IMPACT OF ANTENNA CONFIGURATION ON UMTS PERFORMANCE IN HIGH ALTITUDE PLATFORMS

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ABSTRACT

The target of the paper is to study the impact of antenna- and cell configuration of a single high altitude platform (HAP) station on the overall network performance point of view. In the studied approach, one HAP station alone provides UMTS services to terrestrial mobile users. Large number of different antenna and cell configurations has been simulated with a system level Monte Carlo WCDMA simulator. The results emphasize the differences between of the used antenna- and cell configurations. The optimum performance was achieved by using antennas with 2 degree beam width and 6 tiers of cells for the reference location. The overall service probability with high number of users varied from 42 % to 95 %, when the antenna- and cell configuration were updated from the worst to the optimum one. The results of this paper will give some guidelines for the HAP antenna- and cell configuration planning, and emphasize the importance of proper radio network planning when targeting to maximum system performance.

I. INTRODUCTION

The use of high altitude platforms (HAP) is a novel concept for providing mobile communication service by using flying vessels (manned or un-manned) carrying the required equipment for the transmission. All cells are located on HAPs, thus the signal will be transmitted from the single points in space, i.e. from the HAP location. HAPs are typically located in the stratosphere, at the height of 17 - 22 km. The HAP approach could be especially beneficial in providing UMTS (universal mobile telecommunications system) service for large sparsely populated areas, providing possibility to avoid deployment costs of terrestrial base stations (BS). In addition, the HAP approach could be used as a backup service for emergency situations. [1] Some studies have been made regarding to the HAP antenna optimization, for example by compensating the movement of the HAP station. Ideas have been presented, how the cell locations on the Earth could be kept unchanged in case of disturbance in the HAP station location. This could be done by dynamically modifying the antenna orientations regarding to the HAP station drift. The results show how the carrier-to-interference ratio on the surface of Earth changes when the drift occurs [2]. This will have direct impacts on the short-term network performance. The impact of propagation prediction methods [3] and antenna patterns [4] on HAP capacity in UMTS system have been studied, providing good background for future research. However, extensive references of implementing UMTS system on HAPs are lacking.

The paper concentrates on finding the optimum single HAP antenna- and cell configuration (Fig. 1) for a fixed location that maximizes the service probability for the area to be inspected. Cell- and antenna configurations with different antenna beam widths and cells in different number of tiers are introduced. This will have an effect on the cell overlapping and on interference, and eventually on the network performance. Finally, the changes in the overall network performance in means of different performance indicators, such as service probability, other-to-own cell interference ratio, and soft handover (SHO) probability, are shown.

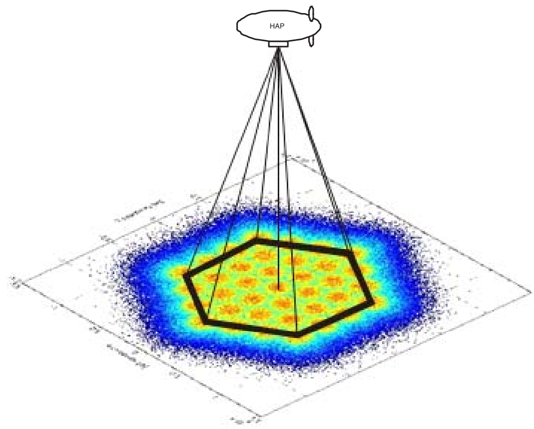

Figure 1: Illustration of HAP configuration.

The paper is organized as follows. Chapter II describes the simulation parameters and the environment together with the used cell and antenna configurations. The results are presented and analyzed in Chapter III. Finally, Chapter IV concludes and summarizes the paper.

II. SIMULATIONS

A. *Simulator and Network Parameters*

System level Monte-Carlo simulations were performed by using a Matlab-based NPSW WCDMA (wideband code division multiple access) simulator with a modification for HAP antennas and propagation [5]. The fundamental free space loss model was used for propagation prediction together with an ideal flat terrain. Propagation losses due to rain and other environmental issues were left out. Also the street level building modeling was left out, so that the effects of non-desired factors

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to the results were minimized. The study concentrated on the effect of antenna- and cell configuration on the overall network performance by using as simple environment as possible. The main network parameters used in the simulations are collected to the Table 1.

