicates a capacity gain can be obtained from higher order sectorisation with predicted gains in the range of 1.5 – 2.1 when moving from three to six sector configuration. Only some of the papers look beyond six sectors to higher order configurations such as nine and twelve sectors. None of the papers consider the optimum beamwidth for the different sector configurations and none support their findings with real network trials of higher order sectorisation.

Therefore to overcome some of the short fallings of the earlier work this paper takes a fresh look at the potential gains of higher order sectorisation through both simulation of higher order sectorisation on an idealised hexagonal network model proposed by the 3rd Generation Partnership Project (3GPP) in [8], [11] as well as on Telefonica UK's central London 3G/HSPA+ network. The paper considers not only the predicted capacity gains but for the first time the ideal horizontal antenna beamwidth required to maximize the downlink capacity of sites with varying sector counts whilst maintaining coverage and other typical network Key Performance Indicators (KPIs) for a 3G/HSPA network.

The paper then presents field trial results from live 3G cell sites within Telefonica UK's network upgraded from three to six sectors as well as results from the deployment of the what is believed to be the Industry's first fifteen sector 3G site and compares these measured results to those found from simulations. Finally the paper for the first time proposes the most practical antenna beamwidths that should be deployed for 3, 6, 9, 12 and 15 sectored cell sites.

II. SIMULATION SETUP

In order to evaluate Higher Order Antenna Sectorisation and other advanced cellular network concepts a bespoke Advanced Cellular Network Simulator (ACNS) has been developed at the University of Leeds [12]. The simulator is able to model both uniform homogenous network configurations as well as real world network deployments for HSPA/HSPA+, LTE and LTE-Advanced technologies.

A. Homogeneous Network Simulations Setup

The homogeneous network model implemented in the ACNS tool was based on the model described in [8], [11] and consisted of a central site encircled by two tiers of surrounding sites giving a total of 19 sites within the simulation area. This three-tier approach is typical in cellular network modeling and allows statistics to be gathered from the central cells plus the 2^{nd} tier to avoid edge effect from cells of the 3^{rd} tier of sites.

The Inter-Site Distances (ISD) considered here are those presented in [11] as Case 1 (ISD = 500 m) and Case 3 (ISD = 1732 m). These distances are typical ISDs found in real Urban and Suburban mobile network deployments although much smaller ISDs (~250 m) are possible for networks deployed in Dense Urban areas such as central London for example. Further homogenous network simulation parameters are presented in TABLE I.

TABLE I
IDEALIZED NETWORK HSPA+ SIMULATION ASSUMPTIONS

Network Parameter	Value
Idealized network sites/sectors per site	19/57 – 19/285
Simulation bin size	10 m x 10 m (bin area=100 m^2)
Base Station Height	32 m
Sector Mechanical Downtilt	Case 1: 10^o, Case 3: 5^o
Sector Electrical Downtilt	0^o - specified by antenna
Sector Max. TX Power	43 dBm
HSPA CPICH Power	33 dBm
HSPA Other Common Channel Power	33 dBm
HSPA Downlink Orthogonality	0.5 (Ideal orthogonality = 1)
HSPA HS-DSCH Power	40 dBm
Operating Frequency – Single carrier	3GPP Band I (2100 MHz)
Path Loss Model	PL=128.1 + 37.6log$_{10}$(R) dB, R in km [8]
Penetration Loss	20 dB [8]
User Equipment (UE) Height	1.5 m
UE Antenna Gain	0 dBi
UE Noise Figure	9 dB

B. Telefonica Central London Network Simulations Setup

In order to evaluate higher order horizontal sectorisation on a more realistic network configuration, simulations were also performed using a sample of actual site locations (51 sites) from Telefonica UK's central London 3G network (Fig. 2). The sites within the central London simulation vary in height and antenna orientation and therefore this network provides a much more representative platform on which to evaluate the benefit of higher order sectorisation than the uniform homogeneous networks assumed in previous studies. The radio propagation path loss model used for the central London simulations was based upon the macrocell model proposed in [8], however rather than using a fixed penetration loss of 20 dB as was used for the homogeneous simulations, the penetration loss was determined from London land use clutter data. Traffic was also distributed according to clutter class.

C. Simulation Antenna and Throughput Modeling

In order to determine the ideal horizontal antenna beamwidth for 3, 6, 9, 12, and 15 sector sites to maximise capacity a large number of antenna patterns with varying beamwidths were required. Since we could not be sure that real antennas actually existed for each and every beamwidth required then all antenna patterns used during this study for both the homogeneous and London simulations were

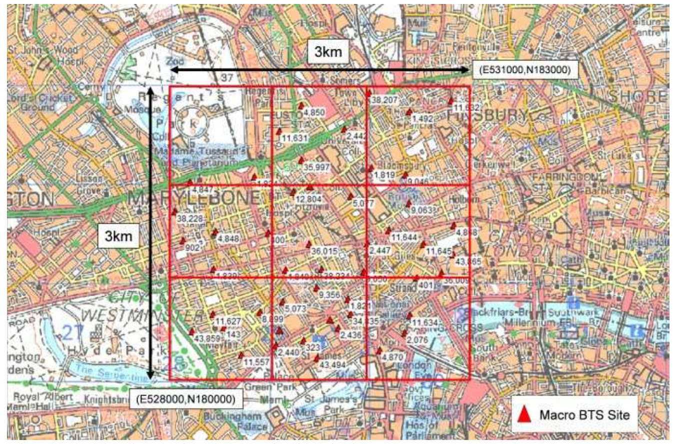

Fig. 2. Central London network simulation area.

generated using the widely used beam pattern generation method proposed by 3GPP in [11]. The 3GPP method uses the following equations to generate the horizontal, $A_H(\varphi)$ and vertical, $A_V(\theta)$ antenna patterns.

$$A_H(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] \tag{1}$$

$$A_V(\theta) = -\min\left[12\left(\frac{\theta - \theta_{etilt}}{\theta_{3dB}}\right)^2, SLA_v\right] \tag{2}$$

where

φ	is the horizontal bearing from the antenna's bore sight
φ_{3dB}	is the horizontal 3 dB beam width of the antenna
A_m	is the front-to-back attenuation (25 dB)
θ	is the vertical bearing from the antenna's bore sight
θ_{3dB}	is the vertical 3 dB beam width of the antenna
SLA_v	is the side lobe attenuation (20 dB)
θ_{etilt}	is the electrical antenna downtilt

The 3GPP method of 3D antenna pattern regeneration also given in [11] was used and is given by the following equation

$$A(\varphi,\theta) = -\min\{-[A_H(\varphi) + A_V(\theta)], A_m\} \tag{3}$$

where

$A(\varphi,\theta)$	is the antenna gain at a point with a horizontal bearing from the antenna of φ and a vertical bearing from the antenna of θ.
A_H, A_V and A_m	are the horizontal, vertical and front-to-back attenuation defined previously in (1) & (2).

