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Space-Time Diversity Techniques for WCDMA High Altitude Platform Systems

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1. Introduction

Third generation mobile systems are gradually being deployed in many developed countries in hotspot areas. However, owing to the amount of new infrastructures required, it will still be some time before 3G is ubiquitous, especially in developing countries. One possible cost effective solution for deployments in these areas is to use High Altitude Platforms (HAPs) (Collela et al., 2000; Djuknic et al., 1997; Grace et al., 2001; 2005; Miura & Oodo, 2002; Park et al., 2002; Steele, 1992; Thornton et al., 2001; Tozer & Grace, 2001) for delivering 3G (WCDMA) communications services over a wide coverage area (Dovis et al., 2002; Falletti & Sellone, 2005; Foo et al., 2000; Masumura & Nakagawa, 2002; Vazquez et al., 2002). HAPs are either airships or planes that will operate in the stratosphere, 17-22 km above the ground. This unique position offers a significant link budget advantage compared with satellites and much wider coverage area than conventional terrestrial cellular systems. Such platforms will have a rapid roll-out capability and the ability to serve a large number of users, using considerably less communications infrastructure than required by a terrestrial network (Steele, 1992). In order to aid the eventual deployment of HAPs the ITU has allocated spectrum in the 3G bands for HAPs (ITU, 2000a), as well as in the mm-wave bands for broadband services at around 48 GHz worldwide (ITU, 2000b) and 31/28 GHz for certain Asian countries (Oodo et al., 2002). Spectrum reuse is important in all wireless communications systems. Cellular solutions for HAPs have been examined in (El-Jabu, 2001; Thornton et al., 2003), specifically addressing the antenna beam characteristics required to produce an efficient cellular structure on the ground, and the effect of antenna sidelobe levels on channel reuse plans (Thornton et al., 2003). HAPs will have relatively loose station-keeping characteristics compared with satellites, and the effects of platform drift on a cellular structure and the resulting inter-cell handover requirements have been investigated (Thornton et al., 2005). Cellular resource management strategies have also been developed for HAP use (Grace et al., 2002).

Configurations of multiple HAPs can also reuse the spectrum. They can be used to deliver contiguous coverage and must take into account coexistence requirements (Falletti & Sellone, 2005; Foo et al., 2000). A technique not widely known is their ability to serve the same

coverage area reusing the spectrum to allow capacity enhancement. Such a technique has already been examined for TDMA/FDMA systems (Chen et al., 2005; Grace et al., 2005; Liu et al., 2005). In order to achieve the required reduction in interference needed to permit spectrum reuse, the highly directional user antenna is used to spatially discriminate between the HAPs. The degree of bandwidth reuse and resulting capacity gain is dependent on several factors, in particular the number of platforms and the user antenna sidelobe levels. An alternative method of enhancement is to apply space-time diversity techniques, such as Single-Input Multiple-Output (SIMO) receive diversity or Multiple-Input Multiple-Output (MIMO) diversity, to improve the spectrum reuse in the multiple HAP scenario.

In the case of many 3G systems the user antenna is either omni-directional or at best low gain, so in these cases it cannot be used to achieve the same effects. The purpose of this chapter is to examine how the unique properties of a WCDMA system can be exploited in multiple HAP uplink architectures to deliver both coverage and capacity enhancement (without the need for the user antenna gain).

In addition to the spectral reuse benefits, there are three main benefits for a multiple HAP architecture:

- The configuration also provides for incremental roll-out: initially only one HAP needs to be deployed. As more capacity is required, further HAPs can be brought into service, with new users served by the newly deployed HAPs.
- Multiple operators can be served from individual HAPs, without the need for complicated coexistence criteria since the individual HAPs could reuse the same spectrum.
- HAPs will be payload power, volume and weight constrained, limiting the overall capacity delivered by each platform. Capacity densities can be increased with more HAPs. Moreover, it may be more cost effective to use more lower capability HAPs (e.g., solar powered planes), rather than one big HAP (e.g., solar powered airship), when covering a large number of cells (Grace et al., 2006).

