WCDMA for Air to Ground and Ground to Air communications – Case Study for Greek airspace

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Contents

Objectives

- The problem which is being studied in this paper concerns the communications between aircraft passengers with the rest of the world through their mobile phones or through internet.
- Today, the current systems of Air Traffic Management (ATM) and Air Traffic Control (ATC) have already reached peak conditions in some major airports due to the increasing numbers of flights in the last years.
- The WCDMA was regarded as a possible solution due to its relatively high spectral efficiency and due to the fact that there has been more than a decade of experience since the development of the terrestrial WCDMA systems worldwide. A capacity study of the airspace of Greece will be given.

Contribution

- The main contribution of this work is the calculation of the number of voice users in a Air-to-Ground communication systems by using closed form equation through the use of load factor, activity factor and sectoring gain.
- A Case Study of the capacity of the Air-to-Ground system for the airports of Greece for voice service of 12.2 kbps, is provided. The number of users per cell are calculated for the three major airports of Greece, using a cell radius of 175 km.

PROBLEM FORMULATION

Reverse link

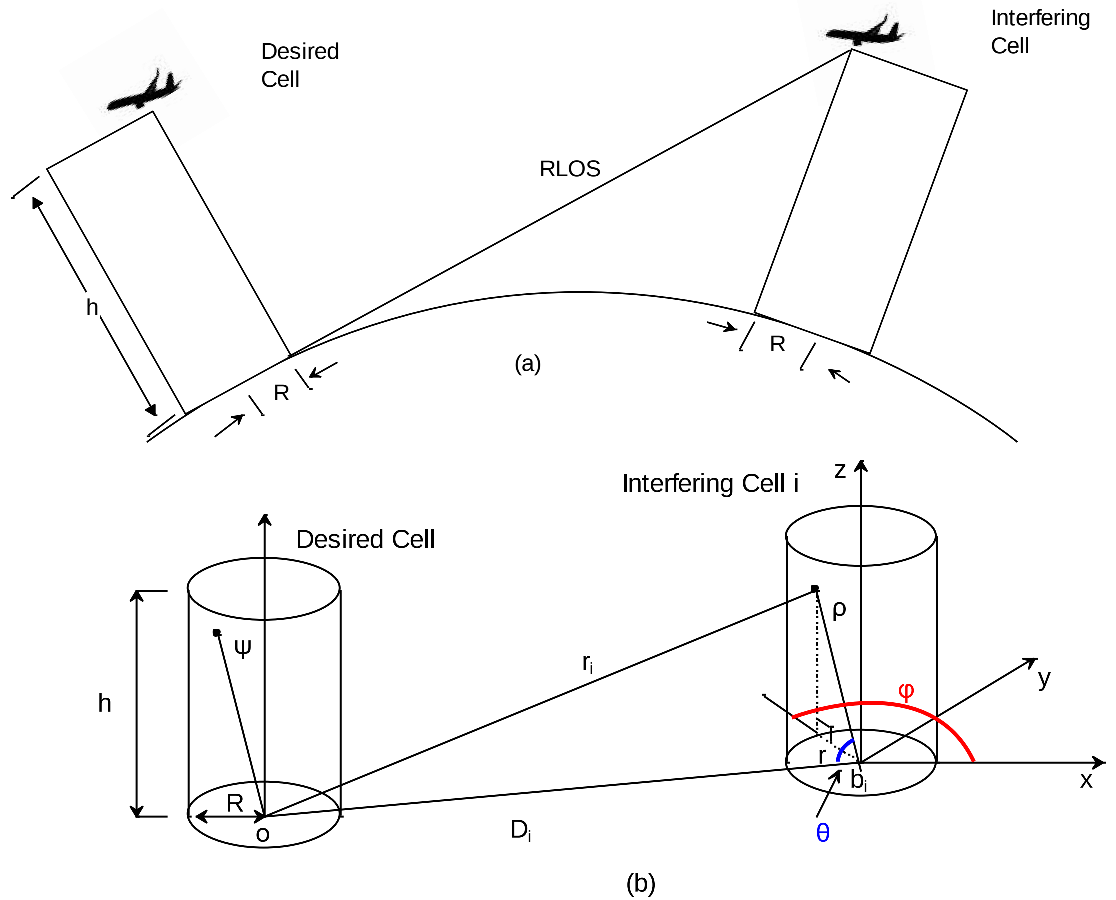

Fig. 1. The Air to Ground system - Reverse link (a) cross-sectional view (b) 3-D representation.