All beam patterns generated for this study had a fixed electrical tilt of 0^o, a fixed vertical beamwidth of 7^o (typical of practical cell site antennas) and only the horizontal beamwidth, β was varied from 14^o to 90^o in steps of 2^o in order to generate some 39 different antenna beam patterns. The bore sight gain, $G(\beta)$ dBi (dB gain relative to that of an isotropic antenna) of each antenna was set relative to the typical 17 dBi gain, ($G(70)$) of a 70^o horizontal beamwidth antenna using the relationship assumed below in (4). This relationship models an increase in antenna gain for narrower beam antennas and a reduction in antenna gains for wider beam antennas.

$$G(\beta) = G(70) - 10\log_{10}\left(\frac{\beta}{70}\right) \quad (4)$$

Simulation studies by Nokia [13] suggest that the performance of 3G/HSDPA using 15 channelisation codes in the downlink is within 2 dB of the Shannon limit, the shortfall is claimed to be mainly due to decoder limitations and receiver estimation inaccuracies. Ericsson also propose a similar relationship between 3G/HSPDA throughput and the Shannon's limit in [14] which quantifies the relationship between the High Speed Downlink Shared Channel (HS-DSCH) bit rate, $R_{HS\text{-}DSCH}$, WCDMA system bandwidth BW (3.84 MHz) and HS-DSCH signal to noise ratio, $C/I_{HS\text{-}DSCH}$ as

$$R_{HS-DSCH}[Mbps] = BW \cdot \begin{cases} 0, & C/I_{HS-DSCH} < 10^{-1.4} \\ \log_2\left(1 + \frac{C/I_{HS-DSCH}}{2}\right), & C/I_{HS-DSCH} \geq 10^{-1.4} \end{cases} \quad (5)$$

III. Simulations Performed

A. Homogeneous Network Simulations Performed

Static homogenous Monte-Carlo network simulations were performed for the homogeneous network (Cases 1 & 3) with all sites having 3, 6, 9, 12, and 15 sectors with varying antenna horizontal beamwidths generated using the method presented in the previous section. Since higher order sectorisation may not necessarily be deployed uniformly across the network, the homogeneous network was also used to evaluate the capacity benefits of a single higher order site placed at the centre of the network surrounded by a network of three and six sector sites. Network statistics were gathered from only sectors of the central eight sites to avoid edge effects.

B. Central London Network Simulations Performed

Simulations were performed for all 51 sites of the central London area of Telefonica UK's network, with each site having 3, 6, 9, 12, and 15 sectors, again using ideal antennas generated using the method presented in the previous section but with the optimal beamwidths determined from the homogeneous network simulations for Case 1, since the Case 1 ISD was more representative of the ISDs of the central London network. In order to evaluate the potential capacity benefits of higher order sectorisation on individual sites further runs were also performed evaluating the gains a higher sector count had when deployed on just five out of the 51 network sites, the remaining sites having three, then six sectors per site. Network statistics were gathered from only the central 2x2 km portion of the central London simulation area to avoid edge effects.

IV. Network Quality Key Performance Indicators Used To Assess The Performance Of The Different Horizontal Antenna Beamwidths

In order to assess other effects the introduction of higher order horizontal sectorisation may have on network quality such as increased areas of soft/softer handover, loss of coverage and increase areas of outage due to pilot pollution a set of typical cellular network performance Key Performance Indicators (KPIs) were utilized to assess both homogeneous and central London simulation results. The KPIs chosen to be used for the evaluation of simulation results are outlined in the following subsections.

A. KPI 1: Ec/Io Outage Area

The Energy per chip to Interference Ratio (*Ec/Io*) is a measure of the serving cells' received signal quality. It is used by the mobile to periodically select the best cell and when all 3G/HPSA cells are below a certain *Ec/Io* threshold then it is used to trigger the mobile to reselect to another access technology, for example reselection to an underlying 2G radio access technology such as GSM (Global System for Mobile Communications). The trigger level at which a WCDMA mobile reselects to GSM is an operator specific parameter but for the purposes of this study we have assumed a cautious typical GSM reselection *Ec/Io* trigger level of -14 dB (in areas where the best serving cell's *Ec/Io* is less than or equal to -14 dB we have assumed that all mobiles in this area will re-select to GSM and will therefore not be able to access the enhanced services offered by WCDMA). Minimising these so called "outage areas" caused by too many serving cells and the lack of dominance by a single cell (often referred to as "pilot pollution") is one of the key optimisation tasks in any CDMA or OFDMA single frequency based cellular network. Since it is impossible in reality to totally avoid area of pilot pollution, because of non-ideal site placement or users in high locations for example, then it is normal to expect that there will always remain areas in the network where pilot pollution occurs.

B. KPI 2: Ec/Io Mean

As mentioned previously *Ec/Io* is a measure of the quality of the signal of serving cell(s). In order to maintain reliable communications the value of *Ec/Io* must be kept well above the reselection threshold, and therefore *mean Ec/Io* was used as a further network KPI to assess the performance of horizontal sectorisation.

C. KPI 3: RSCP Mean

The Received Signal Code Power (*RSCP*) is defined as the received signal level of a serving or nearby neighbour cell. It provides a measure of the strength of the serving cells in the area and is used by the network planning/optimisation Engineer to determine the level of coverage provided by the network. Clearly any attempt to increase capacity through higher order sectorisation should not severely compromise coverage and therefore the *mean RSCP* was chosen as a further evaluation KPI.

D. KPI 4: Cell Edge RSCP (5^{th} Percentile RSCP)

Whilst mean *RSCP* is a measure of coverage across the entire cell, it is the cell edge users who will be most affected by loss of coverage. For this reason a second *RSCP* based KPI was defined based upon the *5^{th} percentile RSCP*.

