Antenna Selection Procedure for BTS Over HAPs

A. Araghi [1], M. Mayiami [1], A. Montazeri [2], A. Foudazi [1], M. Yaghubi [3], and M. Bod[4]

[1] Department of Electrical and Computer Engineering
Shahed University, Tehran, Iran
{a.araghi, ma.ramezani, foudazi}@shahed.ac.ir

[2] Iran Telecommunication Research Center, Tehran, Iran
montazeri@itrc.ac.ir

[3] Department of Electrical Engineering
University of Tehran, Tehran, Iran
m.yaghoobi@ece.ut.ac.ir

[4] Department of Electrical Engineering
Amirkabir University, Tehran, Iran
mbod@aut.ac.ir

Abstract **─** In this paper, a method is proposed to find the suitable antenna for a GSM urban macro cell covered by a base transceiver station (BTS) mounted on high altitude platform (HAP) at the stratosphere layer. To this end, an ideal cosine shape radiation pattern raised to the power of N is applied to select the appropriate antenna for achieving the optimum coverage. The optimum selection is based on minimizing the blind area, having less overlapped to total area ratio, and increasing the total coverage area, simultaneously. Our proposed scheme has two degrees of freedom; first, the values of N determining the directivity and half power beam width (HPBW), and second the angle α denoting to the mechanical tilt of the antenna elements. To find the optimum pair of (N, α), several simulations are done and the corresponding footprint contours are depicted. Simulation results show that utilizing three ideal cosine function antennas with N = 9 installed by α = 38 degrees of mechanical tilt with respect to the normal is optimum for a macro cell coverage in an urban area by using HAPs located at 17 km altitude.

Index Terms **-** BTS antenna, GSM, and high altitude platforms.

I. INTRODUCTION

High altitude platforms (HAPs) are spatial stations, which can hold and serve communication system instruments in the stratosphere altitude (17 km-22 km) by using an airship or aero plane [1]. Since the stratospheric layer faces with mild wind and is above the commercial air-traffic heights, it is recommended to use this altitude to have more stabilized stations [2, 3].

Using HAPs for providing the desired coverage is advantageous for a terrestrial wireless communications, which usually suffers from non-line-of-sight (NLoS) signal component. Moreover, using HAPs results in more efficient communication link in comparison with applying satellites, which suffer from delay and implementation cost.

In the common commercial wireless communication networks, global system for mobile communications (GSM) has become one of the most popular technologies for providing the voice services for these two decades [4]. Due to the large path loss for long distances (distance > 10 km) from the base transceiver station (BTS) in urban areas, the conventional BTS cannot provide such a large coverage. The GSM BTS antennas mounted on HAPs may be one of the solutions to

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cope with this problem, since it can provide more line-of-sight (LoS) signal propagation between MS and BTS [5]. Therefore, transmitted signals experience less path loss for long distance in comparison with conventional BTS antennas. Moreover, covering larger area within a macro cell can be reliable.

Common BTS antennas (i.e., linear array of cross dipoles or slotted apertures) are installed at the height of about 30 m [6] and directed to the region of interest by using proper electrical or mechanical tilt (Fig. 1 (a)). As shown in Fig. 1 (a), the main lobe experiences the path with longer distance (results in much amount of path loss). This kind of antenna is inefficient for covering the desired circular shaped cell when it is mounted on HAP (Fig. 1 (b)). Since, the radiation pattern of the conventional BTS antennas is narrow in the yz-plane (the plane of element's placement) and wide in the xy-plane, the antenna radiation pattern has an elliptical shape footprint over the earth surface when it mounts on HAP. Thus, a large amount of desired area cannot be covered in a commonly circular macro cell, like a cell which covers urban city. For more clarity, it is useful to note that since we assume a macro cell with 20 km of radius at most, the area of the cell is very small relative to the earth surface. Hence, we assume flat earth hereafter.