Reverse link

- $f_{R_i}(h,R) = \iiint_{Vi} \left({}^{\rho}/_{r_i}\right)^2 I(RLOS(z) - r_i)p(r,\varphi,z)r\,dr\,d\varphi\,dz$

- $p(r,\varphi,z) = \frac{1}{\pi R^2 h}$

- If there is LOS the indicator function $I(RLOS(z) - r_i)$ will be one, while if there is no LOS it will be zero and this should solely depend on the height z in which the aircraft flies

- $f_R = \sum_{\iota=1}^{168} f_{R_i}(h,R)$

Reverse link

- $M = \frac{(W/R_b).n_{UL}}{(E_b/N_o)} \cdot \frac{G_v G_A}{1+f_R}$
  - M is the number of active users, W/R_b is the bandwidth to data rate transmission ratio, E_b/N_o is the ratio of the energy per bit of transmitted information to the spectral noise density and interference and f_R is the outside cell interference factor.
  - The n_{UL} expresses the cell load and an indicative maximum values that can take the n_{UL} is 0.9.
  - Gv: is the gain due to voice or data activity $G_v = \frac{1}{v}$, where v is the voice activity factor, a typical value is $v = 3/8$.
  - G_A: is the gain due to antenna sectoring. This gain is derived when a sector antenna is used.

Forward link

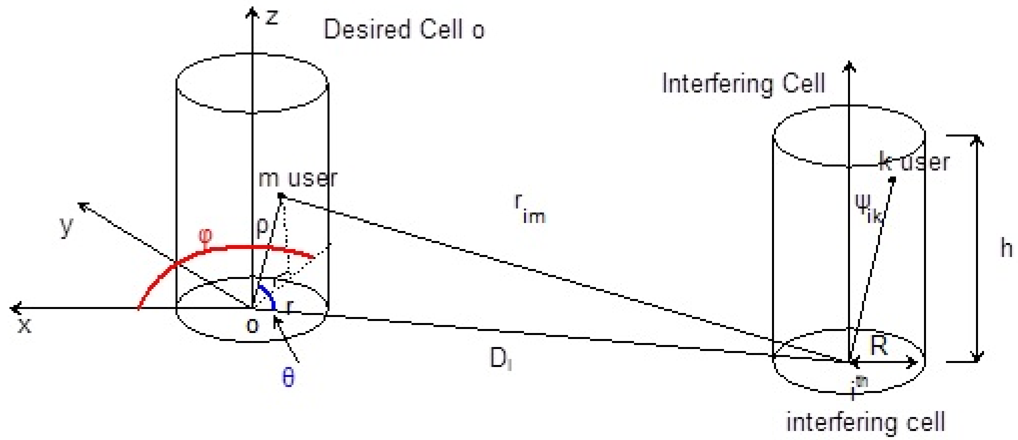

Fig. 2 Air – Ground model for forward link.

Forward link

- $$f_F = \sum_{i=1}^{168} \mu_i$$

From Fig. 2 by taking the triple integral on the cylindrical cell we have

$$\mu_i = f_{Fi}(h, R) = \int_o^{2\pi}\int_o^{R}\int_o^{h} \frac{E\left(\psi_{ik}^2\right)}{r_{im}^2} \cdot I\left(RLOS - r_{im}\right) \cdot p(r, \varphi, z) rdrd\varphi d$$

where, ψ_{ik} is the distance between the i-interfering BS and the k-th user of the i-BS and r_{im} is the distance between the i-interfering BS and the user m in cell o.

$$E\left(\psi_{ik}^2\right) = \frac{R^2}{2} + \frac{h^2}{3}$$

Thus, the number of users is given

$$M = \frac{(W/R_b) n_{DL}}{\left(\frac{E_b}{N_o}\right)} \cdot \frac{G_v n}{f_F}$$

in which n is the number of the sectors and n_{DL} is the corresponding to n_{UL} load factor for down link (or forward link). The above is valid when each sector is considered as one cell.