Table 1: Simulation Parameters

Parameter	Value	Unit
HAP antenna height	22	km
BS max. Tx power	37	dBm
BS max. Tx power per link	30	dBm
Common pilot channel Tx power	27	dBm
UL load limit	0.75	
BS noise figure	5	dB
UE max. TX power	21	dBm
SHO add window	3	dB
Traffic bit rate	12.2	kbps
E_b/N_0 UL	5	dB
E_b/N_0 DL	9.5	dB
Slow fading standard deviation	4	dB
DL orthogonality factor	0.9	
SHO gain (UL and DL)	1	dB

In the simulations, a single HAP station is used to provide service to a hexagonal area from the altitude of 22 km. The HAP station is assumed to stay in a static position. The HAP station carries all the equipment needed to provide the required amount of Node Bs (cells) in each particular scenario. The antennas for the Node Bs are located in a single point in space, which equals to the location of the HAP station. Each of the antennas are then tilted and oriented to the proper direction in such a way that the desired cell footprint is formed on the Earth surface. The radius of the studied hexagonal area on Earth is 10 km thereby forming an area of 260 m^2 to be covered. The size and the shape of the studied area are kept fixed through all simulation scenarios. Different scenarios are created by changing only the antenna and cell configuration at the HAP station. The traffic consisted of homogenously distributed UMTS voice users with uplink and downlink data rate of 12.2 kbps. In addition, the traffic was present only inside the hexagonal area under study.

B. HAP Antenna Pattern

The calculation of antenna loss (antenna pattern) was implemented to the simulator according to [6] in order make it consistent with HAP approach. In this approach, the antenna loss is calculated by deriving the elevation and azimuth angles relative to antenna boresight in polar coordinates. The elevation and azimuth angles, Θ_a and ϕ_a, can be calculated as:

$$\Theta_a = \arctan \frac{\sqrt{x_a^2 + y_0^2}}{h\cos(\Theta_0) + x_0 \sin(\Theta_0)} \quad (1)$$

$$\phi_a = \arctan \frac{y_0}{x_a} \quad (2)$$

where Θ_0 is the antenna tilt angle, (x_0, y_0) are the coordinates of the point under test, and x_a is the displacement x_0 transformed into a plane normal to and centered on the antenna boresight. [6] The antenna patterns chosen for the simulations comply with the recommendations given by ITU (International Telecommunication Union) [7]. Three versions of the beam widths were selected for the simulations: 5°, 3.14°, and 2°. The front-to-back ratio of the ITU antenna are rather low (about -73 dB), and practical antennas may have higher average side-lobe level. Therefore, an additional modified version of the 3.14° ITU antenna with front-to-back ratio of about -38 dB was made. On the other parts, the modified antenna pattern is similar to the ones recommended by ITU. The antenna patterns are shown in Fig. 2.

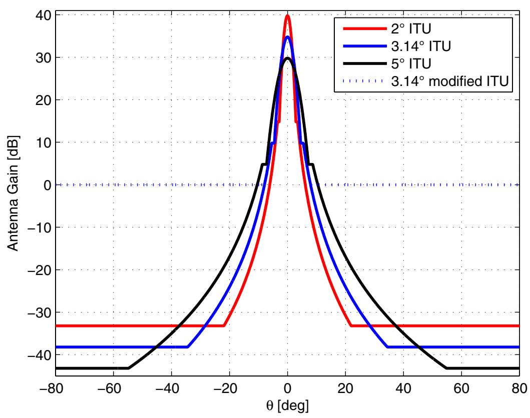

Figure 2: Antenna pattern functions for the simulations.

Simulations have been made with both, original and modified patterns, in order to see the effect of the side lobe levels on other cell interference and system performance.

C. Cell Configurations

Different cell configurations were studied in order to find the one that gives the optimum network performance with the selected antenna patterns. The 1-tier cells circulate the one cell in the middle, which is located straight below the HAP station. The cells circulate in hexagonal manner in order to fill the desired hexagon-shaped area under study. 2-tier cells are then located around the 1-tier cells. This continues until the whole hexagonal area is covered. In addition to the different antenna patterns, the different cell configurations are studied by changing the number of tiers (while the area under study stays unchanged). Thereby, the distance between the cells in different tiers is increased, and thus increase the overlapping of the cells. This has significant impact on the other cell interference and soft handover rates. The target is to find the optimum tier setting for the given configuration that gives the best coverage still without causing excess interference to neighboring cells. An example of different antenna- and cell configurations are given in Fig. 3.