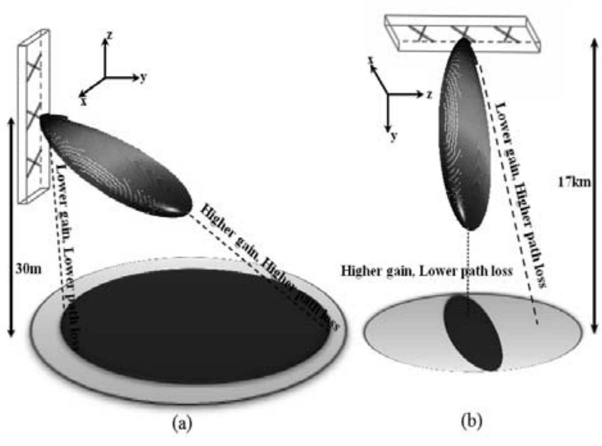

Fig. 1. Coverage area of a conventional BTS antenna (a) located at the altitude of 30 m (the direction of peak gain is electrically tilted so as to achieve the maximum possible coverage) and (b) mounted on HAP at the altitude of 17 km (without any electronical or mechanical tilt).

In this paper, to provide desired footprint contour, ideal cosine function is used to propose suitable pencil beam antennas [7, 8]. Moreover, cell sectorization [4, 6] is used for achieving a high capacity along with low signal to interference and noise ratio (SINR) within the cell.

The remainder of this paper is organized as follows; in section II, the coverage contour of conventional BTS antenna mounted on HAP is described and then an overview of antenna selection procedure is presented. Section III is devoted to the simulation and discussion of the results. Finally, in section IV, we are going through the conclusion.

II. ANTENNA SELECTION PROCEDURE FOR HAPS

In a communication system, antenna coverage depends on four independent factors: path loss, transmitted power, MS antenna gain, and BTS antenna gain, which must be considered in the link budget calculation. It is clear that in link analyzing, the first factor is an uncontrollable issue for a fixed propagation environment. Furthermore, in GSM systems, transmitted power is supposed to be selected from some specific values where most applicable transmitted power are 41 dBm for BTS transmitter (downlink) and 29 dBm for MS transmitter (uplink). Also, a typical MS antenna gain is 0 dBi and the system designer cannot control it. Considering above mentioned discussions, it seems that the only controllable factor for a system designer is BTS antenna design and configuration (the task, which is performed in this section). In subsection A, the coverage of the conventional BTS antenna mounted on HAPs is investigated and it is shown that these antennas cannot cover the urban macro cell from the altitude of 17 km. Then, the procedure of designing suitable antenna by using the ideal cosine function for covering the macro cell via HAPs is presented in subsection B.

A. Conventional BTS antenna

Suppose that a conventional BTS antenna (an array of three cross dipole antennas) is located on a platform at the altitude of 17 km and directed to the earth surface. Obviously, during the propagation, the environment has an inevitable impact on path loss. Also, path loss depends on the carrier frequency where higher frequencies result in much amount of loss. Since GSM operates in two bands (900 MHz and 1800 MHz), to meet the worst case condition from wave attenuation point of view, in this paper f = 1800 MHz has been chosen for simulations along with uplink transmission scenario due to its lower transmitted power.

The coverage contour is computed by using the Lazgare-Penin channel model given for HAPs based systems [9]. This model is based on the fact that the total path loss can be divided into two distinguished terms: the free space loss (FSL) and the effects surrounding the terrestrial terminal that are relative to its neighboring scatterers named terrestrial loss [9]. For more clarity, HAPs is considered to be an extremely high base station that can provide a propagation path consisting of the diffraction from rooftops and multiple reflections from nearby buildings beside the mentioned FSL. The FSL only depends on the frequency and line-of-sight distance between transceivers (in this case, the altitude of platform standing). The other discussed term of loss (terrestrial loss) is entirely affected by the buildings height and street width of environment alongside with the direction of arrival.

To simulate a dense urban area, we assume that the desired area includes the building with average height of 25 m and street with of 15 m. By applying the sensitivity level of -110 dBm, 20 km radii of a circular shape area (shown in Fig. 2) cannot efficiently be covered by the conventional BTS antenna at the height of 17 km. The residual parts of the circular desired area, named blind areas, experience weak received signal leading to lack of coverage. As a result, while conventional BTS antennas provide a suitable coverage in terrestrial communication, providing a method to propose an applicable antenna based on the best footprint contour coverage at the earth surface is extremely demanded for GSM-HAPs application at the stratosphere layer.