NUMERICAL RESULTS

Illustration of Calculation Algorithm

- Let's assume that we have a desired cell o (in the center of Fig. 3). Around the desired cell, we will assume seven rings of interfering cells.
- We are interested to calculate the distance D between the desired cell o and each interfering cell with the use of the shift parameters (i, j) where i, j are integers.
- Let's take a side, randomly, of the desired cell o. The vertical in this side is the axis movement of i, and the value of i, expresses how many cell positions we move over this axis.
- The direction of j derives, if from the direction of i, we turn for 60 degrees anticlockwise and the value of j, expresses how many cell positions we move over this axis.
- The distance D between the desired cell and the interfering cell is given

$$D = \sqrt{3}\sqrt{(iR + \cos(60^o)\, jR)^2 + (\sin(60^o) jR)^2}$$

Illustration of Calculation Algorithm

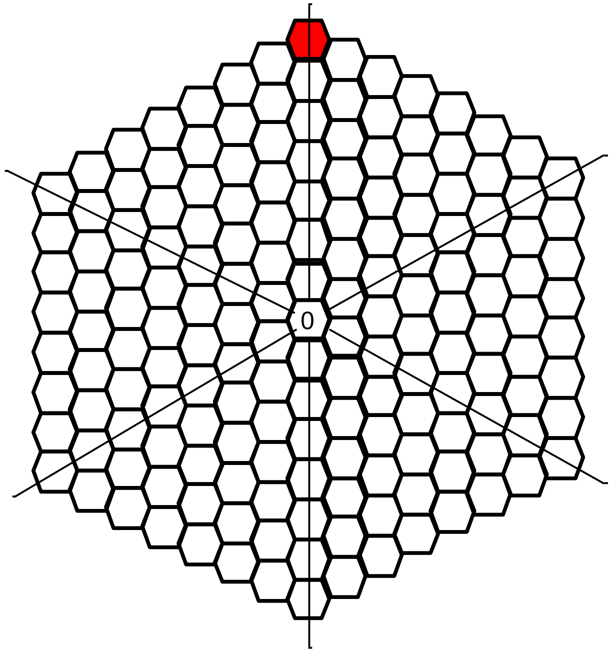

Fig. 3 The cell pattern with the central cell o which is the Desire cell and around it there are 7 rings of interfering cells. The cell pattern with the red marked interfering cell (shift parameters i=7 and j=0).

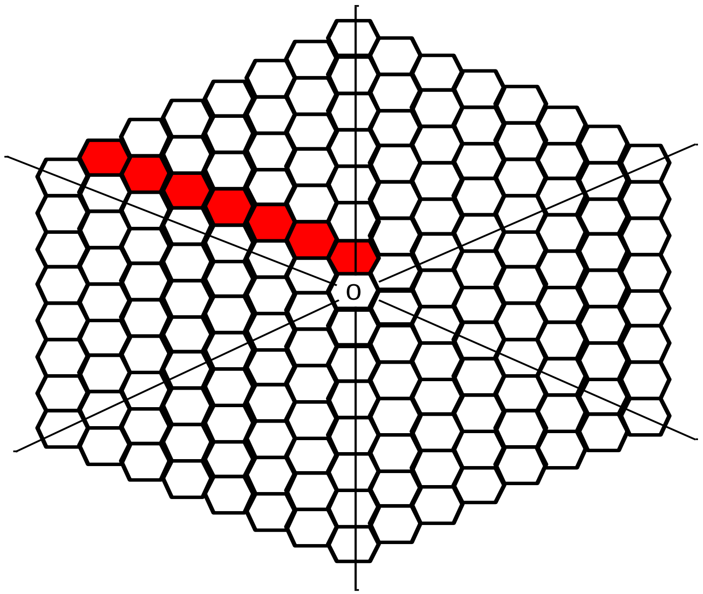

Fig. 4 The cells pattern with the red marked interfering cells (i=1 and j=0,1,2,3,4,5,6).

Illustration of Calculation Algorithm

- In the calculation of f_R, f_{R_i} is calculated for each one of the 168 interfering cells (seven rings).
- The scanning mode of these 168 cells is done by taking each one of these six sides of the desired cell o, and we draw the vertical lines to these sides. The interfering cells are divided in six sectors as can be seen in Fig. 3. Without loss of generality we can focus on one of these six sectors, for example top left sector.
- The indicator i begins from the value 7 and the indicator j takes only zero price, see Fig. 3.