E. KPI 5: Mean Downlink Cell Throughput

Mean HSPA downlink cell throughput measured in Mbps was used to measure any capacity increased caused by higher order sectorisation.

F. KPI 6: Downlink User Cell Edge Throughput

In order to measure the downlink throughput at cell edge a second throughput KPI was defined as the 5th percentile of the user's downlink throughput.

G. KPI 7: Percentage of Users in Soft Handover (SHO)

This KPI measured the total percentage of users that would be in soft (inter-cell handover) or softer (intra-cell) handover or a combination of the two (soft/softer). Whilst handover is required within a WCDMA network for mobility purposes, since soft/softer handover typically requires resources from two or more cells then generally it is best to keep the number of users in SHO as small as possible whilst still maintaining reliable mobility within the WCDMA network.

H. KPI 8: Mean Downlink Cell Site Throughput

This KPI provides a measure of the total downlink throughput through the entire cell site and is the summation of the mean downlink throughput across all cells (3, 6, 9 etc.) of the cell site.

V. Homogeneous Network Simulation Results

The optimal beamwidths to maximise the site capacity whilst maintaining network quality for the different sector counts considered were determined by evaluating the homogeneous simulation results against the KPIs presented in the previous section. Whilst assessing the results it was seen that the choice of the optimal beamwidth for each configuration considered (3, 6, 9 12, and 15 sectors) is really a compromise between conflicting KPIs. For example shown in Fig. 3 and Fig. 4 is the effect that the horizontal antenna beamwidth has on KPIs 2:*Mean Ec/Io*, 3:*Mean RSCP* and 7:*Percentage of users in SHO*, for the three sector, Case 1, network. As expected we see from Fig. 3 that we achieve better coverage with a wider antenna beamwidth, but at the cost of signal to noise ratio (*Ec/Io*). In Fig. 4 we see that again as expected a wider beamwidth antenna leads to greater sector overlap and much greater SHO.

In order to find the horizontal beamwidth that provided the best compromise, targets were set against each of the KPIs as either an absolute threshold for example *Ec/Io outage* <= 5% or as a relative threshold across the results for the different antenna horizontal beamwidths considered. Each configuration then was assessed against these KPI targets. Configurations that did not meet one or more of the KPI targets were discounted and the most optimal beamwidth was determined as the configuration that maximise the remaining KPIs. Tables II-XI present a full summary of the results for the sector counts considered for the idealized homogeneous Case 1 & Case 3 networks against the aforementioned KPIs. The green shaded cells indicate where the KPI targets have been met and in each case the antenna beamwidth considered to be optimal is also indicated by a grey shaded value.

For example considering the results in Table III for the six sector Case 1 network configuration, here it can be seen that

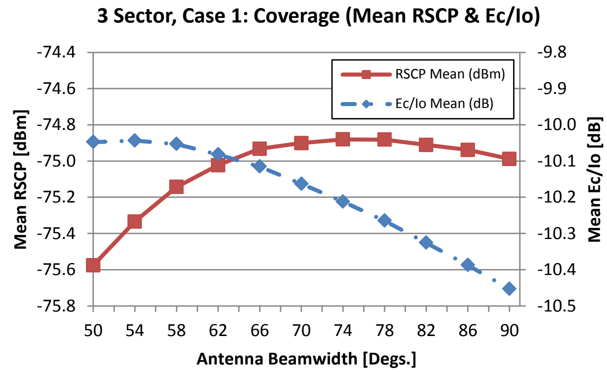

Fig. 3. Mean RSCP and Ec/Io for the horizontal antenna beamwidths considered for the three sectored Case 1 homogeneous network.

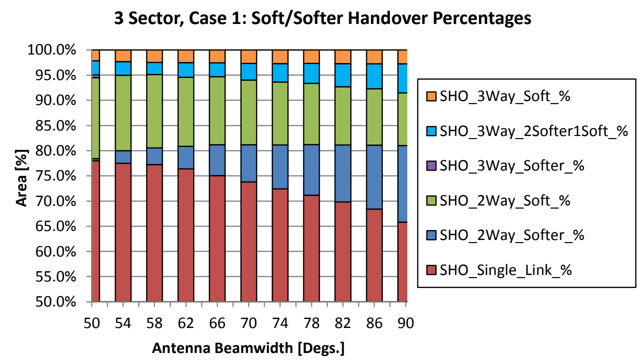

Fig. 4. Soft/Softer handover percentages for the horizontal antenna beamwidths considered for the three sectored Case 1 homogeneous network.

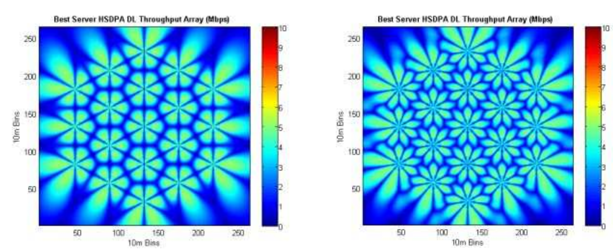

Fig. 5. Best server HS-DSCH throughput arrays for 6 and 9 sectors per site, showing better inter-sector tessellation for 9 sector configuration.

of the beamwidths considered, 34°, 38° and 42° were the most optimal beamwidths providing the best compromise across all the KPIs. In this case it was concluded that 34° was the optimum beamwidth since it provided the highest cell site capacity out of the three beamwidths meeting all KPIs.

It was also found from the results that sector tessellation plays an important part in determining the effectiveness of higher order sectorisation for the idealized homogeneous network with site configurations with an odd numbers of sectors providing better inter-site sector tessellation (Fig. 5) than those with an even number of sectors. Site configurations with an even number of sectors tended to have inter-site sectors pointing directly at one another leading to areas where there was no dominance and high pilot pollution as can be seen in the Case 3 KPI summaries of the six and twelve sector configurations (Tables VIII & X).

Table XII presents an overall summary of the optimum horizontal beamwidths determined by the homogenous network simulations and the capacity gains obtained over a baseline three sector configuration of 3x62°.