B. The main idea: selection procedure

Large macro cell can be covered by cell sectorization. In a sectored cell, there are three types of zones in terms of coverage; (a) covered areas, (b) uncovered areas or blind areas, and (c) overlapped areas where adjacent sectors cover common region (Fig. 3).

To obtain the optimum coverage area, it is desired to decrease the blind areas as well as intersector overlapped areas. If there are no overlapped areas, several blind areas would exist and consequently more call blockage would be happened. On the other hand, by increasing the amount of total overlapped areas, the number of GSM signalling procedures, especially handover or handoff, are increased which causes signalling congestion and low quality of services in the GSM network.

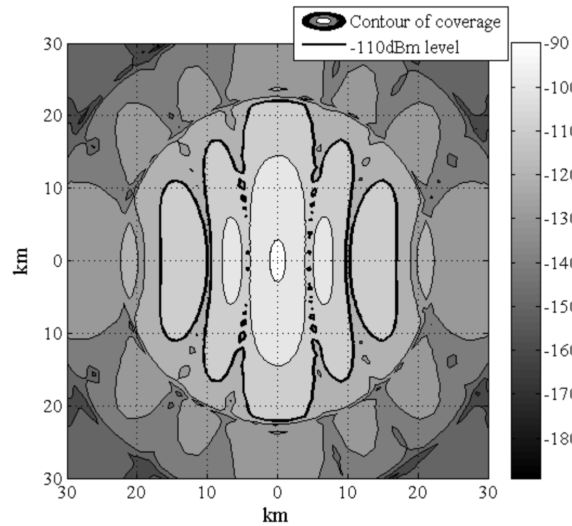

Fig. 2. Uplink coverage of a conventional BTS antenna mounted on a platform at the height of 17 km (transmitted power of MS is 29 dBm, antenna gain of MS is 0dBi, antenna gain of BTS is 17 dBi).

Therefore, we put a restriction on the amount of intersector overlapping as follows,

$$\frac{\text{Overlapped Area}}{\text{Total Area of Each Sector}} < cte \qquad (1)$$

where cte is some constant determining the signalling congestion of the network. In this paper, we suppose that the distribution of users is uniform since we do not know any priori information about the MS distribution in the cell. Also, it is assumed that the acceptable level of signaling for GSM procedure (e.g., registration, handover or handoff, and location updating) would be obtained by cte = 15 %. This is a practical assumption for GSM network manager to maintain the network quality of service appropriately. Figures 2 and 3 show that conventional BTS antenna cannot be used for satisfying this condition.

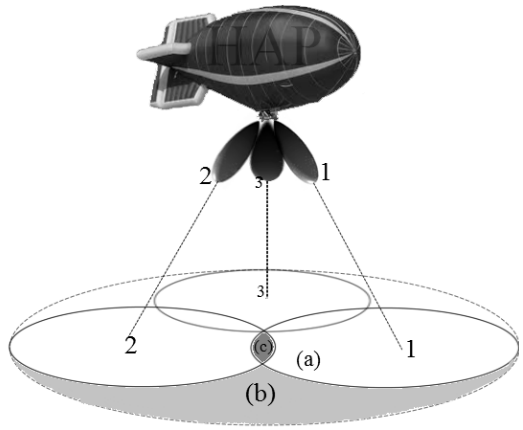

Fig. 3. The coverage zones of a three sector macro cell (a) covered area, (b) blind area, and (c) overlapped area.

Form Fig. 3 it is clear that antennas with symmetrical beam radiation pattern could satisfy the desired condition. According to [8], antennas of medium to high directivity (D) have main lobe patterns, which may conveniently be approximated by a cosine function raised to a power of N for $-\pi/2 < \theta < \pi/2$ and symmetrical properties with respect to φ as follows,

$$D = (\cos\theta)^N \frac{32\log_{10} 2}{2\left(2\arccos\left(\sqrt[N]{1/2}\right)\right)^2}. \qquad (2)$$

According to equation (2), by utilizing the higher values of N, higher directivity (and gain) and lower HPBW of radiation pattern are achieved. Figure 4 represents the radiation patterns of N = 5, 10, 15, and 20. By using these radiation patterns, directed to the area of interest, pseudo circular shaped footprints are obtained. In a covered sectored cell, as shown in Fig. 5, each sector needs to use the proposed antenna by appropriate mechanical tilt (α) with respect to the normal.