Illustration of Calculation Algorithm

- Next, the indicator i is reduced by one and it becomes six, and the indicator j will take the values zero and one (i=6 and j=0,1).
- Next, the indicator i is reduced by one and it becomes five, and the indicator j will take values zero, one and two, (i=5 and j=0,1,2).
- Using the same reasoning, the indicator i is reduced each time by one and it ends up in its final value which is one and the indicator j will take the values 0, 1, 2, 3, 4, 5 and 6, see Fig. 4.
- It is obvious that in order to take the final value of f_R, it is enough to multiply f_{R_i} by six, because for each cell in the mentioned sector, there are five similar interfering cells, one in each sector, in the other five sectors.

Results for the f_R

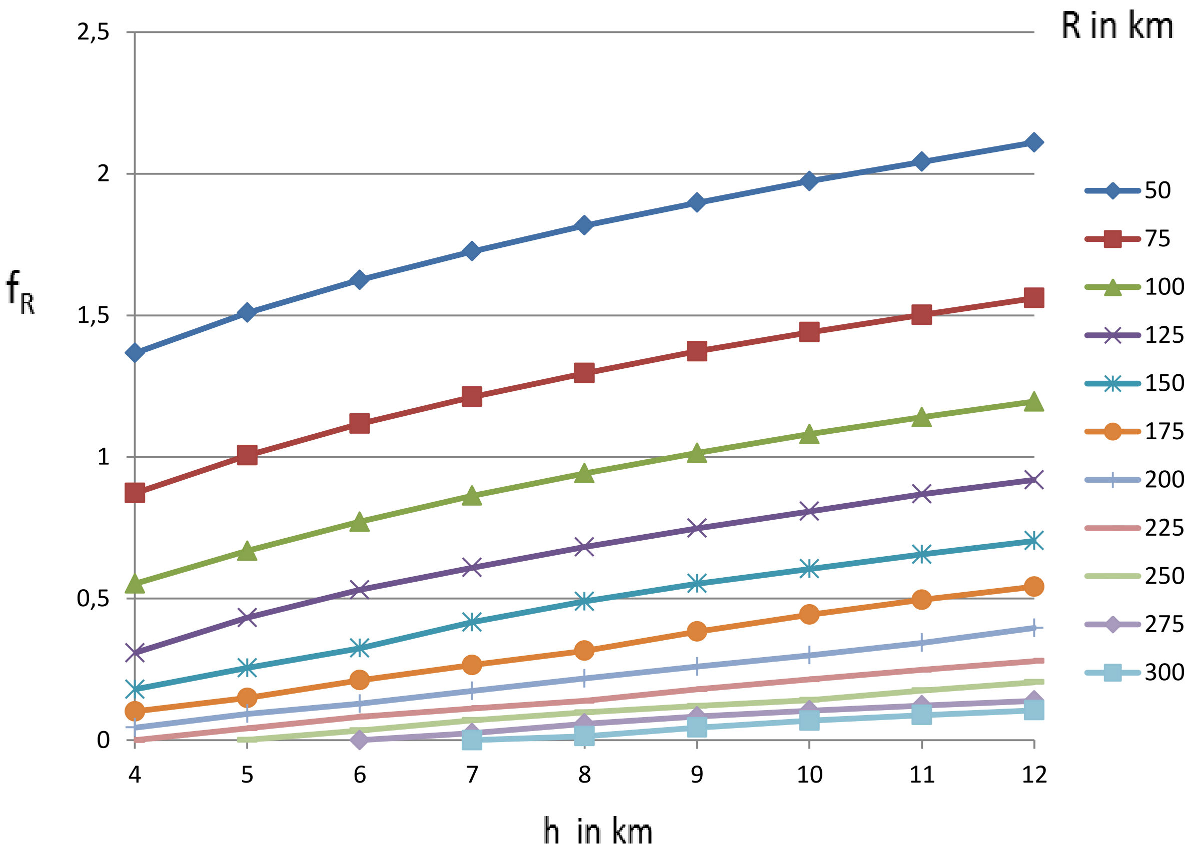

Fig. 5 The f_R as a function of h (step 1 km). Each curve is for a specific value of R=50 km, R=75 km, R=100 km, R=125 km, R=150 km, R=175km, R=200 km, R=225 km, R=250 km, R=275 km and R=300 km.