TABLE II
IDEALIZED HOMOGENEOUS NETWORK, CASE 1, THREE SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 50	54	58	62	66	70	74	78	82	86	90
Ec/Io Outage Area <= 5%	5.0%	0.2%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ec/Io Mean >= 11dB	-11.0	-10.0	-10.0	-10.1	-10.1	-10.1	-10.2	-10.2	-10.3	-10.3	-10.4	-10.5
RSCP Mean <= 1dB from Peak	-74.9	-75.6	-75.3	-75.1	-75.0	-74.9	-74.9	-74.9	-74.9	-74.9	-74.9	-75.0
Cell Edge RSCP <= 2dB from Peak	-81.2	-82.9	-82.3	-81.9	-81.6	-81.3	-81.3	-81.2	-81.2	-81.2	-81.2	-81.2
Throughput Mean <= 10% from Peak	3.51	3.51	3.50	3.48	3.44	3.39	3.32	3.25	3.17	3.08	2.99	2.89
Cell Edge Throughput <= 10% from Peak	1.16	1.15	1.16	1.16	1.15	1.15	1.13	1.11	1.10	1.08	1.06	1.03
Total SHO	40.0%	22.0%	22.5%	22.8%	23.6%	25.0%	26.2%	27.6%	28.8%	30.2%	31.6%	34.2%
Site Throughput	N/A	10.52	10.51	10.45	10.32	10.17	9.96	9.74	9.50	9.23	8.96	8.67

TABLE III
IDEALIZED HOMOGENEOUS NETWORK, CASE 1, SIX SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 22	26	30	34	38	42	46	50	54	58	62
Ec/Io Outage Area <= 5%	5.0%	11.2%	3.4%	1.3%	0.9%	0.8%	0.7%	0.7%	0.8%	0.9%	1.1%	1.4%
Ec/Io Mean >= 11dB	-11.0	-10.9	-10.5	-10.3	-10.3	-10.4	-10.5	-10.6	-10.7	-10.8	-11.0	-11.1
RSCP Mean <= 1dB from Peak	-71.9	-74.3	-73.0	-72.3	-72.0	-71.9	-71.9	-72.0	-72.1	-72.3	-72.4	-72.6
Cell Edge RSCP <= 2dB from Peak	-78.2	-87.4	-83.3	-80.9	-79.5	-78.6	-78.3	-78.2	-78.3	-78.4	-78.5	-78.6
Throughput Mean <= 10% from Peak	3.18	2.8	3.1	3.2	3.1	3.0	2.9	2.7	2.6	2.4	2.2	2.0
Cell Edge Throughput <= 10% from Peak	1.03	0.5	0.8	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
Total SHO	40.0%	25.9%	22.5%	25.9%	28.6%	31.4%	34.3%	37.0%	39.7%	44.9%	47.6%	52.9%
Site Throughput	N/A	16.93	18.61	19.05	18.81	18.20	17.38	16.42	15.37	14.29	13.22	12.23
Capacity Gain Over 3 Sector	N/A	1.64	1.80	1.85	1.82	1.76	1.68	1.59	1.49	1.38	1.28	1.18

TABLE IV
IDEALIZED HOMOGENEOUS NETWORK, CASE 1, NINE SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 12	14	16	18	20	22	24	26	28	30
Ec/Io Outage Area <= 5%	5.0%	14.5%	8.5%	3.9%	1.7%	0.6%	0.2%	0.1%	0.1%	0.1%	0.2%
Ec/Io Mean >= 11dB	-11.0	-11.3	-10.8	-10.5	-10.3	-10.3	-10.3	-10.4	-10.4	-10.5	-10.6
RSCP Mean <= 1dB from Peak	-70.1	-72.5	-71.7	-71.1	-70.6	-70.3	-70.2	-70.1	-70.1	-70.2	-70.2
Cell Edge RSCP <= 2dB from Peak	-76.8	-84.7	-82.4	-79.7	-78.0	-77.2	-76.9	-76.9	-76.8	-76.8	-76.8
Throughput Mean <= 10% from Peak	3.07	2.72	2.88	2.99	3.06	3.07	3.05	2.98	2.90	2.80	2.68
Cell Edge Throughput <= 10% from Peak	1.05	0.21	0.47	0.79	1.00	1.05	1.05	1.04	1.03	1.01	0.99
Total SHO	40.0%	23.1%	20.7%	20.9%	21.2%	24.7%	25.2%	27.6%	29.8%	33.4%	33.8%
Site Throughput	N/A	24.45	25.89	26.93	27.53	27.65	27.42	26.84	26.10	25.17	24.16
Capacity Gain Over 3 Sector	N/A	2.37	2.51	2.61	2.67	2.68	2.66	2.60	2.53	2.44	2.34

TABLE V
IDEALIZED HOMOGENEOUS NETWORK, CASE 1, TWELVE SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 8	10	12	14	16	18	20	22	24
Ec/Io Outage Area <= 5%	5.0%	33.0%	22.3%	10.4%	6.1%	4.4%	3.1%	2.9%	2.8%	2.9%
Ec/Io Mean >= 11dB	-11.0	-13.4	-12.2	-11.2	-10.8	-10.7	-10.7	-10.7	-10.8	-10.9
RSCP Mean <= 1dB from Peak	-69.1	-73.9	-72.2	-70.8	-69.9	-69.5	-69.2	-69.1	-69.1	-69.2
Cell Edge RSCP <= 2dB from Peak	-76.4	-90.1	-87.1	-82.6	-80.0	-79.0	-77.8	-77.0	-76.5	-76.4
Throughput Mean <= 10% from Peak	2.73	1.85	2.16	2.45	2.65	2.73	2.73	2.67	2.57	2.44
Cell Edge Throughput <= 10% from Peak	0.86	0.12	0.15	0.43	0.67	0.72	0.80	0.84	0.86	0.84
Total SHO	40.0%	45.2%	39.6%	33.5%	33.3%	32.1%	35.4%	34.7%	40.1%	42.4%
Site Throughput	N/A	22.16	25.93	29.37	31.78	32.76	32.75	32.04	30.82	29.27
Capacity Gain Over 3 Sector	N/A	2.15	2.51	2.84	3.08	3.17	3.17	3.10	2.99	2.84