The chapter is organized as follows: in section 2 the multiple HAP scenario is explained. The interference analysis is presented in section 3. In section 4 we examine the completely overlapping coverage area case, different numbers of platforms, and simulation results showing the achievable capacity enhancement are presented. Finally, conclusions are presented in section 5.

2. Multiple HAP system setup

In this chapter we use a simple geometric positioning of the high altitude platforms to create signal environments that can easily be compared and analyzed. In each constellation, the HAPs are located with equal separation along a circular contour, as shown in figure 1.

The separation distance d_m along the line from the vertical projection of the HAP on the ground to the cell centre is varied from 70 km to zero (i.e., all the HAPs will be located on top of each other in the latter case). All HAPs are assumed to be flying in the stratosphere at an altitude of 20 km. The size of the coverage area assigned to each HAP is governed by the shape of the base station antenna pattern. If we assume that we only have one cell per HAP, then the coverage area is also synonymous with the total cell area of the HAP.

Fig. 1. An example of a system simulation setup with $N = 2$ HAPs with overlapping cells of radius R . d_m is the distance on the ground between the cell centre and the vertical projection of the HAP on the ground and θ_m is the elevation angle towards the HAP.

2.1 User Positioning Geometry

Each UE (User Equipment) is positioned inside the cell according to an independent uniform random distribution over the cell coverage area with radius R , as shown in figure 2. The position of each UE inside each cell is defined relative to the HAP base station that it is connected to, and also relative to every other HAP borne base station. This is necessary in order to evaluate the impact of interference between the different UE-HAP transmission paths.

Fig. 2. A plot showing a sample distribution of 150 UE, where 50 UE are assigned to each of the three base stations (BS1, BS2 and BS3).

2.2 Base station antenna pattern

The base station antenna pattern for the simulations were chosen to be simple but detailed enough to show the effects of the main and side lobes, especially in the null directions, as illustrated in figure 3. A simple rotationally symmetric pattern based on a Bessel function is used for this purpose, and is defined by (Balanis, 1997)

$$G(\varphi) \approx 0.7 \cdot \left(\frac{2 \cdot J_1 \left(\frac{70\pi}{\varphi_{3dB}} \sin(\varphi) \right)}{\sin(\varphi)} \right)^2, \quad (1)$$

where $J_1(\cdot)$ is a Bessel function of the first kind and order 1, φ_{3dB} is the 3 dB beamwidth in degrees of the main antenna lobe. The 3 dB beamwidth of the antenna is computed from the desired cell radius according to

$$\varphi_{3dB} = 2 \cdot \arctan \left(\frac{\text{cell radius}}{\text{HAP altitude}} \right). \quad (2)$$

Fig. 3. HAP base station antenna patterns for different cell radii.

2.3 User equipment antenna pattern

In this analysis we assume that each UE employs a directive antenna and communicates with its corresponding HAP basestation. Using this assumption we only need to set the desired maximum gain of the UE antenna we want to use, as shown Table 1. The antenna pattern of the directive antennas is calculated according to equation (1), but with a fixed maximum gain instead of a fixed main beamwidth, the beamwidth is then $\varphi(G_{max})$.

User Equipment	Max. ant. Gain [dBi]
Mobile phone	0
Data terminal	2,4,12

Table 1. Antenna gains used in the simulation setup.

2.4 UE-HAP radio propagation channel model

In this chapter we use the Combined Empirical Fading Model (CEFM) together with the Free Space Loss (FSL) model. CEFM combines the results of the Empirical Roadside Shadowing (ERS) model (Goldhirsch & Vogel, 1992) for low elevation angles with the high elevation angle results from (Parks et al., 1993) for the L and S Bands. Using the FSL model the path loss from UE n to HAP base station m , is given by

$$l_{m,n}^{FSL} = \frac{(4\pi \cdot d_n^m)^2}{G_{m,n}^{tx} \cdot G_{m,n}^{rx} \cdot \lambda^2},$$