Results for f_F

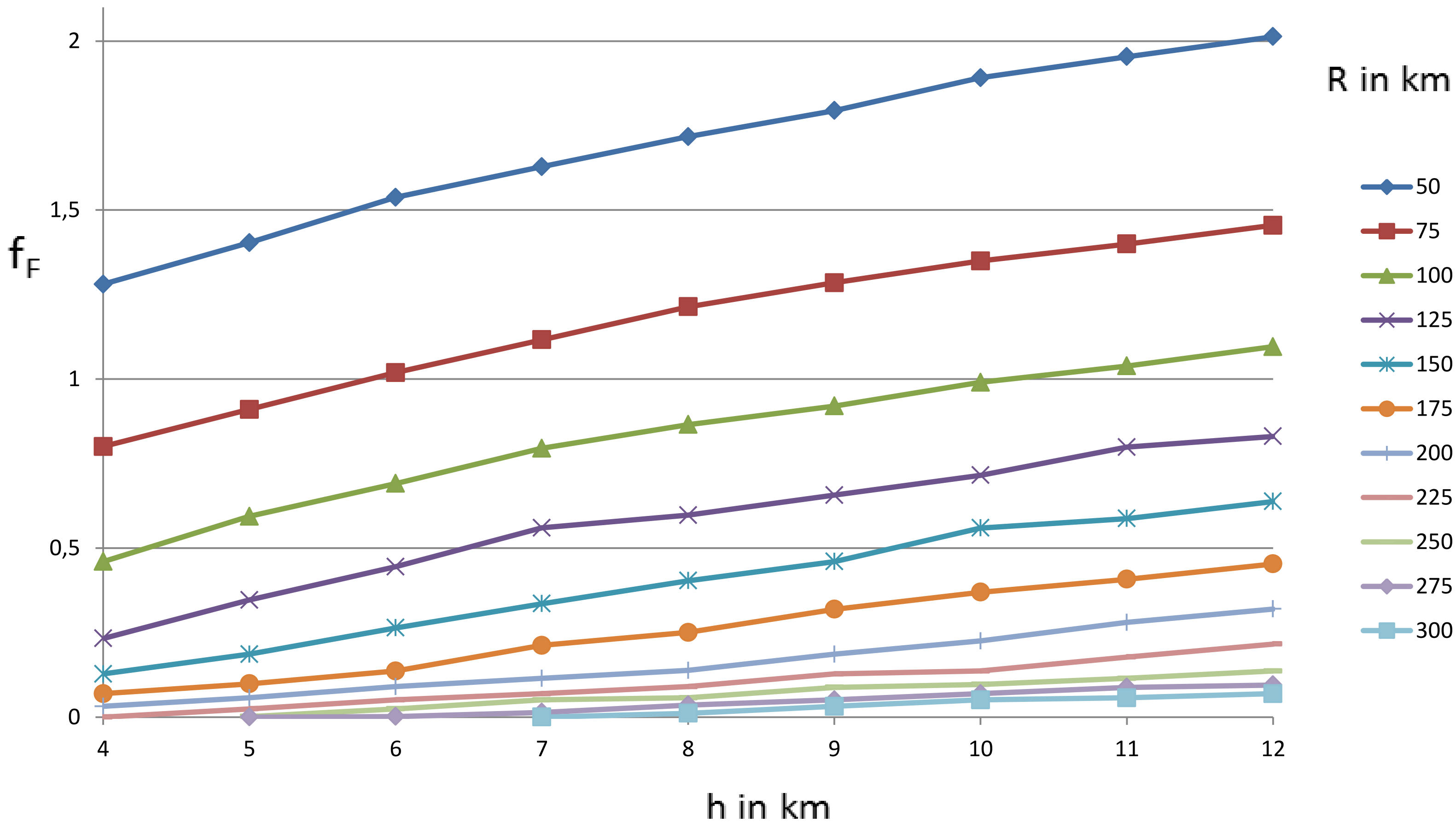

Fig. 6 The f_F as a function of h (step 1 km). Each curve is for a specific value of R=50 km, R=75 km, R=100 km, R=125 km, R=150 km, R=175km, R=200 km, R=225 km, R=250 km, R=275 km and R=300 km.