Naturally, if an antenna with large beamwidth is used, lower number of tiers is enough to provide the required coverage. Similarly, if antennas with narrow beam widths are used, more

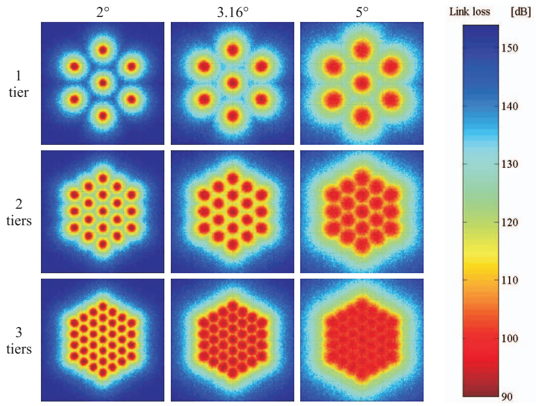

Figure 3: Examples of link loss maps of different antenna- and cell configurations used in the simulations (1 to 3 tiers).

tiers are needed in order to provide sufficient coverage. The simulations were made using the three different antenna patterns mentioned and with cell configurations from 1-tier case (7 cells in total) up to 7-tiers (169 cells in total). In addition, different load cases with total number of users from 2000 to 8000 were used to study the behavior of the network performance.

D. System Performance Indicators

The system performance indicators used in the analysis are E_C/I_0, which is the received energy per chip to interference ratio, defined as:

$$E_C/I_0 = \frac{RSCP}{RSSI} \tag{3}$$

where RSCP is received signal code power for common pilot channel, and RSSI is the total received wideband noise plus interference. E_C/I_0 95 % is the minimum value of E_C/I_0 that is exceeded in 95 % of the locations in the area studied. Service probability (SP) is the number of served users divided by the total number of users. Reasons for users not being served are capacity or coverage limitations in uplink (UL) or downlink (DL). UL Tx power is the average UE (user equipment) transmit (Tx) power, and DL Tx power is the average base station transmit power. UL i is the uplink other-to-own cell interference. UL load is defined as:

$$\text{UL load} = \frac{(I_{own} + I_{oth})}{(I_{own} + I_{oth} + N)} \tag{4}$$

where I_{own} is the total UL own cell interference power, I_{oth} is the total UL other cell interference power and N is the BS receiver noise power [5]. SHO probability is the average probability of a user having more than one connection. Cell throughput is the average throughput per cell, including SHO connections, and HAP throughput is the total throughput through the HAP, taking into consider also SHO overhead.

III. Results

A. Simulations with ITU Antenna Patterns

Since 1- to 2-tier cases are clearly coverage limited scenarios (Fig. 3), deeper analysis is not included in the paper. Low and high loaded scenarios, with total number of users of 2000 and 7000, respectively, were selected for more detailed analysis. Results for 3- to 6-tier cases with 2°, 3.14°, and 5° antennas, and 2000 and 7000 users are shown in Table 2.

1) Simulations with low load

With low load (2000 users), 3-tiers case is already providing sufficient coverage for all users in all antenna configurations, noted as service probability (SP) of almost 100 % in all low loaded scenarios. While number of tiers is increased, or antenna beam is widened, the required UL transmit power is decreasing in all scenarios, thus UL coverage is improved. DL transmit powers are decreasing while adding tiers, as long as cell overlapping is remaining low. With low load, UL load remains below the load limit 0.75, thus no users are being dropped due to high UL loading. However, UL load and UL i are increasing together with cell overlapping, indicating potential problems with higher number of users.

Increase of cell overlapping produces additional overhead in downlink due to increased number of SHO connections. With 2° antenna SHO probability remains reasonable (below 30 %) even with 6 tiers case. With 3.14° antenna, 3- to 5-tiers cases are usable, but in 6-tiers case the SHO probability is already almost 34 %. As indicated in Fig. 3, 5° antenna, with 3 tier configuration provides already moderate cell overlapping, and higher number of cells causes excess cell overlapping. 3.14° antenna with 6 tiers and 5° antenna with 4 to 6 tiers have excess overlapping, and can not therefore be considered as useful HAP configurations (SHO probability from 36.1 to 66.6 %). Since all users can be served in low load, cell throughput is affected only by number of cells and amount of SHO connections, and total HAP throughput is constant 24.4 Mbps.

2) Simulations with high load

The high load scenario, with 7000 users, reveals the capacity differences between configurations. Typical target service probability for radio network planning is minimum 95 %. In the high loaded scenario, it can be ensured only by 2° antenna with 6 tiers configuration. Also 2° with 5 tiers and 3.14° with 6 tiers provide sufficient grade of service, but all other configurations are clearly below acceptable, thus not capable of serving that many users.