It is necessary to say that the coverage footprint is not the projections of half power beam with. The coverage of a radiation pattern is obtained via calculating the link budget for all angles θ of that radiation pattern. For more clarity, see Fig. 1 (a) where a schematic of the contour of coverage is depicted. As it is illustrated, higher amount of path loss could be compensated by higher gain of radiation pattern (provided by the main lobe) and its lower gain (provided by side lobe) is faced to shorter path (resulting in lower amount of path loss). Therefore, every angles of a radiation pattern could contribute to the coverage.

Our proposed approach is illustrated via three steps; 1) using the ideal cosine functions to model the radiation pattern of pencil beam antennas with different N and simulate the corresponding footprint on the earth surface. 2) Mechanical tilt (α) is used to fit the radiation pattern of three antennas to the cell sectors. 3) The optimum parameters, N and α, are determined (illustrated in sec. III) to satisfy the aforementioned condition.

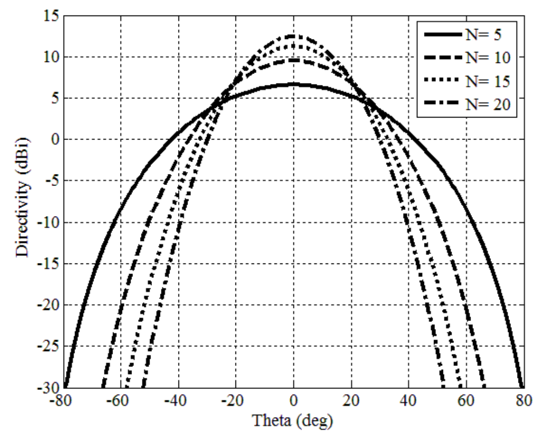

Fig. 4. Simulated radiation patterns by using the ideal cosine function for different values of N.

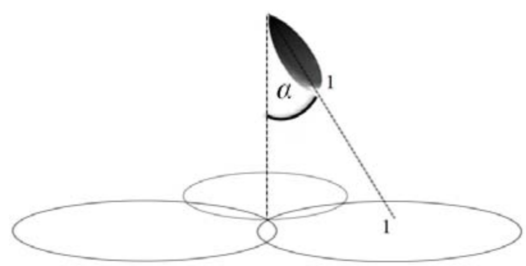

Fig. 5. Mechanical tilt by α degrees with respect to the normal.

III. SIMULATIONS AND DISCCUSIONS

The aim of this section is to find the proper values of two adjustable parameters N and α at the same time. By considering a 20 km radii circular shaped cell, which is an applicable assumption for a common urban macro cell, the proposed approach is initiated. It is assumed that the BTS antenna is mounted at the height of 17 km and other parameters are the same as in section II.

Then, parametric study has been started for different values of N and α. It has been observed that values of $10 < N < 20$ along with $30 < \alpha < 40$ result in reasonable coverage footprint. Antenna mechanical tilt leads to elliptical footprint contour instead of circular ones. The more tilt, the much resemblance to elliptical shape is occurred.

According to Tables 1 and 2, it is shown that by increasing N at a fixed tilt angle, overlapped area of two adjacent sectors as well as overlapped to total area ratio are being decreased, while the total blind area is being increased. At the same way, by increasing α for a constant N, similar results are obtained.

Table 1: Cell parameters for different pairs of N and α.

