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Self Organising Network Techniques to Maximise Traffic Offload onto a 3G/WCDMA Small Cell Network using MDT UE Measurement Reports

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Abstract—**This paper presents a number of Self-Organising Network (SON) based methods using a 3GPP Minimisation of Drive Testing (MDT) approach or similar and the analysis of these geo-located UE measurements to maximise traffic offload onto lamppost mounted 3G/WCDMA microcells. Simulations have been performed for a real 3G/WCDMA microcell deployment in a busy area of central London and the results suggest that for the network studied a traffic increase on the microcell layer of up to 175% is achievable through the novel SON methods presented.**

I. Introduction

Telefonica UK, was the first UK cellular operator to deploy large numbers of 3G/Wideband Code Division Multiple Access (3G/WCDMA) microcells (small cells) into central London in order to cope with the increasing mobile data demand generated by an increasing number of smartphones on the Telefonica UK/O2 network [1]. For these or any microcells to be effective they must offload significant traffic from the macro cellular network.

This paper proposes a four SON based methods that attempt to maximise the traffic offloaded from the macrocell layer onto the microcell layer. The first two methods proposed use only microcell based measurements on which to make macrocell network optimisation decisions. The third method is based upon automatic collection of UE measurements using a 3GPP MDT [2] approach or similar and the analysis of these geo-located UE measurements. Finally a fourth method based upon a hybrid of the first three methods is shown to be the most effective method at maximising traffic offloaded onto an under laid co-channel microcell layer.

The paper begins by reviewing earlier work on SON for microcell offload and the approaches used in these earlier references. The paper then describes the four SON methods developed during this study. Simulations are presented which model the four SON methods when applied to a real network of lamppost mounted 3G/WCDMA microcells along a busy street in central London. The results of the simulations are then presented and finally conclusions are drawn.

II. Review of Previous Small Cell SON Optimisation Techniques

There have been many papers related to SON for macrocell networks and many papers applying SON to small cell (micro/pico/femto) networks but very few focussing on using SON together with MDT to maximise the traffic offload from the macrocell layer onto the small cell layer.

SON for macrocell networks has been the topic of many research papers and indeed entire European research projects [3]. References [4, 5, 6] for example present three typical approaches to SON when applied to antenna tilt in macrocellular networks, namely brute force, simulated annealing and methods based on network Key Performance Indicator (KPI) feedback. While all macrocell methods presented in the literature generally result in an improved network performance, none specifically address the problem of traffic offload to an under laid low power microcellular layer by applying SON techniques to the tilt and power settings of the macrocell layer as is proposed here in this paper.

SON for small cell networks (micro, pico and femto) has also received a great deal of focus over recent years, for example [7, 8, 9] consider changes at the small cell only and not the macrocell in order to maximise the coverage and capacity provided by standalone small cells. And while some papers clearly state the benefit of macrocell to small cell offload for both the macro and small cell users [10, 11], none can be found that propose a joint macro/microcell approach to maximise this offload nor can any references be found on MDT based methods for optimising clusters/linear deployments of lamppost mounted 3G/WCDMA microcells.

III. Telefonica UK Kensington Microcell Network

Telefonica UK deployed over 100 outdoor 3G/Wi-Fi small cell access points into central London throughout 2012 [12] in readiness for the anticipated mobile data traffic increase during the London 2012 Olympics games. Deployment was focused on areas with high 3G traffic levels as reported from network statistics. This paper focuses only on the portion of the small cell network deployed along Kensington High Street (KHS) since this portion of the network has been used by Telefonica UK as its small cell testbed.