(3)

where $d_{m,n}$ is the line of sight distance between the UE n and HAP m . The receiver $G_{m,n}^{rx}$ and transmitter $G_{m,n}^{tx}$ antenna gain patterns are calculated using equations (1) and (2), respectively. The carrier frequency f_c used in the simulation is 1.9 GHz which gives a wavelength λ of 0.1579 meters. The CEFM fading loss associated to HAP m is calculated as

$$L_f(\theta_m) = a \cdot \log_e(p) + b \quad [\text{dB}],$$

(4)

where p is the percentile outage probability, and the data fitting coefficients a and b are calculated according to (Goldhirsch & Vogel, 1992)

$$\begin{cases} a = 0.002 \cdot \theta_m^2 - 0.15 \cdot \theta_m - 0.7 - 0.2 \cdot f_c \\ b = 27.2 + 1.5 \cdot f_c - 0.33 \cdot \theta_m \end{cases},$$

(5)

where θ_m is the elevation angle of HAP m . The total channel gain from UE n to HAP m is then given by

$$g_{m,n}(\theta_m) = \left(l_{m,n}^{FSL} \cdot 10^{\left(\frac{L_f(\theta_m)}{10} \right)} \right)^{-1}.$$

(6)

2.5 WCDMA Setup

The different service parameters used in this chapter are collected from the 3GPP standard (3GPP, 2005) and are summarized in Table 2. In order to account for the relative movement between the UE and the base stations, a fading propagation channel model based on equation (6) is simulated. This results in a Block Error Rate (BLER) requirement of 1% for the 12.2 kbps voice service and a BLER of 10% for 64, 144 and 384 kbps data packet services, respectively.

	Type of service			
Parameters	Voice	Data	Data	Data
Chip rate	3.84 Mcps			
Data rate	12 kbps	64 kbps	144 kbps	384 kbps
Req. E_b/N_0	11.9 dB	6.2 dB	5.4 dB	5.8 dB
Max. Tx. Power	125 mW	125 mW	125 mW	250 mW
Voice activity	0.67	1	1	1

Table 2. WCDMA service parameters employed in the simulation.

2.6 Space-Time Diversity Techniques

The spatial properties of wireless communication channels are extremely important in determining the performance of the systems. Thus, there has been great interest in employing space-time diversity schemes since they can offer a broad range of ways to improve wireless systems performance. For instance, receiver diversity techniques such as Single-Input Multiple-Output (SIMO) and Multiple-Input Multiple-Output (MIMO) can enhance link quality through diversity gain or increase the potential data rate or capacity through multiplexing gain. In this section, we apply these techniques to HAPs and in the next section we determine their impact on performance via simulations.

In this scenario, we assume that the link between the UE and the HAP BS is setup according to the previous sections in this chapter. The total spatio-temporal and polarization degrees of freedom is, in an Orthogonal User Multiple Access SIMO system, restricted by the number of users and the number of receiving antennas. If E_s is the average transmit energy per symbol, the received signal r is given by (Li & Wang., 2004)

$$r = \sqrt{E_s} \cdot \mathbf{w}^H \mathbf{h} s + \mathbf{w}^H \mathbf{n},$$

(7)

where s is the transmitted signal, $\mathbf{h}$ is the channel response vector, $h_n = |h_n|e^{j\phi_n}$, $n = 1, 2, \dots, N_{rx}$, for all receiving antennas, in which $|h_n|$ is defined as the inverse of the channel gain in equation (6) assuming that the separate channels are independent. The received noise vector $\mathbf{n}$ for all receiving antennas is assumed to be AWGN and $\mathbf{w}$ are the combining weights at the receiver. Choosing the combining weights $\mathbf{w}$ to be equal to the channel response vector $\mathbf{h}$ will result in the Maximum Ratio Combining (MRC) method, which can be represented as

$$r = \sqrt{E_s} \cdot \|\mathbf{h}\|^2 s + \mathbf{h}^H \mathbf{n}.$$

(8)

