Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	OFMDA System Simulation in a Single/Multi Cell Configuration
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Re:	Call for Contributions 80216e-02_01 dated 2002-12-19.
Abstract	The document presents simulation results
Purpose	This document should help and give some guidance to the IEEE802.16e group regarding the scenario/scenarios for the Single/Multi cell configuration they should adopt as the base-line scenarios.
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OFMDA System Simulation in a Single/Multi Cell Configuration

1. Introduction

In this document we present the actual cell spectral efficiency (given in bps/Hz/Cell) for different deployment scenarios of the OFDMA technology. The calculation is made by estimating the probability distribution of the C/(I+N) ratio of such a system in a hexagonal cell pattern, with a given number of frequency channels (or sets of sub-channels). The resulting distribution determines the capacity that can be utilized and hence the spectral efficiency and the spectral efficiency per cell can be calculated.

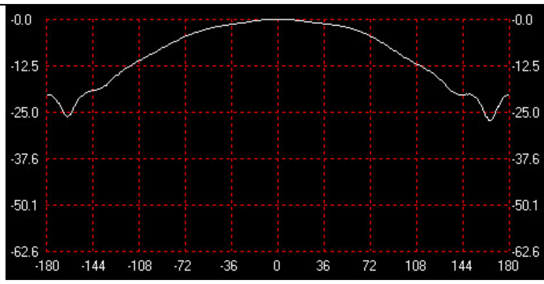
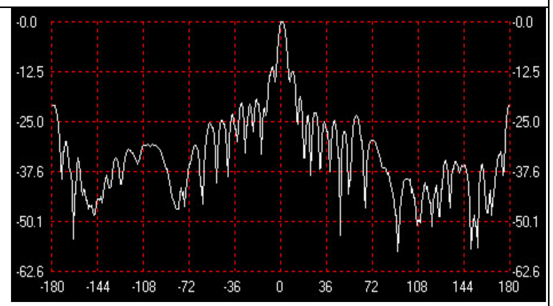
2. System parameters

The following parameters are taken for the deployment scenarios of a synchronized system:

Transmission Power: 25dBm (both Base station and CPE)
Base station antenna:
- Beam width: 120 degrees (3 sectors configuration), 60 degrees (6 sectors configuration)
- Gain: 16 dB (for both; this is only a scaling factor)
- Polarization: Vertical

CPE antenna:
- Beamwidth: 360 degrees
- Gain: 6 dB
- Polarization: Vertical.

Simulated radiation patterns were used for all three antennas, both in azimuth and in elevation. The patterns are presented below.

<table>
<tr><th></th><th>Azimuth Patterns</th><th>Elevation Patterns</th></tr>
<tr><td>Base Station Antenna 3 Sectors</td><td>
</td><td>
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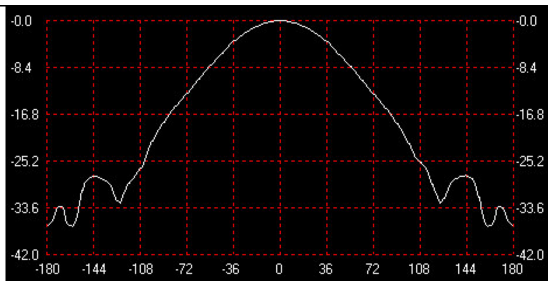
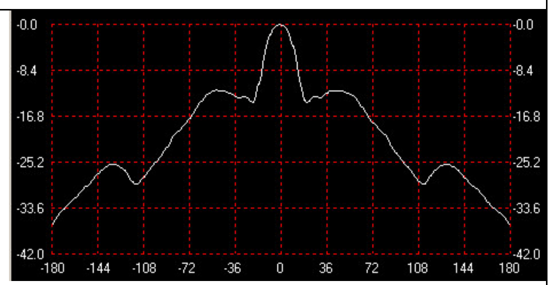
<tr><td>Base Station Antenna 6 Sectors</td><td>
</td><td>
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Antenna Patterns

The required C/N values were determined from earlier work of the IEEE802.16a, and they are presented in the following table (when using the CTC coding):

Modulation	Coding Rate	Required SNR (dB)	Required Eb/No (dB)
QPSK	1/2	6.6	6.6
QPSK	3/4	10.7	8.9
16QAM	1/2	10.5	7.5
16QAM	3/4	16.1	11.3
64QAM	2/3	15.3	12.3
64QAM	3/4	20.8	14.3

We have taken the values for Rayleigh channel and bit rate corresponding to an OFDMA system using a 10MHz bandwidth channel with a GI of $\Delta/T_U = 1/32$. For each C/I interval the average bit rate for that interval was taken. The following table gives the system throughput for the 10MHZ channel bandwidth (values within the table are in Mbps units, and were calculated for the Down-Link):