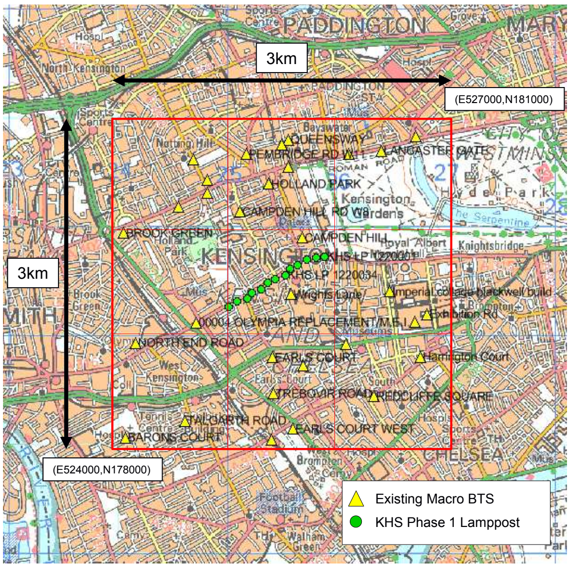

Fig. 1. Map showing the KHS microcell network in relation to existing Telefonica macrocells and the 3x3km Kensington simulation area.

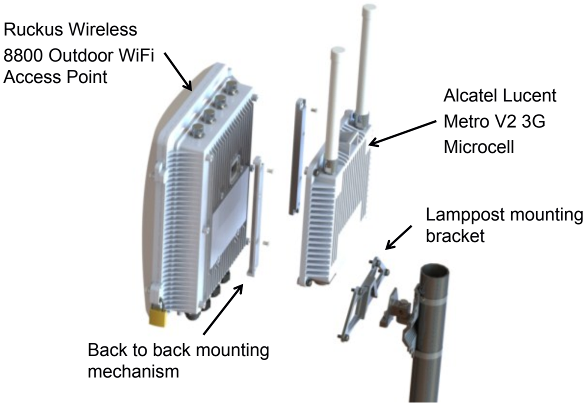

Fig. 2. Exploded schematic of the Telefonica 3G/Wi-Fi microcell.

The KHS small cell network consists of thirteen 3G/Wi-Fi microcells deployed upon existing lampposts along a 1.4km stretch of KHS, with the inter-site distances between the chosen lampposts ranging from 60 to 100m. The layout of the KHS microcell network is shown in Fig. 1 which also shows the locations of the surrounding Telefonica macrocell sites. Each KHS small cell consists of a hybrid 3G/Wi-Fi microcell located at a height of 8m on an existing KHS lamppost. The Wi-Fi Access Point was a Ruckus Wireless 8800 and the 3G microcell unit was an Alcatel Lucent Metro V2 outdoor microcell BTS. Based on a design proposed by the Telefonica both units were mounted back to back using a special mounting bracket developed by Ruckus Wireless (Fig. 2) and when mounted together appeared as an integral single unit.

IV. Maximising Traffic Offload onto the Kensington High Street Small Cells

As stated in the previous section the KHS microcell network is surrounded by many existing Telefonica UK macrocells and since these macrocells are located within central London most are high capacity three carrier 3G/WCDMA macrocells, typically having two carriers at 2100MHz and a third carrier at 900MHz. Some of these surrounding sites have also been upgraded from three to six sectors in order to increase their capacities [13] and consequently KHS is already well served by the surrounding macrocells. Therefore, when optimising the coverage and capacity of the co-channel (2100MHz) under-laid KHS microcell network, antenna and parameter adjustments will be required to be made to a number of the surrounding macrocells.

One problem identified by Telefonica's Network Engineers during the initial KHS network optimisation was how to identify which surrounding macrocells should be adjusted, and what parameters would be most effective in increasing the coverage footprint of the microcells? From the manual analysis of the KHS drive surveys it became clear that this manual optimisation process was non-optimal and it was very difficult for the Network Engineers to have an understanding from just the street level drive surveys of how the changes they were planning to make to the macrocell network would improve the coverage of the KHS microcell network and what performance effects these changes would have on the macrocell network. What was actually required was a method to automatically adjust the parameters (predominantly antenna tilts and CPICH powers) of the surrounding macrocells in order to maximise microcell coverage/traffic while still maintaining acceptable performance on the surrounding macrocells.

For KHS the Network Engineers had detailed radio coverage drive surveys of the entire deployment area, however, in the future as the volumes of small cells deployed increases, the ability to perform drive surveys before and/or after small cell deployment will not always be possible because of access or Operational Expense (OPEX) issues or both. Therefore there a second requirement of being able to estimate the actual macrocellular coverage by means other than dedicated drive surveys was also identified.