TABLE VI
IDEALIZED HOMOGENEOUS NETWORK, CASE 1, FIFTEEN SECTOR RESULTS

Key Performance Indicator	Target/Peak	Antenna Horizontal Beamwidth [Degrees] 8	10	12	14	16	18	20
Ec/Io Outage Area <= 5%	5.0%	16.5%	5.7%	1.7%	0.6%	0.3%	0.4%	0.7%
Ec/Io Mean >= 11dB	-11.0	-11.7	-10.8	-10.6	-10.5	-10.6	-10.7	-10.9
RSCP Mean <= 1dB from Peak	-67.9	-70.0	-68.7	-68.2	-68.0	-67.9	-68.0	-68.2
Cell Edge RSCP <= 2dB from Peak	-74.6	-82.4	-77.4	-75.4	-74.8	-74.6	-74.6	-74.6
Throughput Mean <= 10% from Peak	2.78	2.42	2.67	2.78	2.77	2.67	2.52	2.34
Cell Edge Throughput <= 10% from Peak	0.97	0.18	0.65	0.86	0.97	0.97	0.95	0.91
Total SHO	40.0%	22.8%	18.0%	24.4%	25.7%	31.9%	32.8%	39.9%
Site Throughput	N/A	36.25	40.11	41.71	41.50	40.07	37.85	35.15
Capacity Gain Over 3 Sector	N/A	3.51	3.89	4.04	4.02	3.88	3.67	3.41

The Case 1 capacity gains of 1.8, 2.7 and 3.2 for the six, nine and twelve sector configurations tie in well with some of the earlier work referenced and it is interesting to see that the homogeneous simulation results also suggest yet further gains (>4) are possible by using fifteen sectors – assuming a practical 14^{o} horizontal beamwidth antenna could be produced and deployed. The results of the standalone higher order sectorisation simulations using the optimal antenna

TABLE VII
IDEALIZED HOMOGENEOUS NETWORK, CASE 3, THREE SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 50	54	58	62	66	70	74	78	82	86	90
Ec/Io Outage Area <= 5%	5.0%	0.6%	0.5%	0.5%	0.6%	0.7%	0.7%	0.8%	0.9%	1.1%	1.3%	1.5%
Ec/Io Mean >= 11dB	-11.0	-10.4	-10.5	-10.5	-10.5	-10.6	-10.6	-10.7	-10.8	-10.8	-10.9	-11.0
RSCP Mean <= 1dB from Peak	-92.9	-93.4	-93.2	-93.1	-93.0	-92.9	-92.9	-92.9	-92.9	-92.9	-93.0	-93.0
Cell Edge RSCP <= 2dB from Peak	-101.0	-101.6	-101.3	-101.2	-101.1	-101.0	-101.0	-101.0	-101.0	-101.1	-101.1	-101.2
Throughput Mean <= 10% from Peak	3.02	3.02	3.01	2.98	2.94	2.89	2.83	2.76	2.69	2.62	2.54	2.46
Cell Edge Throughput <= 10% from Peak	0.94	0.94	0.93	0.92	0.91	0.89	0.87	0.86	0.84	0.83	0.81	0.79
Total SHO	40.0%	24.7%	26.1%	27.0%	28.2%	29.4%	30.7%	32.0%	33.4%	34.6%	36.0%	38.4%
Site Throughput	N/A	9.07	9.03	8.94	8.81	8.66	8.49	8.29	8.08	7.86	7.63	7.39

TABLE VIII
IDEALIZED HOMOGENEOUS NETWORK, CASE 3, SIX SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 22	26	30	34	38	42	46	50	54	58	62
Ec/Io Outage Area <= 5%	5.0%	15.9%	10.9%	6.0%	3.9%	3.2%	3.0%	3.1%	3.4%	3.8%	4.6%	5.7%
Ec/Io Mean >= 11dB	-11.0	-11.5	-11.1	-10.9	-10.8	-10.9	-10.9	-11.0	-11.1	-11.3	-11.4	-11.6
RSCP Mean <= 1dB from Peak	-90.0	-92.4	-91.2	-90.4	-90.1	-90.0	-90.0	-90.1	-90.2	-90.3	-90.5	-90.6
Cell Edge RSCP <= 2dB from Peak	-98.3	-104.3	-103.6	-101.3	-99.7	-98.8	-98.4	-98.3	-98.3	-98.5	-98.6	-98.8
Throughput Mean <= 10% from Peak	2.73	2.43	2.64	2.73	2.72	2.64	2.53	2.39	2.24	2.09	1.94	1.80
Cell Edge Throughput <= 10% from Peak	0.78	0.49	0.50	0.64	0.75	0.78	0.78	0.77	0.76	0.74	0.71	0.68
Total SHO	40.0%	34.7%	31.9%	30.7%	32.8%	35.9%	38.7%	41.3%	43.9%	48.9%	51.4%	56.5%
Site Throughput	N/A	14.57	15.83	16.39	16.31	15.84	15.16	14.35	13.46	12.53	11.63	10.78
Capacity Gain Over 3 Sector	N/A	1.65	1.80	1.86	1.85	1.80	1.72	1.63	1.53	1.42	1.32	1.22

TABLE IX
IDEALIZED HOMOGENEOUS NETWORK, CASE 3, NINE SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 12	14	16	18	20	22	24	26	28	30
Ec/Io Outage Area <= 5%	5.0%	15.0%	8.1%	3.0%	1.3%	0.9%	0.7%	0.7%	0.8%	1.2%	1.5%
Ec/Io Mean >= 11dB	-11.0	-11.5	-11.0	-10.7	-10.6	-10.6	-10.6	-10.7	-10.8	-10.9	-11.0
RSCP Mean <= 1dB from Peak	-88.1	-90.5	-89.5	-88.8	-88.5	-88.3	-88.2	-88.1	-88.1	-88.2	-88.3
Cell Edge RSCP <= 2dB from Peak	-96.5	-102.7	-99.5	-97.7	-97.0	-96.6	-96.5	-96.5	-96.5	-96.6	-96.6
Throughput Mean <= 10% from Peak	2.78	2.45	2.61	2.73	2.78	2.78	2.74	2.68	2.59	2.50	2.40
Cell Edge Throughput <= 10% from Peak	0.94	0.21	0.51	0.82	0.91	0.94	0.93	0.90	0.87	0.84	0.81
Total SHO	40.0%	24.9%	21.8%	23.1%	24.8%	28.4%	29.7%	32.0%	34.2%	37.9%	38.5%
Site Throughput	N/A	22.09	23.53	24.54	24.99	24.98	24.65	24.09	23.35	22.50	21.58
Capacity Gain Over 3 Sector	N/A	2.51	2.67	2.78	2.84	2.83	2.80	2.73	2.65	2.55	2.45