(N, α)	Overlap area of two adjacent sectors (km^2)	Overlap to total area ratio (eq. 1)	Total blind area within the cell (km^2)	Common overlap area among three sectors (km^2)
(5, 30)	324.1	%42.2	-	160.4
(5, 35)	248.4	%34.6	-	98.6
(5, 40)	183.7	%27.5	-	51.0
(10, 30)	157.5	%25.5	27.4	57.8
(10, 35)	103.9	%18.2	28.7	22.5
(10, 40)	57.1	%10.6	37.6	2.9
(15, 30)	85.3	%16.2	92.7	21.4
(15, 35)	44.5	%9.0	93.7	2.6
(15, 40)	12.2	%2.6	115.3	-
(20, 30)	48.0	%10.4	159.3	6.5
(20, 35)	16.2	%3.7	160.5	-
(20, 40)	-	-	246.1	-

For choosing the optimum pair of (N, α), the following criteria have to be satisfied; i) as is discussed in section II, part B, optimum (N, α) has to minimize both of the overlapped area of adjacent sectors and blind area, simultaneously. ii) The overlapped to total area ratio for each (N, α) has to satisfy the constraint of equation 1 with cte < 15%. iii) The optimum (N, α) should be capable of having the largest cell radius. By considering the data in Table 1, the pairs (5, 30), (5, 35), (5, 40), (10, 30), (10, 35), and (15, 30) are not suitable because they cannot satisfy equation's (1) constraint. Also, since it is required to have the minimum possible blind area and overlapped area simultaneously, all remained rows should be omitted, except for (10, 40).

As a result, it is seen that the value of (10, 40) can be a good candidate to design an appropriate antenna that can be used in three sectors macro cell in an urban area using HAP at the stratosphere layer. On the other hand, (10, 40) is a suboptimum solution since we use large steps for increasing N and α (the consecutive values of α differs in 5 degrees). For finding the optimum value of (N, α) the resolution of the simulations should be increased by decreasing the steps as much as possible. To this end, the simulations are run for all integers between $N = 5$ and $N = 20$ along with $30 < \alpha < 40$ and the results are depicted in Figs. 6 and 7. From Fig. 6, it can be concluded that the upper bound of proper (N, α) is (20, 40), since for $N \geq 20$ or $\alpha \geq 40$ the overlapped area of the two adjacent sectors is zero. Also, it is useful to mention that the flat horizontal surface of Fig. 7 shows the threshold cte = 15% of equation (1).

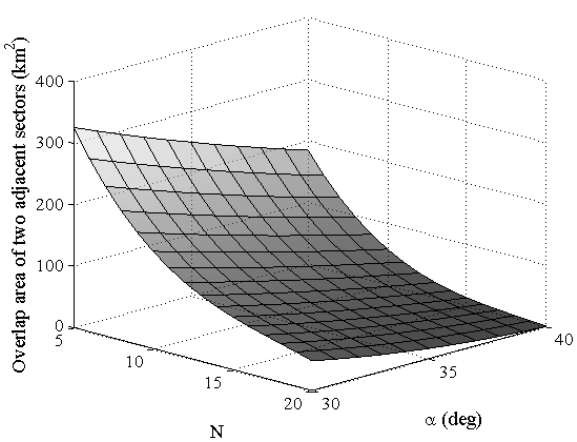

Fig. 6. The overlap area of two adjacent sectors for all $5 < N < 20$ and $30 < \alpha < 40$.

Table 2: Simulated coverage zones for different pairs of N and α.