3GPP's MDT approach or similar geo-location techniques are now being proposed to achieve this understanding of macrocell coverage across all areas of the network without the need for dedicated detailed drive or walk surveys and given the above two requirements it became apparent that an automated network optimisation method to maximise traffic offload onto small cells based upon the analysis of geo-located UE measurement reports might be possible. Therefore simulations were performed for the KHS small cell network in order to investigate automated means to optimise both macro and micro coverage to maximise the capacity offload from the macrocells onto the KHS microcell layer – without compromising the network quality on the macrocell layer.

One other factor that also had to be borne in mind when investigating possible SON technique based upon analysis of collected measurements was the period over which measurements must be taken in order to have a representative view of the network. Generally, Network Engineers analyse and compare daily statistics in order to observe trends within the network following a network change, since analysing statistics collected across a whole day captures the entire traffic patterns seen by the cell. Therefore if SON algorithms are expected to make their decisions by analysing the entire traffic patterns then it is also likely that they are programmed to consider daily statistics on which to base these decisions. This means that a SON algorithm that analyses daily statistics may consider only one network change per day and then will wait until the next day to review this change and then make another change and so on. SON algorithms that take too many steps to reach an optimised solution based on daily statistics are therefore unlikely to keep up with the pace of change of the network as new cells are added and removed from the network. Therefore in order to be effective, SON algorithms based on the analysis of daily statistics requiring the least number of changes to arrive at an optimised solution are likely to be the most effective when deployed in a live cellular network.

V. Small Cell SON Simulations & Assumptions

A bespoke 3G/4G Network Simulator developed at the University of Leeds was used to evaluate various SON methods on the KHS small cell network. The simulation area used was a 3x3km area that contained 31 surrounding macrocell sites as well as the thirteen KHS lamppost mounted microcells (Fig. 1). The macrocell radio propagation model assumed for the small cell SON offload simulations was based upon the “Macrocell distance-dependent path loss model” proposed in [14] and the microcell radio propagation model assumed was the “Urban Micro Line of Sight” model proposed in [15]. The same clutter based building penetration loss was applied for both models using land use clutter data made available by Telefonica UK (Fig. 3). Cellular traffic was also distributed according to clutter class across the entire simulation area with greater user densities being applied to dense urban and urban areas than for parks and open spaces. A special hotspot class of clutter (clutter class = 17) was also defined for the KHS area (Fig. 3), and the traffic density for this area was set at five times the traffic density applied to the dense urban clutter area at 1500 users/km^2. While all sites and cells were active in the simulations to avoid edge effects macrocell statistics were gathered from only the sites and users within the central 2x2km region of the simulation area. This area included all street level microcells as well as the key sites surrounding KHS. The other main network simulation parameters for the KHS network are given below in Table I.

TABLE I. Assumed Penetration Loss & Nominal Traffic Density For Each Clutter Category Within Simulation Area.

Simulation Assumption	Value
Macro Sector Max. TX Power	37-43dBm (SON adjustable)
Micro Max. TX Power	10dBm
CPICH Power	10% Macro TX. power
Other CCCH Power	10% Macro TX. power
HSPA HS-DSCH Power	50% Macro TX. power
Macro Antenna Mechanical Tilt	As per Telefonica network setting
Macro Antenna Electrical Tilt	0-10^o (SON adjustable)
Micro Antenna Gain	2dBi
Downlink Orthogonality	0.5 (Perfect orthogonality = 1)
UE Height	1.5m
UE Antenna Gain	0dBi
UE Noise Figure	9dB
Accuracy of geo-location	25m (root mean square error)
Users Distributed	500 users per snap shot, of which 136 within the KHS high traffic area

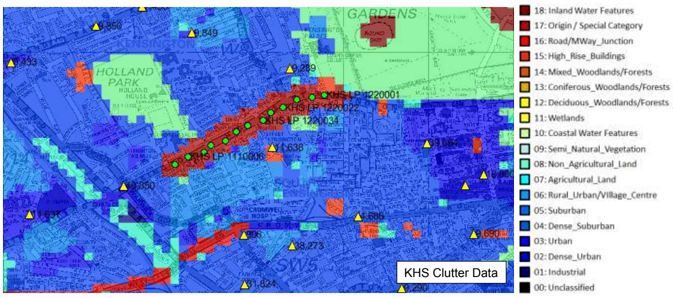

Fig. 3. Clutter Categories for Kensington small cell simulation area — showing the use of clutter category 17 to define the KHS high traffic area surrounding the thirteen lamppost microcells.