The SNR for the received signal can now be written as

$$\text{SNR}_{MRC} = \frac{(\sqrt{E_s} \cdot \|\mathbf{h}\|^2)^2}{(\mathbf{h}^H \mathbf{n})^2} = \frac{s \cdot E_s}{\sigma_n^2} \cdot \mathcal{E} \left\{ \frac{\|\mathbf{h}\|^4}{\|\mathbf{h}\|^2} \right\} = \text{SNR}_n \cdot \|\mathbf{h}\|^2 = \text{SNR}_n \cdot N_{rx},$$

(9)

where SNR_n is the signal to noise ratio in each receiving antenna and N_{rx} is the number of receiving antennas.

A similar combining method as in the SIMO receiver diversity is used in the MIMO diversity method. MIMO diversity utilize N_{tx} transmitting antennas and N_{rx} receiving antennas and assumes the channel response matrix $H_{nm} = |H_{nm}|e^{j\phi_{nm}}$, $n = 1, 2, \dots, N_{rx}$, $m = 1, 2, \dots, N_{tx}$. $|H_{nm}|$ is the inverse of the channel gain from equation (6), and provided that the separate

channels are independent then $\mathbf{H}$ is a diagonal matrix. The noise is AWGN and the received signal from the MIMO diversity system can then be expressed as (Li & Wang., 2004)

$$r = \sqrt{E_s} \cdot \mathbf{w}_{rx}^H \mathbf{H} \mathbf{w}_{tx} s + \mathbf{w}_{rx}^H \mathbf{n}, \quad (10)$$

The SNR for the received signal is then given by

$$\text{SNR}_{\text{MRC}} = \frac{(\sqrt{E_s} \cdot \|\mathbf{H}\|_F^2)^2}{(\mathbf{H}^H \mathbf{n})^2} = \frac{s \cdot E_s}{\sigma_n^2} \cdot \mathcal{E} \left\{ \frac{\|\mathbf{H}\|_F^4}{\|\mathbf{H}\|_F^2} \right\} = \text{SNR}_n \cdot N_{tx} \cdot N_{rx}, \quad (11)$$

where SNR_n is the signal to noise ratio in each receiving antenna and N_{rx} is the number of receiving antennas and N_{tx} is the number of transmitting antennas.

3. Interference analysis

Assuming that we have a setup of M different HAPs covering the same cell area and N users connected to each HAP, we can denote each UE position as $(x_{m,n}, y_{m,n})$, where $n = \{1, 2, \dots, N\}$ and $m = \{1, 2, \dots, M\}$. An example of a scenario setup with $N = 50$ and $M = 3$ is shown in figure 2. The maximum power $p_{m,n}^{tx}$ that the user in location $(x_{m,n}, y_{m,n})$ is transmitting dependent of the type of service used and can be obtained from Table 2. In WCDMA systems, power control is a powerful and essential method exerted in order to mitigate the near-far problem. The power received at base station (HAP) m from user n is

$$p_{m,n}^{rx}(\theta_m) = p_{m,n}^{tx} \cdot g_{m,n}(\theta_m), \quad (12)$$

where $g_{m,n}(\theta_m)$ is the total link gain, as defined in equation (6), between UE transmitter n and its own cell's BS receiver m . To be able to maintain a specific quality of service we need to assert that we maintain a good enough SINR (Signal to Interference plus Noise Ratio) level. From Table 2 we can see the required E_b/N_0 values for different services, and we can express the required SINR, $\gamma_{m,n}$ for user n at HAP base station m as

$$\gamma_{m,n}^{req} = \frac{R}{W} \cdot \left(\frac{E_b}{N_0} \right)_{req}, \quad (13)$$

where R is the data rate of the service and W is the *Chip-rate* of the system. The required SINR can then be expressed as