TABLE X
IDEALIZED HOMOGENEOUS NETWORK, CASE 3, TWELVE SECTOR RESULTS

Key Performance Indicator	Target/ Peak	Antenna Horizontal Beamwidth [Degrees] 8	10	12	14	16	18	20	22	24
Ec/Io Outage Area <= 5%	5.0%	35.6%	23.3%	12.9%	8.8%	7.8%	7.2%	6.5%	6.2%	6.5%
Ec/Io Mean >= 11dB	-11.0	-13.6	-12.5	-11.6	-11.2	-11.1	-11.1	-11.1	-11.1	-11.2
RSCP Mean <= 1dB from Peak	-87.2	-91.9	-90.2	-88.6	-87.8	-87.4	-87.2	-87.2	-87.2	-87.3
Cell Edge RSCP <= 2dB from Peak	-96.5	-109.2	-106.8	-101.7	-99.3	-98.2	-97.8	-97.1	-96.7	-96.5
Throughput Mean <= 10% from Peak	2.47	1.71	1.99	2.25	2.41	2.47	2.46	2.40	2.31	2.19
Cell Edge Throughput <= 10% from Peak	0.65	0.13	0.16	0.40	0.58	0.61	0.62	0.63	0.65	0.65
Total SHO	40.0%	51.2%	45.4%	39.5%	38.8%	38.4%	41.2%	40.7%	45.0%	47.0%
Site Throughput	N/A	20.57	23.87	26.99	28.86	29.63	29.47	28.76	27.69	26.29
Capacity Gain Over 3 Sector	N/A	2.33	2.71	3.06	3.27	3.36	3.34	3.26	3.14	2.98

TABLE XI
IDEALIZED HOMOGENEOUS NETWORK, CASE 3, FIFTEEN SECTOR RESULTS

Key Performance Indicator	Target/Peak	Antenna Horizontal Beamwidth [Degrees] 8	10	12	14	16	18	20
Ec/Io Outage Area <= 5%	5.0%	17.4%	7.2%	2.5%	1.2%	1.3%	2.1%	3.0%
Ec/Io Mean >= 11dB	-11.0	-11.8	-11.0	-10.8	-10.8	-10.9	-11.1	-11.2
RSCP Mean <= 1dB from Peak	-86.0	-87.9	-86.7	-86.1	-86.0	-86.0	-86.1	-86.2
Cell Edge RSCP <= 2dB from Peak	-94.3	-100.1	-96.4	-94.8	-94.4	-94.3	-94.4	-94.5
Throughput Mean <= 10% from Peak	2.56	2.24	2.47	2.56	2.53	2.43	2.29	2.12
Cell Edge Throughput <= 10% from Peak	0.86	0.23	0.57	0.82	0.86	0.84	0.80	0.76
Total SHO	40.0%	26.8%	22.9%	27.9%	30.7%	36.4%	37.9%	44.7%
Site Throughput	N/A	33.65	37.04	38.39	37.88	36.42	34.30	31.85
Capacity Gain Over 3 Sector	N/A	3.82	4.20	4.36	4.30	4.13	3.89	3.61

beamwidths determined from the Case 1 network simulations are presented in Tables XIII and XIV. Here we see that the higher order standalone configurations provide a slightly greater gain than they provide as a contiguous network of sites all having the same sector count. This is due to the fact that in these cases the central site has a higher antenna gain and is therefore able to provide greater coverage dominance than the surrounding sites with a lower sector count.

TABLE XII
OVERALL HOMOGENEOUS SUMMARY AND OPTIMUM HORIZONTAL BEAMWIDTHS FOR 3, 6, 9, 12, AND 15 SECTOR SITES

No. Sectors	Homogeneous Network Case	Optimum Antenna Horizontal Beamwidth [Degs.]	Capacity Gain Over 3 Sector Config.
3	1	62	N/A
	3	62	N/A
6	1	34	1.82
	3	34	1.85
9	1	20	2.67
	3	18	2.84
12	1	18	3.17
	3	16	3.36
15	1	14	4.02
	3	12	4.36

TABLE XIII
CASE 1 STANDALONE RESULTS, 3 SECTOR NETWORK

Central Site Sector Count	6	9	12	15
Central Site Beam Width [Degs.]	34	20	18	14
Central Site Coverage Area Increase [%]	14%	22%	26%	31%
Central Site Mean RSCP Improvement [dB]	2.1	3.1	4.2	4.9
Central Site Mean Ec/Io Improvement[dB]	-0.1	-0.2	-0.3	-0.3
Central Site Throughput Gain Over 3 Sectors	1.89	2.75	3.49	4.30

TABLE XIV
CASE 1 STANDALONE RESULTS, 6 SECTOR NETWORK

Central Site Sector Count	9	12	15
Central Site Beam Width [Degs.]	20	18	14
Central Site Coverage Area Increase [%]	6%	11%	15%
Central Site Mean RSCP Improvement [dB]	1.2	2.3	3.0
Central Site Mean Ec/Io Improvement[dB]	0.0	-0.1	-0.1
Central Site Throughput Gain Over 6 Sectors	1.48	1.88	2.31

VI. CENTRAL LONDON NETWORK SIMULATIONS RESULTS

An example downlink RSCP coverage map from the central London network simulations is shown in Fig. 6 for the case of six sectors per sites. Here we see that the non-uniform site placement and varying antenna heights leads to much more site/sector overlap than was present in the homogeneous simulations. This in turn leads to the situation that not all sites benefit equally from higher order sectorisation and some may actually lose traffic through higher order sectorisation for example site CSR 323 in Fig. 7. However on average higher order sectorisation does improve the throughput per site and the results from the simulations of the central London network are given in Table XV.

From the results it is clear that the amount of traffic and how this traffic is spread effects the gains seen, with the lowest gains being seen for the lowest amount of traffic (500 active users per scheduling period). For the 2000 user case the gains seen are very similar to those presented for the idealized homogeneous network, suggesting that the gain from higher order sectorisation can be achieved even for a network with non-ideal site placement such as the central London network.