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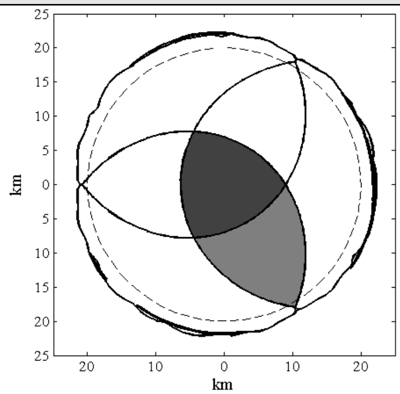
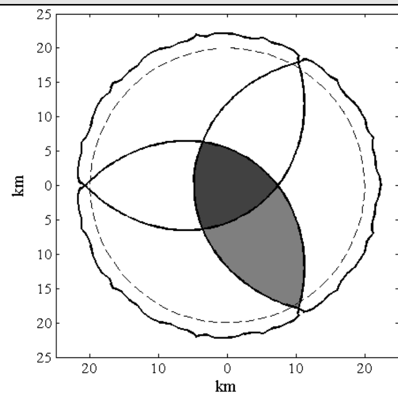
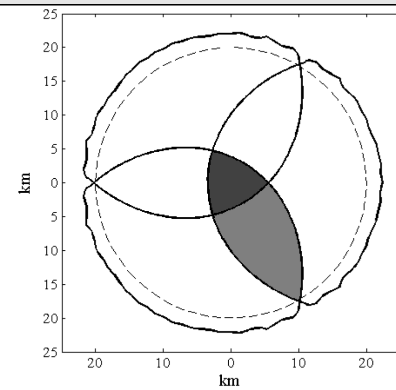
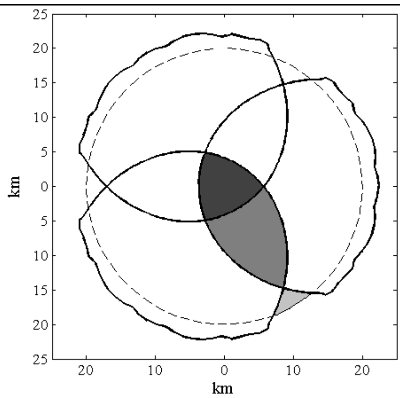
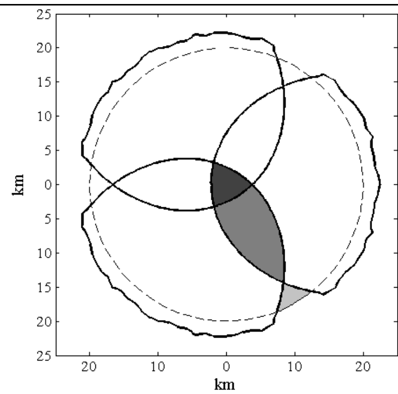
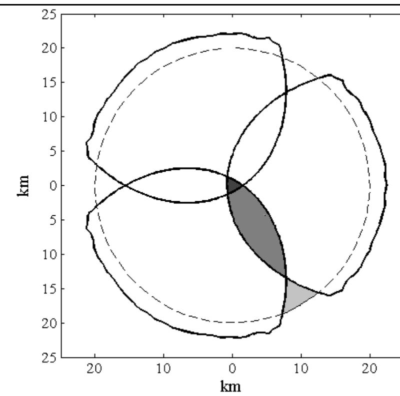
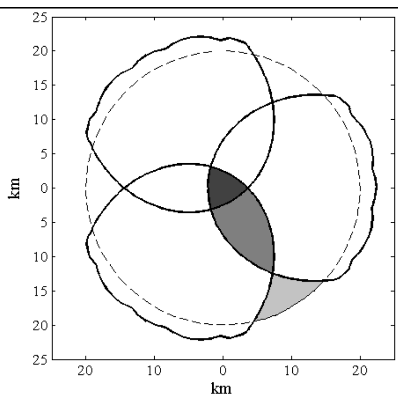
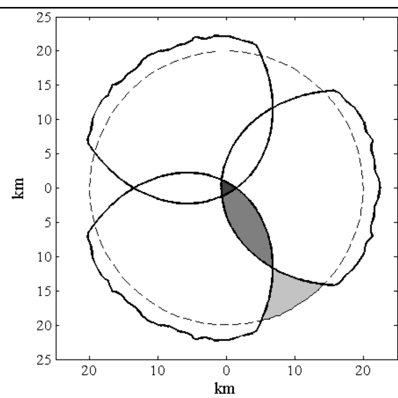
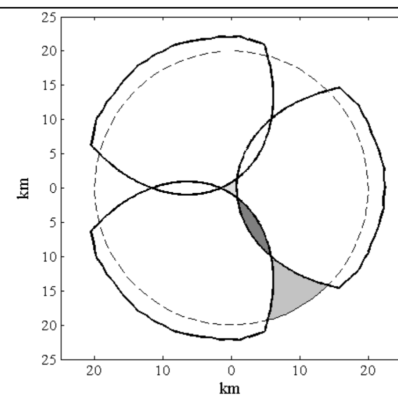
