# Replacing Terrestrial UMTS Coverage by HAP in Disaster Scenarios

P. Lähdekorpi, T. Isotalo, K. Kylä-Liuhala, and J. Lempiäinen
Department of Communications Engineering, Tampere University of Technology
Tampere, Finland
panu.lahdekorpi@tut.fi

*Abstract*— This paper discusses the use of high altitude platforms, HAPs, to provide mobile communication services to on-ground customers. The paper explains the behavior of UMTS radio network in a situation, where the service is being provided by HAP and terrestrial base stations in a disaster scenario. In the disaster scenario, a set of adjacent terrestrial cellular base stations in the middle of the network have been disabled. A HAP station has been launched to the disaster location to provide UMTS service. The possible effects between the HAP and the terrestrial UMTS network are assessed from the system point of view by analyzing the simulation results of the radio interface. The results show that the HAP is able to improve the performance in the radio network by providing UMTS coverage from the HAP station. The HAP station is able to restore the disaster area throughput to the level of 70 % from the original level. However, to achieve good network performance using HAP, careful configuration planning is required. Thus with careless HAP configuration design, the HAP service performance could totally be lost.

*Key words–disaster, HAP, UMTS.*

## I. INTRODUCTION

High altitude platforms (HAPs) are airships or planes, operating in the stratosphere, at altitudes of typically 17 - 22 kilometers. At this altitude (which is well above commercial aircraft height), they can maintain a quasi-stationary position, and support payloads to deliver a range of services. HAPs may become an important approach in future, when providing mobile communication services in disaster areas. HAPs have many interesting properties, when compared to satellites. For example, signal propagation characteristics from a HAP station are better, since the operating altitude is clearly lower compared to the satellites. In addition, utilization of more sophisticated, high sensitivity, mobile receivers (such as satellite receivers) is not compulsory for HAPs. The most demanding challenges in HAP communication systems are perhaps more related to the mechanical phenomena such as station keeping due to wind and energy storing and consumption.

The integration of a HAP within terrestrial UMTS network has been investigated e.g. by the authors in [1] by showing the system performance estimates achievable from the HAP with different network dimensioning schemes. In this paper, the system performance is analyzed in a disaster scenario with different conditions for the on-ground mobile customers. This paper concentrates on the HAP radio communication aspects, thereby ignoring most of the HAP station keeping and other mechanical aspects. A static, MATLAB-based system-level WCDMA simulator has been used to study the capability of HAP to replace part of the terrestrial UMTS network in a disaster scenario. A disaster event was created by disabling a set of neighboring terrestrial base station sites originally providing UMTS service. The average performance in different parts of the network is then assessed in three phases: normal operation, disaster operation, and HAP assisted operation. The target of the paper is to find out how well the HAP is able to restore the service into the disaster area. Furthermore, interference between the HAP and terrestrial parts of the UMTS network was assessed.

## II. SIMULATION MODEL AND PARAMETERS

### A. Simulator

The simulations for the HAP- and terrestrial UMTS performance were performed using a MATLAB-based, static, WCDMA/UMTS simulator [2] due to its technical flexibility. A HAP base station is similar compared to the terrestrial base stations in the simulated network. Only the radio parameters such as antenna pattern and -height, receiver noise properties, and propagation characteristics are different due to different operating environment for HAP base station. A flat grid was used as a map due to poor support in the simulator for digital map and terrain modeling. The simulator only covers the radio path between the mobile station and the base station (not the connections e.g. between radio network controller elements). Thus, the scope of this system level study has been narrowed down to the physical layer in the radio interface.