VI. Microcell SON Methods Evaluated

Previous simulations and measurements of the KHS microcell network [16] have shown that 3G/WCDMA microcells deployed with a transmit power of +24dBm on the thirteen lampposts of KHS provided dominant outdoor coverage along KHS. Therefore in order to provide a challenge for any SON algorithms being developed as part of this work, the simulated KHS microcells had their maximum transmit power limited to +10dBm (10mW), leading to a much reduced microcell coverage footprint from which to begin network optimisation. The best server areas of the +10dBm microcells prior to SON optimisation is shown in Fig. 4. This limited microcell coverage area provided just 0.08km^2 of coverage, covered just 34% of the KHS high traffic area and served on average only 47 out of the potential 136 users distributed with this area.

Fig. 4. KHS Lamppost microcell best server areas prior to network optimisation. Microcell BTS maximum output power = +10dBm.

A. *SON Offload Method 1 – Post Based Measurement Method*

The first SON method evaluated was a method that attempted to maximise the microcells’ coverage footprint by making adjustments to the surrounding macrocells’ antenna tilts and transmitter powers based upon measurements taken only at the lamppost microcells themselves. This of course would mean that the microcell would also need some additional hardware in order to be able to measure the co-channel downlink signals from the macrocells. Method 1’s microcell measurement based SON algorithm operated as follows:

1. *Each lamppost microcell reported the strongest measured macrocell to the centralised SON algorithm.*
2. *The SON algorithm then generated a **Target Macrocell List** ranked by the number of reports from the microcells for each unique best serving macrocell detected.*
3. *The SON algorithm then worked through the cells of the ranked **Target Macrocell List** considering the following conditions until a candidate macrocell to change (tilt or power) was found*

   ***if** the current candidate macrocell's downtilt could be increased (i.e. the antenna electrical tilt was not at the maximum downtilt angle of 10^o)*

   ***then** the macrocell's antenna was downtilted by a further tilt step size (in this case 1^o).*

   ***else if** the current candidate macrocell's transmit power could be reduced (i.e. the cell's transmit power was not at the minimum value of +37dBm)*

   ***then** the macrocell's transmit power was reduced by the power step size (in this case 0.5dB)*
4. *Steps 1-3 were repeated until no further changes could be made to the macrocells of the current **Target Macrocell List**.*

This basic post-based measurement method made no attempt to avoid tilting macrocells further towards the KHS microcell network, nor did it take into account the effect it was having on the macrocell coverage since its only source of information was the measurements received by the lamppost microcells. In order to overcome some of the obvious shortfalls of Method 1 a refined post-based measurement algorithm (Method 1+) was also developed to avoid macrocell tilts that increased rather than reduced the macrocell's signal level received at the KHS lamppost microcells. This was done by calculating the linear average of the Received Signal Strength Indication (RSSI) reported by each KHS lamppost microcell ($RSSI_{KHS}$) as

$$RSSI_{KHS} = 10\log_{10}\left[\frac{1}{n}\left(\sum_{i=1}^{n}10^{\frac{RSSI_i - 30}{10}}\right)\right] \text{ [dBm]} \quad (1)$$

where

n	was the number of lamppost microcells over which the linear average is made
$RSSI_i$	was the reported RSSI for lamppost microcell i in dBm.

And then comparing the $RSSI_{KHS}$ value before and after each macrocell tilt change and reverting to the previous macrocell tilt if a new tilt resulted in higher interference from the downtilted macrocell onto the KHS small cells. Also if the cell's tilt was reverted then further tilt changes to that particular cell were no longer allowed.