The number of subscribers in Reverse link

Table 1. M voice users in Reverse link, R_b=12.2Kbps, W=3.84Mcps, activity factor v=0.545, $n_{UL}=0.9$, Eb/No=7 dB, for R=50, 75, 100, 125, 150, 175, 200 km and for various values of h starting from 4 km to 12 km (step 1 km).

h (Km) / R (Km)	4	5	6	7	8	9	10	11	12
50	131	123	118	114	110	107	104	102	100
75	166	155	146	140	135	131	127	124	121
100	200	186	175	166	160	154	149	145	141
125	237	217	203	193	184	177	172	166	162
150	263	247	234	219	208	200	193	187	182
175	282	270	256	245	236	224	215	207	201
200	297	284	275	265	255	246	239	231	222

The number of subscribers in Forward link

Table 2. M voice users in Forward link, R_b=12.2Kbps, W=3.84Mcps, activity factor v=0.545, n_{DL}=0.9 , Eb/No=7 dB, for R=50 km, R=75 km, R=100 km, R=125 km, R=150 km, R=175 km, R=200 km and for various values of h starting from 4 km to 12 km (step 1 km).

h (Km) / R (Km)	4	5	6	7	8	9	10	11	12
50	242	221	202	191	181	173	164	159	154
75	388	341	305	278	256	242	230	222	213
100	676	523	450	391	359	338	314	299	283
125	1336	897	699	555	520	473	434	389	374
150	2438	1672	1177	927	771	675	556	529	487
175	4483	3158	2281	1464	1242	975	842	762	686
200	9759	5439	3445	2710	2255	1672	1380	1110	972

By comparing Tables 1 and 2 it can be seen that the limitation in the capacity is set by the reverse link, where the number of subscribers is significantly smaller. Therefore the values from table 1 will be used for the capacity of the Air Ground system.

CASE STUDY FOR GREEK AIRPORTS

- In order to implement the Air-to-Ground system for Greek Airports, where the base stations are located at the airports, a capacity study is provided for the three major airports in Greece, the Eleftherios Venizelos Airport of Athens, the Macedonia Airport of Thessalonica and the Nick Kazantzakis Airport of Heraklion.
- The distance between the Eleftherios Venizelos Airport of Athens (ATH) and the Nick Kazantzakis Airport of Heraklion (HER) is 308.65km.
- The distance between the Eleftherios Venizelos Airport of Athens (ATH) and the Macedonia Airport of Thessalonica (SKG) is 299.49 km.
- Based on the above distances the size of the cells will be R= 175km, so setting a cell centered at Athens and another centered at Heraklion will cover 2X175 =350 km and there is also overlapping so that the handover can be possible.

CASE STUDY FOR GREEK AIRPORTS

- The maximum height of the cell is chosen to be h=12000m or almost 39344 feet, because commercial flights fly between the 25000 and 39000 feet. In this way by choosing the maximum height of the cellular cell to be h=12000m all the possible heights of commercial flights are included.
- Three sectors will be used for every base station with antenna directions per 120 degrees, so that the coverage can approximate the cellular model we have used for the calculation of the OCIF. In Athens we will have the antenna pointing directions 50, 170 and 290 degrees. Thessalonica will have the same directions as Athens.

CASE STUDY FOR GREEK AIRPORTS

- In Fig. 7 the map of Greece is illustrated showing the three airports along with the directions of the sectors and their base stations.
- In the radio-coverage charts of terrestrial mobile telecommunication systems, the focus is on land coverage and it is obvious the shadowing effect of electromagnetic radiation due to the morphology of earth's surface. Unlike this, in the Air-to-Ground system because the beams of the antennas aim high at the aircrafts, the electromagnetic shadowing which may exist in the low altitudes is not depicted, but the coverage appears at the height the aircrafts fly.
- In Fig. 7 the range of the 175km is depicted in the direction of the sector and the total form of the coverage of each base station, it derives from the combination of the three radiation charts of the sectors. The final form of the coverage of the base station approaches the cylindrical structure of the cells.