### B. Environment and Radio Propagation

The propagation loss was separately calculated for terrestrial- and HAP connections. Okumura-Hata based COST-231-Hata propagation model was used for terrestrial links between a terrestrial base station and mobile station, while free space loss was used for the HAP links. The free space loss model is considered adequate, when the signals from HAP stations are coming almost perpendicular to the ground plane. Additional loss component was added to the link loss data depending on the location of the on-ground user. If the user was located indoors, a building penetration loss (BPL) value was added to model the penetration of radio signal through walls and ceilings. For the terrestrial links, BPL is fixed to 15 dB. For the HAP links, the BPL lies between 20 and 22 dB and

TABLE I

PARAMETERS FOR ENVIRONMENT MODELING.

| Description | Unit | HAP | Terr. BS |
|---|---|---|---|
| SD of shadowing (indoor) [4] | dB | 10 | |
| SD of shadowing (outdoor) [5] | dB | 4 | 8 |
| Building penetration loss [3] | dB | 20-22 dB | 15 |
| COST-231-Hata area correction factor | dB | - | 0 |
| Frequency | MHz | 2140 | |

TABLE II

RADIO NETWORK PARAMETERS.

| Description | Unit | HAP | Terr. BS |
|---|---|---|---|
| BS TX power (total) [6], [7] | dBm | 33 | 3 |
| BS TX power (per link) | dBm | 30 | 40 |
| BS noise figure | dB | 5 | |
| Maximum load in BS | | 0.75 | 0.5 |
| RX noise temperature | K | 223 | 293 |
| Antenna height | m | 17000 | 25 |
| SHO ADD window | dB | 3 | |
| Pilot channel power | dBm | 24 | 30 |
| Req. $E_b/N_0$ uplink [7] | dB | 5 | |
| Req. $E_b/N_0$ downlink [7] | dB | 8 | |
| MS max. TX power | dBm | 21 | |
| Antenna gain | dBi | 38.7 | 17.0 |
| Antenna beamwidth (hor./ver.) | deg | 2 | 65/10 |



Fig. 1.  Cell configuration for HAP assisted disaster.

is a function of the elevation angle (using the model presented in [3]). The shadowing (slow fading or log-normal fading) was modeled by introducing a random component to the link loss data, where the standard deviation (SD) of the random component defines the environment type. The propagation environment related parameters used in the simulations are shown in Table I.

### C. Radio Network Equipment and Configuration

The terrestrial radio network was deployed using a clover-leaf layout, where cell footprints are hexagonally distributed across the map. In the terrestrial network, the base station antennas were located at the height of 25 m, and the site spacing was 1200 m. Table II shows the radio parameters selected for the terrestrial- and HAP parts of the network. The radio parameters for terrestrial base station are typical values for macrocellular network. The HAP parameters are partly based on assumptions. However, values from literature are used where available.

### D. Cell Configuration

3-sectored sites were used in the terrestrial network. Furthermore, 3 tiers of terrestrial sites were simulated in order to make the network behavior homogenous in the center of the network. In the case of disaster all 1st tier sites and the site in the center were disabled. Seven HAP cells were deployed to return the UMTS service to the disaster area. Thus, one HAP cell covers approximately the area of one 3-sectored terrestrial site. Fig. 1 visualizes the cell configuration in case of HAP assisting the disaster area. The HAP cells are shown in gray and the hexagonal disaster area is visualized using dashed line. In addition, the dimensions of the network are shown in Fig. 1.
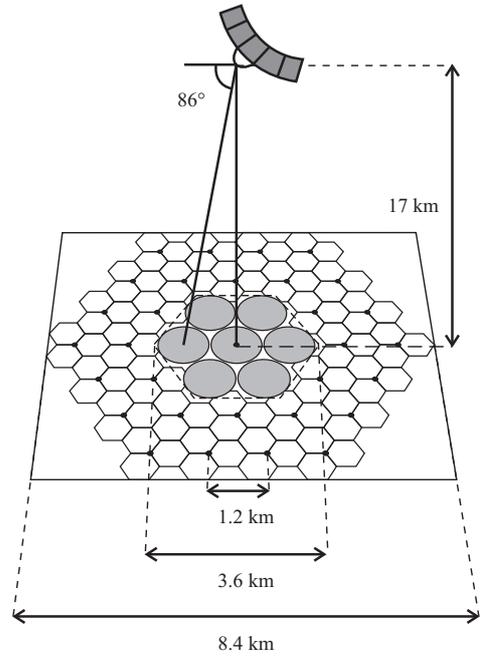
### E. Antenna Configuration