$$\gamma_{m,n}^{req} = \frac{p_{m,n}^{rx}}{I_{tot}} = \frac{p_{m,n}^{tx}}{\sum_{m'=1}^M \sum_{\substack{n'=1 \\ n' \neq n}}^N p_{m',n'}^{tx} \cdot \frac{g_{m',n'}(\theta_{m'})}{g_{m,n}(\theta_m)} + \frac{p_w}{g_{m,n}(\theta_m)}}, \quad \begin{matrix} m = \{1, 2, \dots, M\} \\ n = \{1, 2, \dots, N\} \end{matrix} \quad (14)$$

which can be formulated as

$$\gamma_i^{req} = \frac{p_i^{tx}}{\sum_{\substack{k=1 \\ n' \neq n}}^K p_k^{tx} \cdot \frac{g_k(\theta_{m'})}{g_i(\theta_m)} + \frac{p_w}{g_i(\theta_m)}}, \quad \begin{matrix} m = \{1, 2, \dots, M\} \\ n = \{1, 2, \dots, N\} \\ i = 1 + (n - 1) + N(m - 1) \end{matrix} \quad (15)$$

with $K = M \cdot N$ as the total number of users in all cells and p_w is the additive white Gaussian noise (AWGN) at the receiver, $\gamma_{m,n}^{req} \mapsto \gamma_i^{req}$, $g_{m',n'}(\theta_{m'}) \mapsto g_k(\theta_{m'})$, $g_{m,n}(\theta_m) \mapsto g_i(\theta_m)$, $p_{m',n'}^{tx} \mapsto p_k^{tx}$ are performed according to the index mapping rules in equation (15). To solve for the transmitter power p_k^{tx} of each of the K individual UE simultaneously, equation (14) can be reformulated into a matrix form as

$$\mathbf{p}_{tx} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{b}, \quad (16)$$

where the calculated vector $\mathbf{p}_{tx}$ contains the necessary transmitter power level assigned to each of the K UE to fulfil the SINR requirement and where matrix $[\mathbf{A}]_{K \times K}$ and vector $[\mathbf{b}]_{K \times 1}$ are defined as

$$\begin{aligned} [a_{ik}]_{K \times K} &= \gamma_i^{req} \cdot \frac{g_k(\theta_{m'})}{g_i(\theta_m)} \quad \text{for } n' \neq n \quad \text{and} \\ [a_{ik}] &= 0 \quad \text{for } n' = n, \quad [b_i]_{K \times 1} = \gamma_i^{req} \cdot \frac{p_w}{g_i(\theta_m)}, \\ m &= \{1, 2, \dots, M\}, \quad n = \{1, 2, \dots, N\}, \quad i = 1 + (n - 1) + N(m - 1) \\ m' &= \{1, 2, \dots, M\}, \quad n' = \{1, 2, \dots, N\}, \quad k = 1 + (n' - 1) + N(m' - 1) \end{aligned} \quad (17)$$

Using the $\mathbf{p}_{rx} = \mathbf{g} \odot \mathbf{p}_{tx}$, where $\odot$ denotes an elementwise multiplication and $\mathbf{g}$ is the total channel gain vector $[g_k]_{K \times 1}$ for all $k = \{1, 2, \dots, K\}$ users, then all elements in the vector $\mathbf{p}_{rx}$ for each block that contain the UE of each of the M cells are balanced. The total cell interference can then be calculated as

$$I_m^{own}(\theta_m) = \sum_{n=1}^N p_{m,n}^{rx}(\theta_m), \quad m = \{1, 2, \dots, M\} \quad (18)$$

$$I_m^{oth}(\theta_m) = \sum_{\substack{m'=1 \\ m' \neq m}}^M \sum_{n=1}^N p_{m',n}^{rx}(\theta_{m'}) + p_w, \quad m = \{1, 2, \dots, M\} \quad (19)$$

where p_w is the thermal noise at the receiver, $I_m^{own}(\theta_m)$ is the interference from the UE within the own cell m and $I_m^{oth}(\theta_m)$ is the interference from the UE in the $M - 1$ other cells where M is the total number of cells. We can now calculate $i_{UL}(\theta_m)$ which defines the other to own interference ratio for the uplink to HAP m and is given by

$$i_{UL}(\theta_m) = \frac{I_m^{oth}(\theta_m)}{I_m^{own}(\theta_m)}. \quad (20)$$

This is a performance measure of the simulated system capacity at a specific elevation angle θ_m towards the HAP (see figure 1). If $i_{UL}(\theta_m)$ is between zero and one there is possibility to have multiple HAP base stations covering the same coverage area. The actual number of users that can access the HAP base stations is also dependent of which data rate each user is using for transmission.