The average results for the capacity gains from the five standalone sites deployed into a London network of three and six sectors are shown in Tables XVI and XVII for the different sector configurations deployed. Again as with the contiguous network simulation a greater gain is typically achieved for a higher traffic load and even though we have taken into account the traffic stolen from the surrounding sites in the gain calculations, as with the homogeneous simulation runs, the standalone higher order sectorisation sites take more traffic than when deployed contiguously across the network.

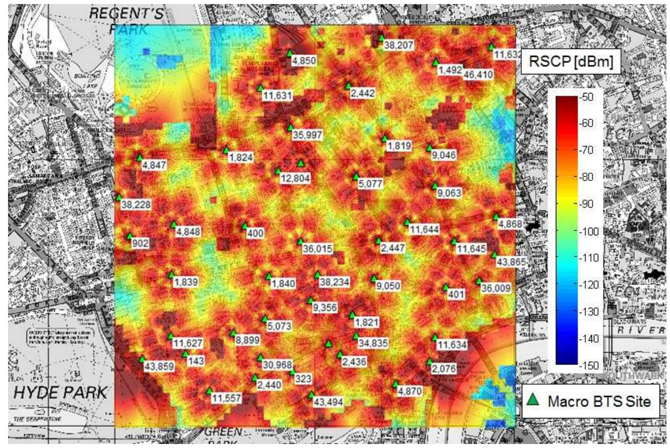

Fig. 6. Six sector RSCP coverage plot for central London simulation area.

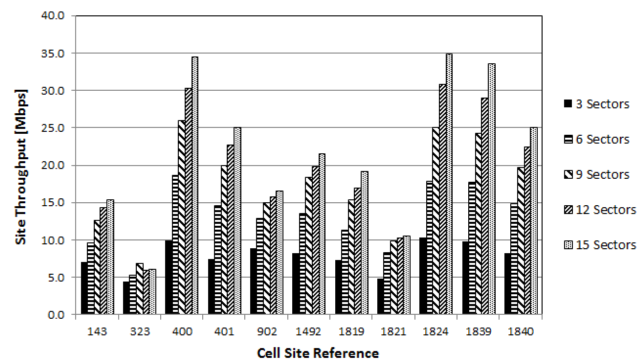

Fig. 7. Higher order gains seen across a sample of the central London sites.

TABLE XV
CENTRAL LONDON SIMULATION CAPACITY GAINS

	Sectors per site			
Traffic	6	9	12	15
500 users	1.41	1.73	1.82	1.92
1000 users	1.71	2.28	2.54	2.80
2000 users	1.85	2.64	3.08	3.56
Uniform Traffic	1.87	2.74	3.42	4.13

TABLE XVI
CENTRAL LONDON STANDALONE CAPACITY GAINS – SURROUNDING NETWORK OF THREE SECTORED SITES

Average standalone gain over three sector site capacity				
	Sectors per site			
Traffic	6	9	12	15
500 users	1.55	2.05	2.30	2.61
1000 users	1.73	2.49	2.91	3.47
2000 users	1.78	2.66	3.21	3.96

TABLE XVII
CENTRAL LONDON STANDALONE CAPACITY GAINS – SURROUNDING NETWORK OF SIX SECTORED SITES

Average standalone gain over six sector site capacity			
	Sectors per site		
Traffic	9	12	15
500 users	1.18	1.27	1.39
1000 users	1.30	1.50	1.72
2000 users	1.37	1.63	1.97

VII. Field Verification Of Higher Order Sectorisation

A. Six Sector Field Results

Telefonica UK has deployed six sector 3G sites across most of its high traffic areas including much of central London. Statistics collected by the Telefonica network performance management system from these live six sector sites have been analyzed before and after their upgrade to six sectors in order to assess the capacity benefit seen from the upgrade. Shown in Fig. 8 and Fig. 9 is the daily HSDPA traffic seen on two of Telefonica UK's central London 3G sites before and after their upgrades from three (65^{o} horizontal beamwidth antennas) to six sectors (33^{o} horizontal beamwidth antennas).

In the case of Site A, it can be seen that the average weekday HSDPA traffic volume increases from approximately 20,000 Mbytes/day prior to the upgrade to just over 30,000 Mbytes/day after the upgrade, representing a site capacity gain of around 1.5. In the case of Site B, we see a similar jump in weekday HSDPA traffic volume this time from around 17,000 Mbytes/day prior to the upgrade to around 27,000 Mbytes/day after the upgrade, representing a site capacity gain of around 1.6. Interestingly this site was included in the central London simulations which predicted a capacity gain of 1.7. Whilst the gains seen for these two sites seem lower than the average predicted by the London simulations, it must be remembered that the actual traffic gains seen are due to the increase in offered traffic to the site and therefore do not necessarily represent the actual maximum gain possible from the upgrade.

Site performance statistics are also shown for a larger sample of sites across the whole of Telefonica's UK network (Fig. 10) considering the average weekday HSDPA data volume on each of these sites two weeks before and two weeks after the site's six sector upgrade. This sample of sites is much more representative of how six sector sites are being used by Telefonica UK as a general 3G capacity upgrade mechanism since it includes city center sites as well as standalone six sector sites in smaller towns and suburban areas. From Fig. 10 it can be seen that not all six sector upgrades have resulted in the site taking more traffic in the period considered although some carry more than double their previous amount of traffic. Traffic reduction on some sites may be due to season variations in the traffic for that site, the non-uniform distribution of the traffic or because of the lack of offered traffic post upgrade. However the majority of sites have benefited from the upgrade with an average capacity gain of 1.5 seen across all 34 sites within the period considered. This average gain aligns well with the predicted 3 to 6 sector upgrade gains of 1.41 – 1.87 presented earlier in Section VI.