A typical base station antenna was used in all terrestrial base stations. The half-power beam width (HPBW) was 65° in horizontal direction. Electrical down tilt (EDT) of 6° was used to reduce the amount of overlapping between the terrestrial cells. The HAP antenna was created based on the recommendations by ITU-R [4]. The antenna has 2° HPBW, but the side lobes were modified from the original model specified in [4]. In the modified model, the side lobes levels are increased to 0 dBi level to make the antenna model more realistic.

### III. SIMULATION SCENARIOS

The simulations for this work were separately made in three operational phases: normal, disaster, and HAP assisted, each using three traffic study cases (TSC). Thus, the total number of simulation scenarios is 9. Fig. 2 shows the combined link loss map for each scenario. The traffic was randomly and homogenously distributed over the network area, and the traffic density was 100 12.2 kbps voice users per km$^2$ (high load). Additionally, some simulations were made with medium load (70 users per km$^2$) and low load (40 users per km$^2$). The values in the result section are averages calculated based on a number snapshots to make the results statistically more accurate.

The first phase represents the normal operation of the terrestrial network (all terrestrial sites operational, normal phase). Furthermore in the second phase, the 7 sites in the middle of the network are disabled due to disaster (disaster phase). Finally, the third phase models the situation where a HAP is deployed to assist the terrestrial network in the disaster area (HAP assisted phase).
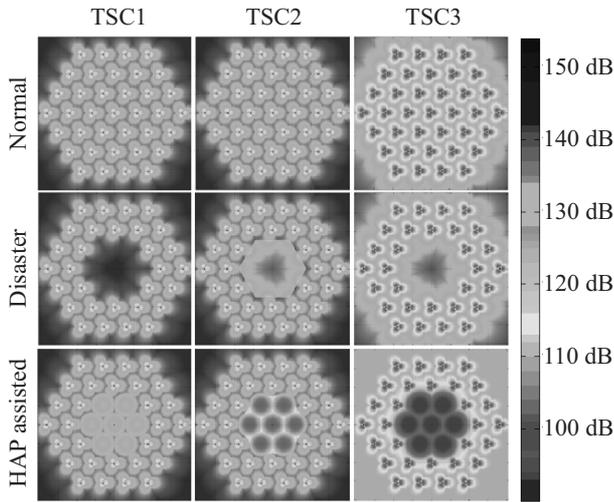
Fig. 2.  Link loss maps of different simulation scenarios.



Fig. 3.   Boundary cells, HAP cells, and regular cells.



Fig. 4.   Received pilot strength maps for TSC1 and TSC2 in disaster and HAP assisted phases.

In traffic study case 1 (TSC1), all the users on the map area are located in indoor. For TSC2, disaster area users become outdoor users at the time of disaster (i.e., in the disaster and HAP assisted phases). In TSC3, all users are outdoors. TSC3 was simulated in order to emphasize the impact of HAP configuration planning on the network performance. In TSC1 and TSC2, the HAP link budget is balanced with the terrestrial link budget by introducing an additional attenuation to the HAP antenna line. Without the attenuation in the HAP (which is the case in TSC3), the HAP links clearly dominate and introduce overlapping with the terrestrial network. The use of signal attenuator in the HAP is not a clever choice in real life due to scarce energy resources in the HAP station, but is used here as a quick solution to emphasize the importance of radio link planning.

Different parts of the network are analyzed separately. When considering disaster area performance, both the HAP cells and the terrestrial cells surrounding the disaster area are taken into account to make the results comparable. The surrounding terrestrial cells are called 'boundary cells' in this document. However, cells from the regular terrestrial network are considered in order to see the impact of disaster on the overall network functioning. Fig. 3 shows the categorization of the cells taken into the analysis based on their location.