B. SON Offload Method 2 – 3D Xmap analysis

The third SON offload method considered (Method 2) was based upon the analysis of what is termed here as 3D or multi-layered (1^{st} best server, 2^{nd} best server, etc.) 3G/WCDMA RF Xmaps constructed through the spatial processing of MDT or similar geo-located UE measurement reports. Each simulated UE measurement report contained the best five servers' Scrambling Code, Received Signal Code Power (RSCP) and Ec/Io measurements. A root mean squared location accuracy of 25m was assumed for each UE measurement report. The 3D Xmaps generated for the MDT based SON methods were *Best Server XMap*, *Best Server RSCP XMap*, *Best Server Ec/Io XMap*, *Best Server Macro within Micro Best Server Area XMap*, *Best Server Micro Xmap* and *Best Server Macro XMap*. Values within each Xmap were overwritten with each new UE measurement report received for that location during the simulation. Method 2's SON algorithm operated as follows:

1. *The SON algorithm generated a **Target Macrocell List** by analysing the "Best Server Macrocells within Microcell Best Server Area" Xmap and ranking the interfering macrocells by the number of pixels within the Xmap that they were the strongest interferer. Only macrocells that made up greater than 5% of this Xmap were considered as change targets.*
2. *The SON algorithm then worked through the cells of **Target Macrocell List** considering the following until a change candidate was found*

   ***if** the current candidate macrocell's downtilt could be increased - (the antenna electrical tilt was not at the maximum downtilt angle of 10^o **and** changes to the cell's tilt were not frozen **and** the tilt would increase the microcells' coverage **and** the tilt would not reduce the macrocell's coverage area by greater than 10% of its original value)*

   ***then** the macrocell's antenna was downtilted by a further tilt step size (in this case 1^o).*

   ***else if** the current candidate macrocell's transmit power could be reduced - (the cell's transmit power was not at the minimum value of +37dBm **and** the power reduction would not reduce the macrocell's coverage area by greater than 10% of its original value)*

   ***then** the macrocell's transmit power was reduced by the power step size (in this case 0.5dB)*
3. *Steps 1-2 were repeated until no further changes could be made to the macrocells of the **Target Macrocell List**.*

C. SON Offload Method 3 – 3D Xmap analysis with change prediction

The fourth and final SON method investigated (Method 3) was again based upon the analysis of 3D RF Xmaps but in addition to this Method 3 also took into account the potential increase in microcell traffic each macrocell network change would provide. It did this by analysing a *Traffic Density Xmap* constructed from the geo-located UE measurement reports. In addition since the microcell locations were already known, pseudo-post reports were also delivered to the SON algorithm simply by averaging the UE reports received for the microcell locations. This method delivered measurements similar to those that would have been received from the lamppost microcells, but without the added cost and complexity of having a separate downlink receiver at each microcell.

To reduce the number of steps required for Method 3 to arrive at an optimised solution, all tilt and power combinations were evaluated for each macrocell within *Target Macrocell List* in order to determine which change resulted in the greatest increase in microcell traffic. This was done by applying the tilt and/or power changes to the RF Xmaps and then "predicting" the traffic offloaded from the macrocell layer onto the microcells that each potential change could deliver. The network change delivering the biggest traffic offload while also maintaining the overall network quality (no more than 2% of macrocell users to have an Ec/Io < -16dB) was the change that was applied to the network. Finally once the algorithm had exhausted all possible changes in the macrocell network, if it was found that a macrocell sector in the *Target Macrocell List* now served fewer than five users then this macrocell sector was powered off. This removal of a dominant interferer could lead to further changes being possible to the remaining macrocells of the Target Macrocell List. Method 3's SON algorithm therefore operated as follows:

1. *The SON algorithm generated a* ***Target Macrocell List*** *by analysing the "Best Server Macro within Microcell Best Server Area" Xmap and ranking the interfering macrocells by the number of pixels within the Xmap that they were the strongest interferer. Only macrocells that made up greater than 5% of this Xmap were considered. In addition to this any additional macrocells reported from the pseudo-post reports were added to the* ***Target Macrocell List****.*
2. *The SON algorithm then worked through the* ***Target Macrocell List*** *considering all possible tilts (uptilts as well as downtilts) and powers for each macrocell on the* ***Target Macrocell List*** *considering which change to which cell delivered the biggest gain in microcell traffic, while maintaining the user outage (Ec/Io <-16dB) below the 2% threshold across the whole macrocell network.*
3. *If no changes were possible to the cells of the* ***Target Macrocell List*** *then if any of these cells now carried five or fewer users, then these cells were switched off.*