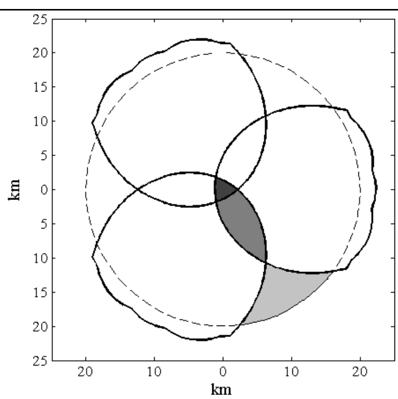
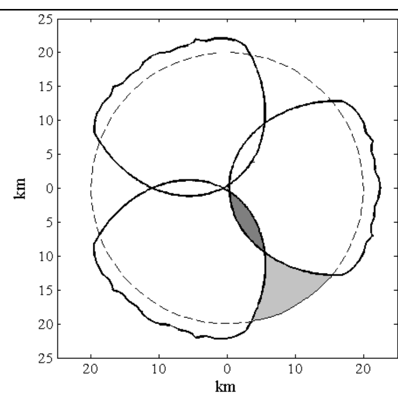
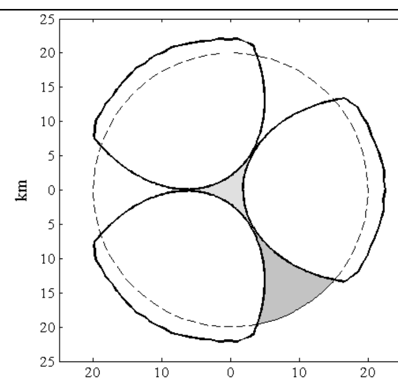
<tr><td>N=5</td><td></td><td></td><td></td></tr>
<tr><td>N=10</td><td></td><td></td><td></td></tr>
<tr><td>N=15</td><td></td><td></td><td></td></tr>
<tr><td>N=20</td><td></td><td></td><td></td></tr>
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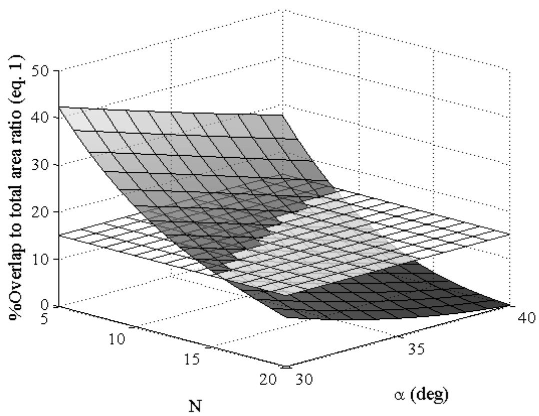