B. Fifteen Sector Field Results

Shown in the photograph of Fig. 11 is a fifteen sector "special event" site deployed for a concert held in London's Hyde Park on the eve of the London 2012 Olympics, 26th July 2012. The site is believed to be the first of its kind to be deployed into a live 3G network and consisted of three NSN Flexi base stations. Each base station supported five sectors of

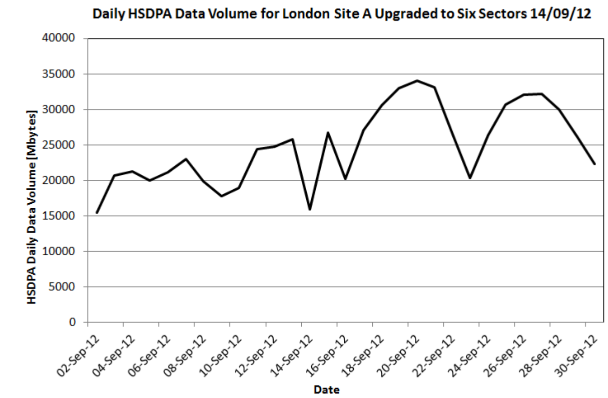

Fig. 8. Site A traffic increase after upgrade from three to six sectors

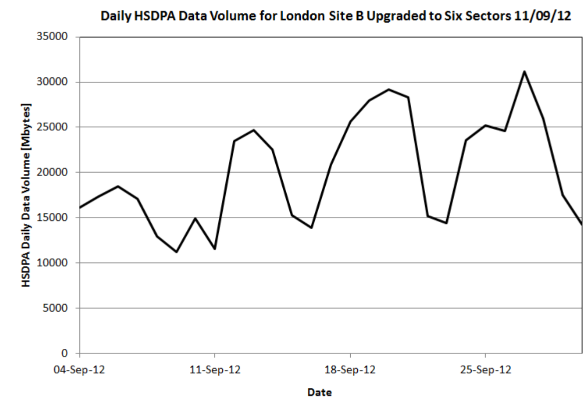

Fig. 9. Site B traffic increase after upgrade from three to six sectors.

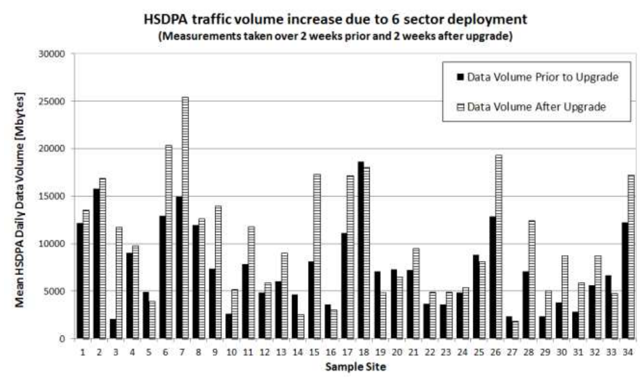

Fig. 10. Higher order sectorisation gains observed over a sample of Telefonica UK's sites upgraded from three to six sectors.

the site, with two carriers per sector (10 cells per base station). The antennas used to create the fifteen sectors of the site were three Argus 5NPX1006F antennas, with each antenna producing five horizontal beams, each beam having a horizontal beamwidth of 12^{o}, a vertical beamwidth of 11^{o} and a fixed electrical downtilt of 6^{o}.

Downlink data throughput statistics from the site for the 15 cells of the primary frequency carrier of the site during the event are shown in Fig 12. As can be seen from the statistics not all fifteen sectors were fully loaded since the site was located at the edge of the event. The peak traffic occurred during the hour between 5 and 6pm when the site carried some 5.44 Gbytes of data, equivalent to 12.1 Mbps on average over the hour. Not quite the fully loaded 35-40 Mbps predicted by the homogeneous and central London simulations for a standalone 15 sector site (Table XIII) but for a site to average

Fig. 11. Photograph of the fifteen sector cell site deployed at a special event in London's Hyde Park, 26th July 2012.

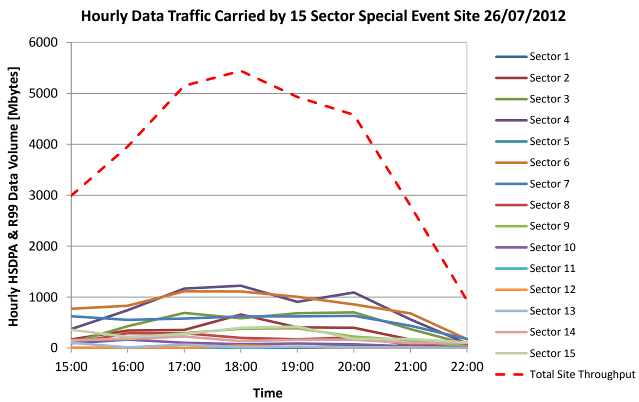

Fig. 12. Traffic volume carried by a 3G fifteen sector site during an Olympic 2012 concert in London's Hyde Park, 26th July 2012.

12.1 Mbps over an hour means there will have been periods during this hour when this site carried significantly more than the average. If the busiest sector (Sector 10) which carried 1.2 Gbytes of data in the busy hour is considered, then it can be calculated that this sector carried on average 2.7 Mbps throughout the busy hour. Had this been the case on all sectors of the site (all sectors equally loaded) then the site would have carried approximately 18 Gbytes of data in the busy hour, equivalent to 40 Mbps on average over the hour and very similar to the standalone simulation results presented earlier.

VIII. Conclusions

This paper has evaluated the gains from higher order horizontal sectorisation for a 3G/HSPA network through both simulations and field trials. Simulations upon an idealized homogeneous network have not only been used to evaluate the potential capacity gains achievable through this technique but by evaluating the results using typical cellular operator network performance KPIs they have also been used to determine the most optimum antenna horizontal beamwidths for 3G/HSPA cell sites employing horizontal sectorisation.

- Three sector site optimum horizontal beamwidth = 62^o
- Six sector site optimum horizontal beamwidth = 34^o
- Nine sector site optimum horizontal beamwidth = 20^o
- Twelve sector site optimum horizontal beamwidth = 18^o
- Fifteen sector site optimum horizontal beamwidth = 14^o

Central London simulation results have shown that for the optimum beamwidths determined from the idealized homogeneous simulations, significant capacity gains also appear achievable in real deployment scenarios with non-ideal site placement. The analysis of live network statistics from numerous six sector 3G cell sites deployed into Telefonica UK's network in both central London and across the UK have verified a downlink capacity gain of at least 1.5 from six sector deployment is typical and aligns well with the unloaded central London simulations.

Finally results from the deployment of a 15 sector special event site at the London 2012 Olympic Games have been presented. Whilst the results from this particular 15 sector trial are by no means conclusive, the trial has shown it is possible to deploy and operate a 15 sectored 3G site, the site took a considerable amount of data traffic and gains are possible through very high order sectorisation.

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