CASE STUDY FOR GREEK AIRPORTS

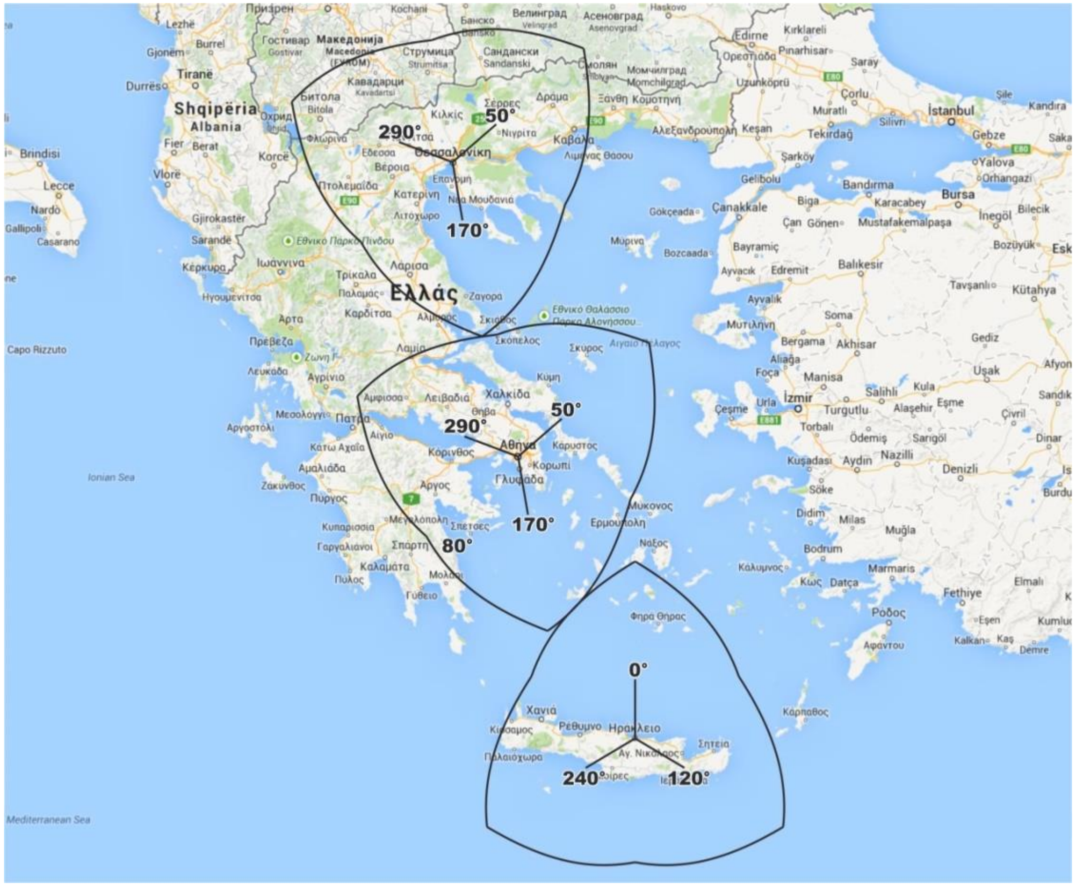

Fig. 7 Coverage map, R=175km, h=12 km.

CASE STUDY FOR GREEK AIRPORTS

Table 5: The number of users M for voice call and video call services – symmetric traffic, as a function of the bit rate R_b for DL and UL, for R = 175 km, h = 12 km, $n_{UL}=0.9$ and $n_{DL}=0.9$.

Services	Voice call	Video call	
R_b (in kbps) for both DL and UL	12.2	64	128
M users per cell for DL	497	71	35
M users per cell for UL	179	33	18
M users per cell (min value from DL and UL)	179	33	18
Total users	537	99	54

CONCLUSIONS

- From the results for the OCIF in the forward and the reverse link is confirmed that the OCIF increases logarithmically with the maximum height of the cell and reduces as long as the radius of the cell becomes longer.
- The capacity of the cell is inversely proportional of the OCIF and therefore as long as the maximum height of the cell increases the users become fewer.
- Moreover, for the same reason the capacity increases as long as the radius of the cell increases. The results above are reasonable because as long as the radius of the cell increases and its maximum height is relatively low, then due to curvature of the earth we do not have line of sight from the interfering cells and so the interference is low, therefore the capacity increases.
- For a cell radius of 175 km, for the 3 major airports of Greece, it was found that we can service at the same time up to 179 voice subscribers per cell at bit rate 12.2 kbps which reduces to 33 users for video call of 64 kbps and in 18 for video call of 128 kbps.

Thank you for your attention.