Fig. 4. A plot illustrating the change of HAP position d_m to create different elevation angles θ_m .

4. Simulation Results

In this simulation we assume M HAPs uniformly located along a circular boundary, with the centre of the circular boundary acting as the pointing direction of the HAPs base station antennas which simulate several overlapping cells, see figure 1. The beamwidth of these base station antennas are determined by the radius of the cell coverage area (see figures 1 and 3). These results are acquired through running Monte Carlo simulations of the multiple HAP system. The aim of the simulation is to assess the effect of adding more HAPs on the system's capacity and of the impact of using space-time diversity techniques. The distance d_m between the cell centre and the vertical projection of the HAP on the earth's surface is denoted as "distance on the ground" and is varied from 0 to 70 km with a fixed cell position, as shown in figure 4. The distance to the cell centre is also changing the elevation angle θ_m towards the HAP base station m as seen from the user. The cell radius has been set to 10 km and 30 km, and the HAP altitude is 20 km. Each HAP base station serves 100 users within each corresponding cell.

From figure 5 it is clear that with the smaller cell radius (10 km) the worst case scenario will occur when all the HAPs are stacked on top of each other at 90 degrees elevation angle from the cell centre (i.e., at a distance d_m on the ground of 0 km). In the larger cell radius case (30 km) the worst case scenario happens approximately at 30 km which is at the edge of the cell.

Comparing the bottom diagram in figure 5 with the two diagrams in figure 6, we can see that if we utilize a maximum allowed other-to-own interference ratio equal to one, then as the service data rate decreases, the number of possible HAP base stations covering the same area can increase from 2-4 HAPs (depending on the distance d_m between the cell centre and the vertical projection of the HAP on the ground) for the combined service (12 kbps and 384 kbps) to 6 HAPs with the same service (12 kbps on all HAPs).

Next, we analyze the impact of different space-time diversity techniques (SIMO and MIMO) on the possible number of HAPs that can coexist within the same cell area and compare them to a single-input single-output (SISO) system. From figure 7 it is obvious that using a space-

Fig. 5. The performance of the voice service (12 kbps) from one HAP in combination with the data service (384 kbps) on the remaining HAPs for cell radius of 10 km (top) and 30 km (bottom). The distance on the ground d_m is varied from 0 to 70 km.

Fig. 6. The other to own interference ratio obtained for a 30 km cell radius for: (top) the performance of the voice service (12 kbps) from one HAP in combination with the data service (144 kbps) on the remaining HAPs and (bottom) the performance when we have voice services (12 kbps) on all HAPs. The distance on the ground d_m is varied from 0 to 70 km.

Fig. 7. The other to own interference ratio obtained for a 30 km cell radius for the performance of the voice service (12 kbps) from one HAP in combination with the data service (384 kbps) on the remaining two HAPs and utilizing different SISO, SIMO and MIMO space-time diversity systems. The distance on the ground d_m is varied from 0 to 70 km.

time diversity technique will enhance the interference mitigating capability and improve the overall performance of the multiple HAP system. This interference mitigation technique can also be interpreted as a capacity improvement, which is clearly seen in figure 7 for a three HAP system and in figure 8 for a seven HAP system. In both of these figures we can observe a decrease in the other-to-own interference ratio as we use an increasing number of antennas at the transmitter and receiver, which in turn will allow more HAPs to provide wireless service to more users by utilizing the remaining degrees of freedom of the system.