## IV. RESULTS

### A. Pilot Coverage

The pilot coverage situation of the network is shortly evaluated to emphasize the disaster effects. Based on the received pilot strength maps, the disaster clearly creates a hole in the coverage in TSC1, where the traffic is located indoors (Fig. 4, top left). The cells in the boundary area are not able to serve the indoor traffic located in the center of the disaster area. The pilot strength map for TSC2 in the disaster phase (Fig. 4, top right) shows how the propagation environment is improved through the elimination of BPL in the disaster area. The boundary cells are able to cover the hole created by
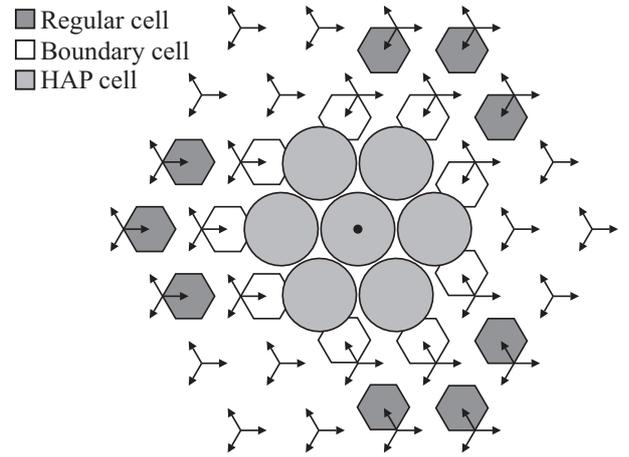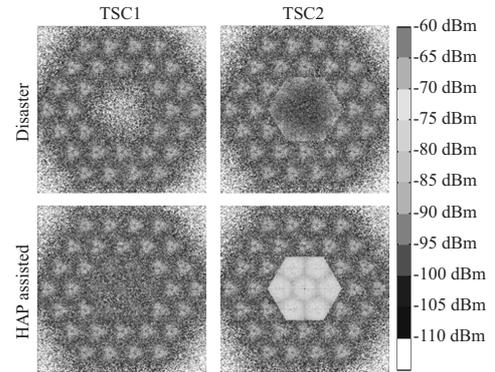
the disaster. By observing the pilot strength for HAP assisted phase (Fig. 4, bottom), it becomes clear that HAP is able to restore (in TSC1) and improve (TSC2) the coverage in the disaster area. Especially in TSC2, the coverage from the HAP links are strong compared to the terrestrial links. Furthermore, in TSC1 the HAP links have slightly higher link loss when compared with terrestrial links. This is due to the different BPL model used in terrestrial and HAP links.

### B. Network Performance

The network performance is assessed keeping in mind the pilot coverage results. The performance indicators presented in Fig. 5 and 6 are from simulations with high traffic load. Fig. 5 shows the received uplink (UL) other cell interference plus noise power level in terrestrial boundary cells. The level of other cell interference is an important indicator, since it affects the capacity in WCDMA-based networks. Based on Fig. 5, received other cell interference stays at acceptable level in all phases of disaster. Only in TSC2 with disaster users outdoors, the other cell interference level in the disaster phase is slightly increased due to the decreased isolation between the cells in the disaster area (traffic moved to outdoor). However, HAP deployment returns the interference clearly below the
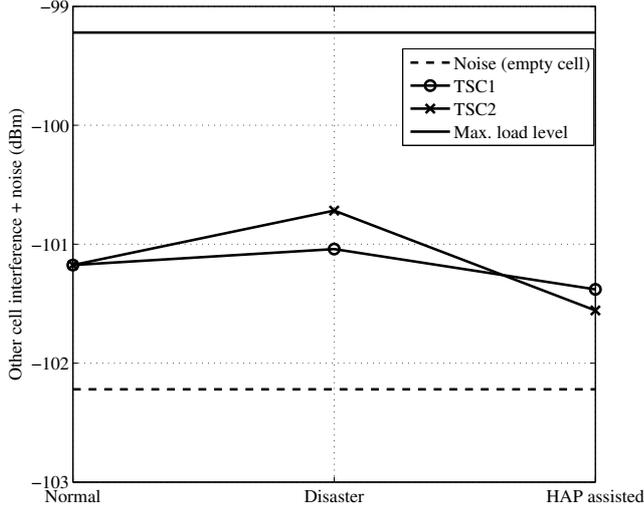
Fig. 5.   Uplink other cell interference power at terrestrial boundary cells.