Due to increased loading and interference, average transmit powers in uplink and downlink are increased. In all scenarios, uplink transmit power decreases while increasing the number of tiers. However, in downlink, Tx power of only 2° antenna is decreased, and with wider antennas, downlink Tx power is increased mainly due to excess amount of SHO connections.

UL load gets rather high in most of high loaded scenarios, thus uplink is limiting in most configurations. However, with excess overlapping (5° antenna with 6 tiers), UL load remains

Table 2: Simulation results for 3-6 tiers with 2000 and 7000 users

Antenna	2° ITU				3.14° ITU				5° ITU			
Number of tiers / cells	3/37	4/61	5/91	6/127	3/37	4/61	5/91	6/127	3/37	4/61	5/91	6/127
Low load, 2000 users												
E_C/I_0 95 % (dB)	-11.5	-11.5	-11.8	-12.9	-8.1	-8.6	-9.4	-10.1	-9.1	-10.1	-11.2	-12.3
Service probability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
UL Tx power (dBm)	-5.8	-9.8	-11.2	-12.0	-12.6	-15.9	-17.2	-18.0	-17.2	-19.6	-20.7	-21.5
DL Tx power (dBm)	28.2	24.5	22.9	22.2	27.0	25.9	25.4	25.2	30.2	30.2	30.2	30.1
UL i	0.31	0.27	0.34	0.49	0.24	0.40	0.66	1.05	0.50	1.00	1.74	2.69
UL load	0.46	0.28	0.19	0.15	0.44	0.30	0.23	0.19	0.52	0.39	0.33	0.29
SHO probability (%)	16.2	10.7	13.9	20.3	9.8	16.3	24.0	33.9	21.2	36.1	52.2	66.6
Cell throughput (kbps)	766	445	305	230	724	467	332	256	799	547	407	317
HAP throughput (Mbps)	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.2
High load, 7000 users												
E_C/I_0 95 % (dB)	-12.0	-12.3	-12.9	-13.7	-9.0	-10.5	-12.1	-13.7	-10.8	-13.0	-14.1	-15.0
Service probability	0.47	0.77	0.89	0.95	0.48	0.72	0.85	0.90	0.42	0.49	0.48	0.46
UL Tx power (dBm)	-3.7	-7.0	-7.7	-8.2	-10.3	-13.1	-14.2	-14.9	-15.1	-16.9	-18.7	-20.1
DL Tx power (dBm)	31.8	30.8	29.7	29.4	30.7	32.5	33.5	33.9	33.7	35.5	35.6	35.4
UL i	0.29	0.25	0.32	0.48	0.23	0.38	0.62	0.96	0.46	0.91	1.65	2.63
UL load	0.73	0.72	0.59	0.50	0.73	0.74	0.67	0.59	0.74	0.66	0.56	0.48
SHO probability (%)	14.0	10.5	14.3	20.5	9.5	16.5	24.4	33.9	14.1	27.6	54.8	76.1
Cell throughput (kbps)	1233	1198	950	766	1223	1185	992	808	1102	884	701	547
HAP throughput (Mbps)	40.0	66.0	75.7	80.9	41.3	61.9	72.7	76.9	35.8	42.2	41.3	39.5

below 0.5, and high DL Tx powers indicate downlink capacity limitation although also uplink interference levels are very high.

The maximum cell throughput, thus most efficient usage of equipment, is achieved with 3-tier cases, but service probability remains low. Therefore, best configuration can be found based on the highest total HAP throughput, which means also the best service probability. The best configuration is 6-tier case with 2° with SP of 95 % and total HAP throughput of 80.9 Mbps. With 3.14° antenna, 6-tier case is also the best with slightly poorer performance compared to 2° antenna. With 5° antenna, differences between different tier cases are small, and 4-tier case is providing the best service probability.

B. *Comparison of ITU and Modified Antenna Patterns*

Results of comparison between 3.14° ITU antenna and modified 3.14° antenna for 4 and 5 tier configuration are shown in Table 3. Lifting up the sidelobe levels by about 38 dB has a significant impact on the system performance. With the ITU antenna, all 2000 users can be served in both, 4 and 5 tier configurations. With the modified antenna, service probability is dropped to 0.97 and 0.92, respectively. Increased side and back lobe levels are providing service in uplink, which is visible in significantly lowered average uplink transmit powers. However, increased uplink interference shows that in dense cell configuration antenna side lobe levels have significant impact on system performance. High loaded scenario with 7000 users emphasizes the impact of increased sidelobe levels, and service probability is dropped down to 0.30 and 0.27 for 4 and 5 tier scenarios, respectively.

Table 3: Comparison between ITU 3.14° and modified ITU 3.14° antenna with 4 and 5 tiers configuration.