Fig. 8. The other to own interference ratio obtained for a 30 km cell radius for the performance of the voice service (12 kbps) from one HAP in combination with the data service (384 kbps) on the remaining six HAPs and utilizing different SISO, SIMO and MIMO space-time diversity systems. The distance on the ground d_m is varied from 0 to 70 km.

Comparing the graphs in figure 8, we can observe that a seven HAP system using SISO would not be possible due to the interference. However, a SIMO diversity system (utilizing two receiving antennas at the HAP base station) would make a seven HAP system possible. Adding more antennas at the receiver and transmitter respectively will increase the number of possible HAPs that can be used in the multiple HAP system. However, the benefit of the diversity system will diminish even with increasing the number of antennas beyond a certain limit. From figure 7 and figure 8 it is obvious that this limit is obtained at approximately a 4x4 MIMO system, beyond which diversity gain is negligible as is evident from the graph of the 8x8 MIMO system.

It is also clear from figure 6 that the worst case distance (highest interference level) is at approximately 30 km, and consequently a worst case elevation angle of 34 degrees. This maximum interference level depends on the cell radius chosen for the HAP base station as shown in figure 9. Simulation results show that for cell radii larger than 10 km the maximum interference level will occur at the cell boundary.

5. Conclusions

In this chapter we have investigated the possibility of multiple HAP coverage of a common cell area in WCDMA systems with and without space-time diversity techniques. Simulation results have shown that as the service data rate decreases, the number of possible HAP base stations that can be deployed to cover the same geographical area increases. It has further been shown that this increment in number of HAP base stations can be enhanced to some extent by using space-time diversity techniques. We have also shown that the worst case position of the HAPs is in the centre of the cell if the cell radius is small (≤ 20 km) and at the cell boundary for large cells (≥ 20 km). We can conclude that there is a possibility of deploying 3-5 (SISO), or 5-8 (1x2 SIMO, 2x2 MIMO and 4x4 MIMO) HAPs covering the same cell area in response to an increase in traffic demands, depending on the type of service used. There also appear to be

Fig. 9. Illustrating the effect of HAP base station cell radius on interference levels. A system of 3 HAPs is utilized here and a voice service (12 kbps) from one HAP in combination with the data service (384 kbps) on the other HAPs. The distance on the ground d_m is varied from 0 to 70 km.

a limit on the number of HAPs that could be deployed using space-time diversity techniques. Simulation results have shown that the maximum number of HAPs that could be sustained is approximately eight when using the voice services with 4x4 MIMO on all HAPs and users.

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Mobile and Wireless Communications have been one of the major revolutions of the late twentieth century. We are witnessing a very fast growth in these technologies where mobile and wireless communications have become so ubiquitous in our society and indispensable for our daily lives. The relentless demand for higher data rates with better quality of services to comply with state-of-the art applications has revolutionized the wireless communication field and led to the emergence of new technologies such as Bluetooth, WiFi, Wimax, Ultra wideband, OFDMA. Moreover, the market tendency confirms that this revolution is not ready to stop in the foreseen future. Mobile and wireless communications applications cover diverse areas including entertainment, industrialist, biomedical, medicine, safety and security, and others, which definitely are improving our daily life. Wireless communication network is a multidisciplinary field addressing different aspects ranging from theoretical analysis, system architecture design, and hardware and software implementations. While different new applications are requiring higher data rates and better quality of service and prolonging the mobile battery life, new development and advanced research studies and systems and circuits designs are necessary to keep pace with the market requirements. This book covers the most advanced research and development topics in mobile and wireless communication networks. It is divided into two parts with a total of thirty-four stand-alone chapters covering various areas of wireless communications of special topics including: physical layer and network layer, access methods and scheduling, techniques and technologies, antenna and amplifier design, integrated circuit design, applications and systems. These chapters present advanced novel and cutting-edge results and development related to wireless communication offering the readers the opportunity to enrich their knowledge in specific topics as well as to explore the whole field of rapidly emerging mobile and wireless networks. We hope that this book will be useful for students, researchers and practitioners in their research studies.

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