Fig. 6.   Disaster area throughput.

initial level as shown in Fig. 5. In the regular cells (not shown here), the other cell interference stayed below -107 dBm in all phases (normal, disaster, and HAP assisted).

The total downlink throughput of the disaster area in disaster and HAP assisted phases can be calculated as:

$$TP_{TOT} = \Sigma_i TP_{BOU} + \Sigma_j TP_{DIS}, \qquad (1)$$

where $TP_{BOU}$ is the sum of average cell throughput values of the 9 terrestrial boundary cells ($i = 1 \ldots 9$) and $TP_{DIS}$ is the sum of average throughput values of the 7 disaster area HAP cells ($j = 1 \ldots 7$). In the disaster phase, the last term in (1) is zero. In the normal phase, the last term in (1) is the sum of averaged throughput values of the 21 terrestrial cells in the disaster area.

Fig. 6 reveals, how the disaster area throughput drops to 43 % (TSC1) and 33 % (TSC2) of the original throughput (approximately 13 Mbps), and how the HAP deployment can return the total disaster area throughput to 68 % (TSC1) and 76 % (TSC2) from the original level, when the HAP links are balanced with the terrestrial links. Before the HAP deployment, in the disaster phase, the throughput has dropped to a level of 6 and 4 Mbps with TSC1 and TSC2 correspondingly. Furthermore, Fig. 6 illustrates how the service performance in the disaster area crashes with TSC3, which lacks the link balancing. As shown in Fig. 6, TSC3 performs clearly better using only the terrestrial boundary cells (HAP disabled, disaster phase) when compared with the HAP assisted phase. The behavior of the performance with TSC3 indicates severe problems with interference between HAP- and terrestrial cells.

In Fig. 6 and in disaster phase, $TP_{TOT}$ is 1.5 Mbps lower in TSC2 than in TSC1. The reason for total disaster area throughput being lower for a TSC with better signal propagation characteristics (i.e., TSC2) is in the regular cells. Due to the fact that the disaster area traffic is considered as outdoor
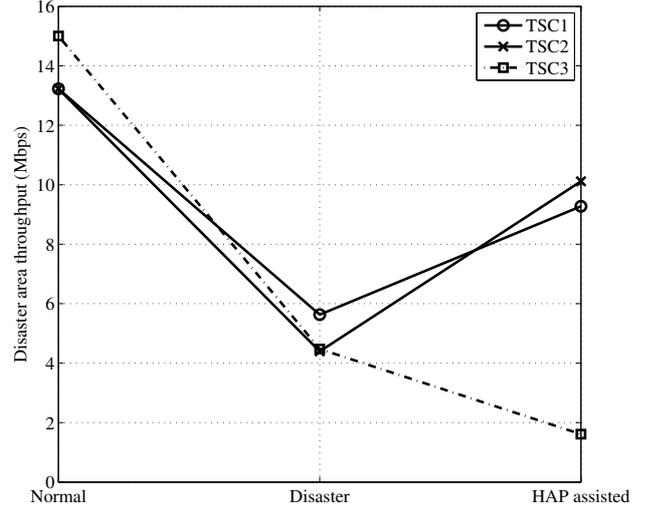
traffic also from the terrestrial cell point of view in TSC2, some part of disaster area traffic is served by the regular cells behind the boundary cells. Furthermore, the regular cell links are excluded from the disaster area throughput calculation. Another explanation is in increased soft handover (SHO) rates. Since the whole disaster area can be covered by the boundary cells in TSC2, large SHO area is generated in the center of the disaster area, where all the boundary cells can be heard at equal reception level. Increased SHO rates lead into increased required power from the boundary cell base stations in utilizing the SHO in TSC2. Since large portion of the BS power is allocated for maintaining the SHO connections, lower number of users can be allowed in the system. In TSC1, this does not happen due to the coverage being insufficient in the center area.