Fig. 7. The overlap to total area ratio for all $5 < N < 20$ and $30 < \alpha < 40$.

By investigating the value of (N, α) exhaustively, the pair (9, 38) is selected as the optimum point, which results in overlapped area of two adjacent sectors of 89.7 km^2, the overlapped to total area ratio of 14.9 %, the total blind area within the cell of 7.2 km^2, and common overlapped area among all three sectors of 14.4 km^2. In Fig. 5, the approximated radiation pattern of a cosine function raised to the power $N = 9$ is shown. The directivity of this radiation pattern is 9 dBi with 46 degree HPBW. Such radiation pattern with mentioned characteristics is feasible using traditional helical antennas [10] or dielectric resonator antennas (DRAs) [11], which is suitable for many applications. By mounting three of this antenna on HAP at 17 km, footprint of Fig. 8 for an urban area is attained. As you can see, the coverage of our proposed scheme is much better relative to the conventional BTS antenna depicted in Fig. 2.

It is necessary to mention that by setting $N = 9$ and $\alpha = 38$, the proportion of the common overlapped area among all three sectors to total cell area is less than 1%. Since, uniform distribution of users in the cell is considered, only 1% of users located in this area encounter with the signaling congestion, which is negligible for an urban GSM network.

IV. CONCLUSION

In this paper, a method is proposed to select the appropriate antenna mounted on high altitude platforms (HAPs) at the stratosphere altitude (17 km - 22 km) and directed to the desired GSM circular sectored macro cell for an urban area. It is shown that the conventional BTS antenna is not suitable due to its elliptical shaped footprint on the earth surface. Also, because of its low gain, the conventional antenna cannot cover the large area of a macro cell. To propose an appropriate antenna mounted on HAPs for three sectors coverage, ideal cosine function is applied. Since the radiation pattern (directivity and HPBW) of an ideal cosine function is a function of N and on the other hand, mechanical tilt (α) alters the overlapped area among three sectors, designing a sectored macro cell via HAPs has two degrees of freedom. This pair of parameters is applied to select the optimum antenna, which covers 20 km radius cell in an urban area. It is demanded to minimize blind area, to have the overlapped to total area ratio less than 15 % for two adjacent sectors, and to achieve the maximum coverage. By employing parametric study for (N, α), the optimum value of (9, 38) is obtained, which results in overlapped area of 89.7 km^2 for two adjacent sectors, the overlapped to total area ratio of 14.9%, and the total blind area of 7.2 km^2.

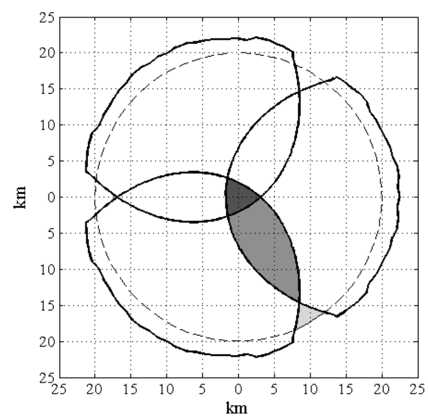

Fig. 8. Footprint of the proposed radiation pattern with (N, α) = (9, 38).

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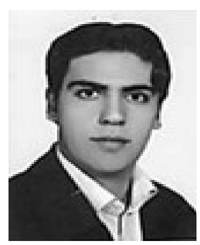
Ali Araghi was born in Mashhad, Iran, in 1985. He received his B.Sc. degree from Islamic Azad University and M.Sc. degree from Shahed University, Tehran, Iran, respectively in 2009 and 2012, both in Communication Eng. Since Jan. 2012 he has been collaborating with ICT Research Institute. His research interests include the modal analysis of open structures, phase array antenna, and printed antennas with linear and circular polarization.

Mahmoud Ramezani Mayiami received his B.Sc. and M.Sc. degrees in electrical engineering, in 2008 and 2011, respectively, both from Shahed University, Tehran, Iran. Previously, he was with Iran Telecommunication Research Center and currently, he is a Ph.D. student in ECE department at Rutgers University, New Jersey, USA. His research interests span the area of wireless communications, statistical signal processing, compressive sensing and signal detection.

Ali Mohammad Montazeri was born in Isfahan, Iran, in 1981. He received the M.Sc. degree in electrical engineering in 2008 from Iran University of Science and Technology, Tehran, Iran. Currently, he has been with Iran Telecommunication Research Center, Tehran, Iran as a researcher. His research interests include wireless communication, channel estimation, and digital beamforming.

Ali Foudazi was born in Tehran, Iran, in 1986. He received his B.Sc. and M.Sc. degrees in communications engineering from Shahed University, in 2009 and 2012, respectively. He is currently Ph.D. student in Missouri University of Science &Technology. His research interests include microwave and mm-wave devices, THz technology, antenna design, and non-destructive test.



Mohsen Yaghubi-Namaad received the B.Sc. and M.Sc. degrees from the University of Tehran, Tehran, Iran, in 2009 and 2012, respectively, all in communication engineering. From 2010, he has been with the Iran Telecommunication Research Center (ITRC), where he was involved with wireless communication projects. His main research interests include wireless communications, compressive sensing and error correcting codes.

Mohammad Bod was born in 1986, in Tehran, Iran. He received the B.Sc. degree in electrical engineering, in 2009, and the M.Sc. degree in communication engineering, in 2012, both from Shahed University, Tehran, Iran. He is currently working towards the Ph.D. degree in Amirkabir University of technology (AUT). His research interests include active microwave circuits, microwave filters, phased arrays and broad-band antenna design.