Number of tiers / cells	4 / 61		5 / 91	
Antenna	ITU	Modified	ITU	Modified
Low load, 2000 users				
E_C/I_0 95 % (dB)	-8.6	-13.4	-9.4	-14.4
Service probability	1.00	0.97	1.00	0.92
UL i	0.40	1.68	0.66	2.87
UL Tx Power (dBm)	-15.9	-24.7	-17.2	-26.0
DL Tx Power (dBm)	25.9	33.8	25.4	33.1
SHO probability (%)	16.3	54.5	24.0	74.3
High load, 7000 users				
E_C/I_0 95 % (dB)	-10.5	-13.7	-12.1	-14.4
Service probability	0.72	0.30	0.85	0.27
UL i	0.38	1.59	0.62	2.86
UL Tx Power (dBm)	-13.1	-24.3	-14.2	-26.0
DL Tx Power (dBm)	32.5	34.2	33.5	33.4
SHO probability (%)	16.5	41.2	24.4	66.9

C. *Practical Capacity of Simulated Configurations*

The maximum number of users that each configuration can handle with 95 % service probability gives a good estimation of practical capacity. Since the simulations are made with 2000-8000 users at intervals of 1000, very accurate results can not be shown. Thus, the results shown in Fig. 4 are interpolated to closest 500 users. With small number of cells (1-3 tiers), different antenna patterns provide approximately the same performance. With 1 tier, 95 % SP for 2000 users can not be offered with any antenna configuration, and also with 2 tiers and 2000 users SP remains still below 95 %. For 4-6 tier configurations, impact of antenna beamwidth can be observed; the narrower the antenna, the more capacity it provides while the number of tiers is increased. With 6 tiers, 5° antennas can take about 3000 users, whereas 2° antennas can serve up to 7000 users. For 7 tier configuration (169 cells), all antennas are too wide and provide excess overlapping between cells, which is seen as dropped number of served users.

Also the differences between the capacities of ITU antenna and modified antenna are shown in Fig. 4. With 3.14° ITU antenna, service for about 5000 users can be guaranteed, whereas with modified antenna capability to serve users with good probability remains at 2000 users.

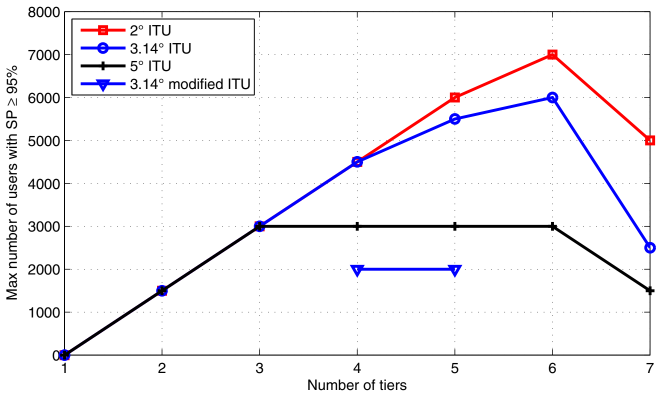

Figure 4: Maximum total number of users with 95 % of service probability for all simulated configurations.

IV. Conclusions and Discussion

Large number of different antenna and cell configurations for high altitude platform was simulated. Simulations with low load show that with low number of users, all configurations are performing well, as long as sufficient coverage can be ensured. Also with low number of tiers, differences between different antennas are rather small. Increasing the number of users create clear differences between different configurations. Cell overlapping sets limits for maximum capacity, and thus antenna beamwidth should be optimized depending on the number of cells on the HAP. Within the simulated configurations, uplink direction is most limiting, and only with excess overlapping, downlink interference is causing outage.

The results emphasize the differences between of the used antenna- and cell configurations. The optimum performance was achieved by using antennas with 2 degree beam width and 6 tiers of cells for the reference location. The overall service probability with high number of users varied from 42 % to 95 %, when the antenna- and cell configuration were updated from the worst to the optimum one.

The results of this paper will give some guidelines for the HAP antenna- and cell configuration planning, and emphasize the importance of proper radio network planning when targeting to maximum system performance. Comparison between ITU and modified antenna pattern emphasize the impact of antenna selection on the HAP performance, and the availability of suitable antennas will be one key factor in planning of UMTS for HAPs .

Since HAP implementations do not yet exist, fully reliable HAP simulations with practical parameters can not be performed. Therefore, while research on HAPs proceeds, future work consists of simulations with more accurate propagation models and information of UMTS equipment designed for HAP.

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