Fig. 7 shows the division of disaster area throughput between the HAP cells and the boundary cells in TSC1 and TSC2. Based on Fig. 7, the HAP cells serve clearly more users after the users have moved from indoor to outdoor. This is due to improvement in the propagation path. However at the same time, the boundary cells lose some throughput. This is an interesting observation and the reason for the behavior is in the BPL. Since the BPL is 5-7 dB higher for the HAP links in TSC1 compared to the terrestrial links (20-22 dB vs. 15 dB), HAP cells gain more from the elimination of the BPL from the corresponding links. Thus, HAP cells become more dominant in TSC2 compared to terrestrial cells (relatively 5-7 dB less transmission power needed) and they steal traffic from the boundary cells. The same phenomenon is also visible in Fig. 4.

### C. Network Load

Fig. 8 shows the average 1st tier HAP cell throughput as a function of network load. According to Fig. 8, the average
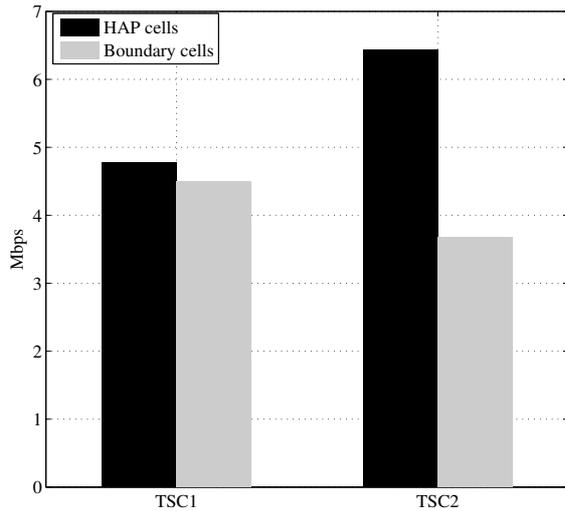
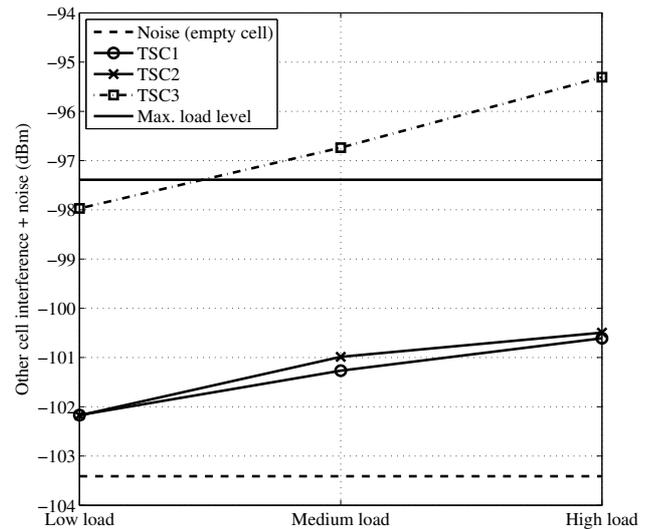Fig. 7. Division of disaster area throughput between HAP and boundary cells.
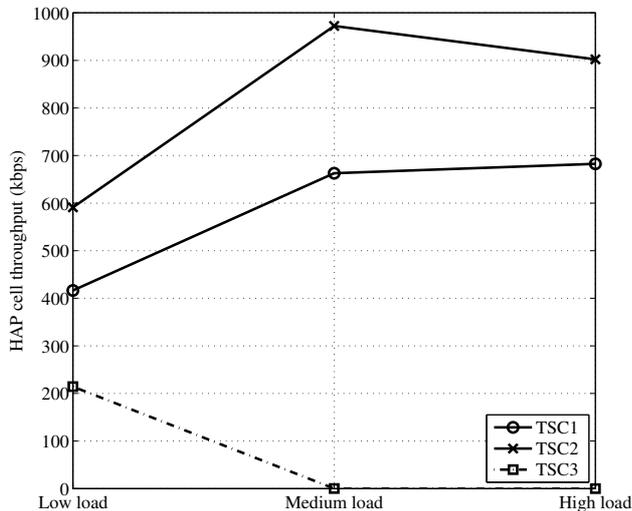