Steps 1-3 were repeated until no further changes/removals could be made to the macrocells of the ***Target Macrocell List*** *that would increase the traffic carried by the microcell layer.*

VII. Simulation Results

The proposed four SON methods were evaluated upon the KHS small cell network using the Network Simulation tool described earlier. For each method evaluated, each network change proposed was preceded by 100 runs of the Network Simulator's Monte Carlo module, with each run seeing 500 users randomly distributed across the simulation area according to clutter class. Reports from 50,000 users were therefore considered for each network change. At the end of each run the microcell reports and Xmaps were updated accordingly and at the end of each set of 100 runs the SON algorithms being evaluated then analysed the microcell reports (Methods 1 & 1+) or Xmaps (Methods 2 & 3) in order to determine the next macrocell network change. A summary of the results for each of the four SON methods evaluated is given below in Table II.

TABLE II. Microcell Coverage and Traffic Improvements for the Four Proposed SON Methods. (Original microcell coverage area = 0.08km2 and original microcell traffic = 47 users.).

SON Method	Steps	Opt. Micro BS Area [km^2]	Micro Area Incr.[%]	Opt. Micro Traffic [Users]	Micro Traffic Incr. [%]	Macro RSCP Red. [dB]
1	162	0.376	370%	124	164%	4.3
1+	26	0.196	145%	102	117%	0.5
2	77	0.217	171%	97	105%	1.6
3	23	0.268	235%	129	175%	1.7

A. SON Offload Method 1 Results

Method 1 resulted in 162 changes being made to the macrocell network. While it significantly increased the coverage area of the microcells by some 370% and increased the offloaded traffic to the microcells by 164%, it did not deliver contiguous microcell coverage along KHS and caused an overall 4.3dB reduction in the macrocell RSCP coverage across the macrocells of the central 2x2km region of the simulation area. This reduction in macrocell coverage was due to the lack of macrocell network feedback, not possible using only microcell based measurements.

B. SON Offload Method 1+ Results

Method 1+ however, did perform much better than Method 1 because of its ability to correct any tilts that resulted in an overall increased RSSI measured at the KHS microcells. This not only avoided macrocells being tilted towards KHS that in turn increased the macrocell interference onto KHS, it also prevented extreme tilts being made to the macrocells and avoided the significant overall macrocell RSCP reduction seen in the case of Method 1. While Method 1+ did not deliver as large a coverage area or as much traffic offload onto the microcell layer as Method 1, in just 26 steps it delivered contiguous microcell coverage along KHS (Fig. 5), it increased the microcell coverage area by 145%, and delivered a reasonable increase (117%) to the traffic carried on the microcell layer. All this was achieved with just a 0.5dB reduction in the macrocell RSCP coverage.

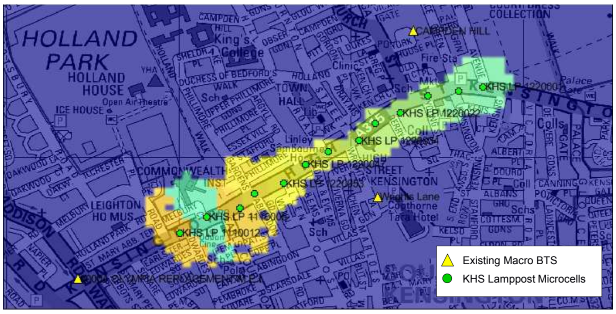

Fig. 5. KHS microcell best server coverage areas delivered by Method 1+.

C. SON Offload Method 2 Results

Method 2 as expected did not deliver the kinds of gains seen by Method 1 since it cautiously optimised the network, checking that each change would actually increase the microcell coverage and would not decrease the macrocells' coverage area by less than 10% of their original values. That said it still provided significant coverage (171%) and traffic (105%) gains for the microcell layer but unfortunately it did not provide contiguous microcell coverage along KHS and took 77 steps to deliver its solution. Method 2 led to a 1.6dB reduction in the macrocell RSCP coverage.