Fig. 8. 1st tier average HAP cell throughput as a function of network load.

cell throughput in medium load case increases by 320 kbps in the HAP cells, when the disaster area users enter the outdoor environment. This is caused by the improved radio propagation conditions (building penetration loss removed). On the other hand in TSC3, HAP cells become totally blocked, thereby allowing no users to access the cells in HAP. According to Fig. 8, even with the lowest traffic density HAP cells are giving the worst performance with unbalanced links (TSC3). Throughput in 1-tier HAP cells with TSC3 and the lowest traffic density is clearly lower than in the center HAP cell (200 kbps vs. 400 kbps). This indicates severe problems with interference from users outside the disaster area.



Fig. 9. UL other cell interference power at 1st tier HAP cells.

Fig. 9 clarifies the behavior of uplink other cell interference at the HAP cells in TSC1, TSC2, and TSC3. As presented in Fig. 9, the uplink other cell interference stays at acceptable level at the 1st tier HAP cells in TSC1 and TSC2. However in TSC3, severe interference is received by the HAP cells. As Fig. 9 shows, interference from the users in other cells blocks the HAP cells. This limits the HAP cell throughput to zero as was already shown in Fig. 8. Since interference observed in 1-tier HAP cells is somewhat higher than in the center HAP cell, it can be concluded that the major part of the other interference is originated from the regular cells.

## V. DISCUSSION AND CONCLUSIONS

Based on the simulation results the utilization of HAP improved the disaster area throughput up to the level of 70 % from the original level before disaster. If the voice users were moved from indoor to outdoor after the disaster, an improvement of 1 Mbps was detected in the total disaster area throughput, when HAP was used in assisting the service in the disaster area. Furthermore, the impact of varying BPL on the cell throughput in terrestrial boundary cells and HAP cells was shown. The higher BPL for HAP connections has an impact on the HAP performance and should be taken into account when doing the HAP configuration planning. Finally, the simulation results also emphasized the importance of HAP antenna line configuration planning. If the HAP- and terrestrial links are left unbalanced, there is a risk of losing the HAP cell performance due to excess interference between the terrestrial- and HAP cells.

## REFERENCES

[1] E. Falletti, M. Mondin, F. Dovis, and D. Grace. Integration of a HAP within a terrestrial UMTS network: interference analysis and cell dimensioning. *Wireless Personal Communications*, 24(2):291–325, 2003.

[2] NPSW - network planning strategies for WCDMA, v.5.0.0, application note, 2003.

[3] D. Axiotis and M. Theologou. An empirical model for predicting building penetration loss at 2 GHz for high elevation angles. In *IEEE Antennas and Wireless Propagation Letters*, volume 2, pages 234–237, 2003.

[4] ITU-R. Minimum performance characteristics and operational conditions for high altitude platform stations providing IMT-2000 in the bands 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz in Regions 1 and 3 and 1885-1980 MHz and 2110-2160 MHz in region 2, 2000.

[5] P. R. King. *Modelling and measurement of the land mobile satellite MIMO radio propagation channel*. PhD thesis, University of Surrey, UK, 2007.

[6] D. Grace, J. Thornton, G.P. White, C. Spillard, and D.A.J. Pearce. The european helinet broadband communications application - an update on progress. In *Japanese Stratospheric Platforms Systems Workshop (invited paper)*, 2003.

[7] J. Lempiäinen and M. Manninen, editors. *UMTS Radio Network Planning, Optimization and QoS Management*. Kluwer Academic Publishers, 2003.