D. SON Offload Method 3 Results

Method 3 took just 23 steps to deliver its optimised solution (Fig. 6) and actually because of its ability to jump to the correct tilt and power setting for each change, rather than the trial and error approach adopted by the other algorithms, within its first nine steps (Fig. 7) Method 3 had delivered more contiguous coverage to the high traffic area of KHS than any of the other algorithms did over all of their entire steps. While Method 3 did not provide as great an increase in the microcell coverage areas (235%) as Method 1, the coverage increases it did provide was precisely aimed at the high traffic area of KHS, which in turn increased traffic offload onto the microcells. For this reason Method 3 provided the greatest traffic offload (175% microcell traffic increase) onto the microcells of all the four SON methods considered. It also provided contiguous coverage along KHS while maintaining the users Ec/Io outage levels below the target level of 2%. Method 3 led to a reasonable 1.7dB reduction in the macrocell RSCP coverage.

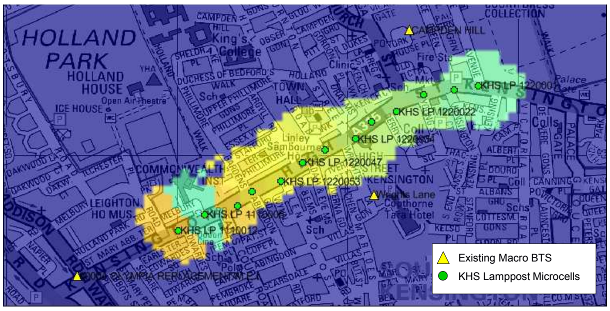

Fig. 6. KHS microcell best server coverage areas delivered by Method 3.

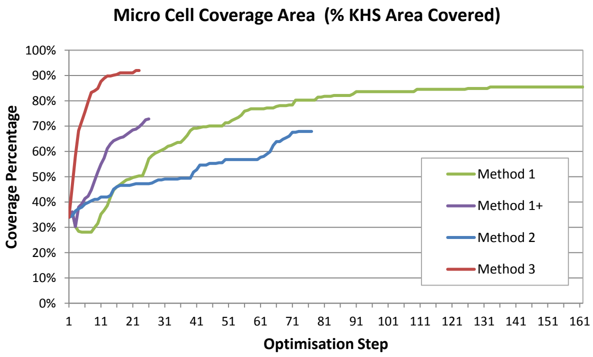

Fig. 7. Percentage of the KHS high traffic area covered versus the optimisation steps taken to achieve these coverage levels for the four SON methods considered.

VIII. CONCLUSIONS

This paper has presented four proposed SON methods developed to maximise traffic offload from a 3G/WCDMA macrocell network onto low power lamppost mounted 3G/WCDMA microcells deployed on a shared carrier frequency with the macrocell layer. Two out of the four algorithms use microcell based measurements only and the remaining two have been designed around the automatic collection and mapping of geo-located UE measurement reports on to a series of what has been termed here 3D Xmaps.

While Methods 1 and 2 delivered reasonable results, because of the number of steps both took to arrive at a solution and since neither achieved contiguous coverage along KHS both methods are discounted as being suitable SON methods for macro to microcell traffic offload.

Methods 1+ and 3 however, do appear to be viable SON based methods for increasing the traffic offload onto the microcell layer. The proposed post-based measurement method, Method 1+ appears from simulation to be a very simple yet effective SON method in order to increase the coverage and the traffic carried by the microcell layer without having a negative impact on the surrounding macrocells' network performance. It also lends itself to a simple implementation within the Radio Access Network. However, the proposed 3D Xmap with change prediction approach of Method 3 appears from simulation to be the most effective method at increasing both microcell coverage and traffic offload onto the microcell layer. The results from both these two approaches suggest that measurement based (microcell or UE) closed loop SON methods for maximising small cell offload do appear to be a realistic possibility and are worthy of further investigation.

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