Modulation	Coding Rate	Guard Interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	6.86	7.62	8.07	8.31
QPSK	3/4	10.29	11.43	12.1	12.47
16QAM	1/2	13.71	15.24	16.13	16.62
16QAM	3/4	20.57	22.86	24.2	24.94
64QAM	2/3	27.43	30.48	32.27	33.25
64QAM	3/4	30.86	34.29	36.3	37.40

The adjacent channel attenuation is taken according to the following table:

Channel	Attenuation
Adjacent channel (dB)	40
2^{nd} adjacent channel (dB)	60
3^{rd} adjacent (dB)	80

3. Single Cell Coverage

Using the HATA model, we have plotted the coverage expected of a single cell

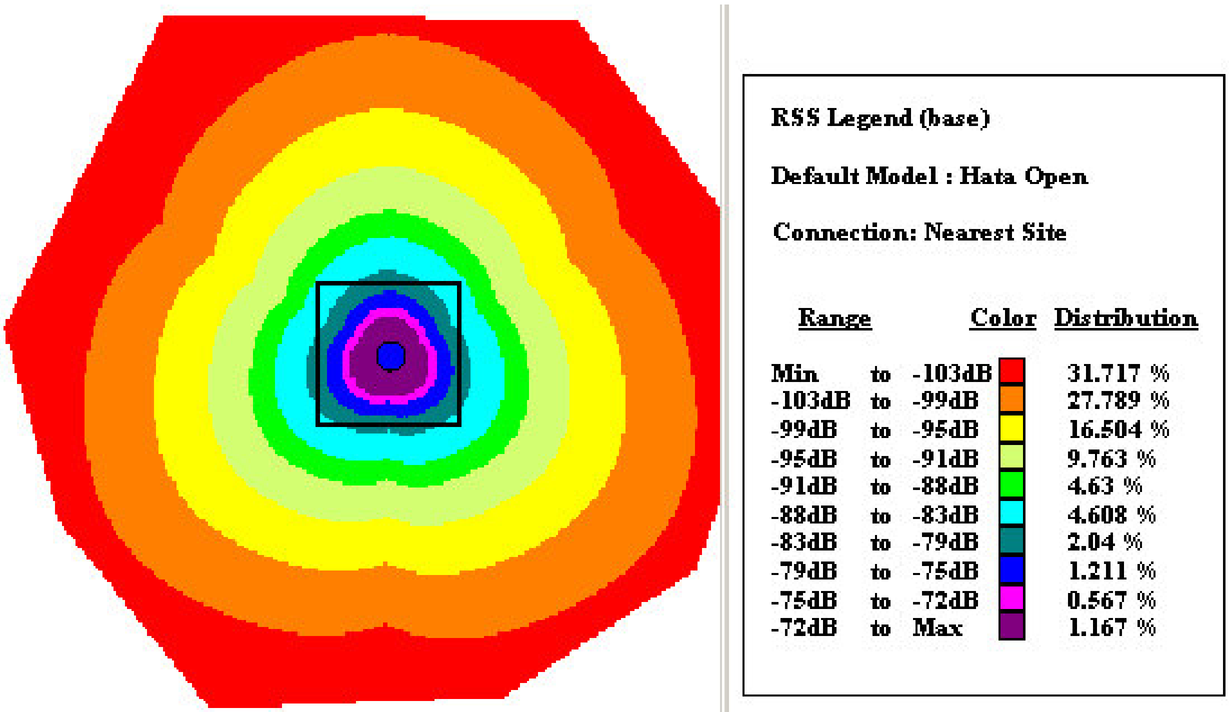


Figure 1: OFDMA coverage in a single cell configuration

The figure shows a single cell (in the middle), with 3 sectors, the Received Signal Strength (RSS) is shown by the colored contours, according to the enclosed legend, ranging between the lowest range (up to –103 dBm, the red zone) to the highest one (above –72 dBm, in magenta)

Basically, with the parameters described above, the system provides a full coverage of a 5km radius cell, as depicted by the 10km x 10km Square in the middle of figure 1. Note that if the system is TDMA, the coverage is limited to the blue line, representing the -79dBm limit of the lowest possible rate. With OFDMA on the other hand, the range can be extended to over 20km, provided the number of usable channels is limited. If only a single channel is used, 15dB can be added to the link budget, as stated in IEEE 802163c-01_11, and the coverage can be extended to the orange contour in Figure 1 representing a –99 to -103dBm line.

4. Multi-cell operation

For the multi-cell coverage, we will assume hexagonal coverage, as depicted in the next figures, with a 2km radius cells (meaning the cell coverage is Interference limited rather then coverage limited).

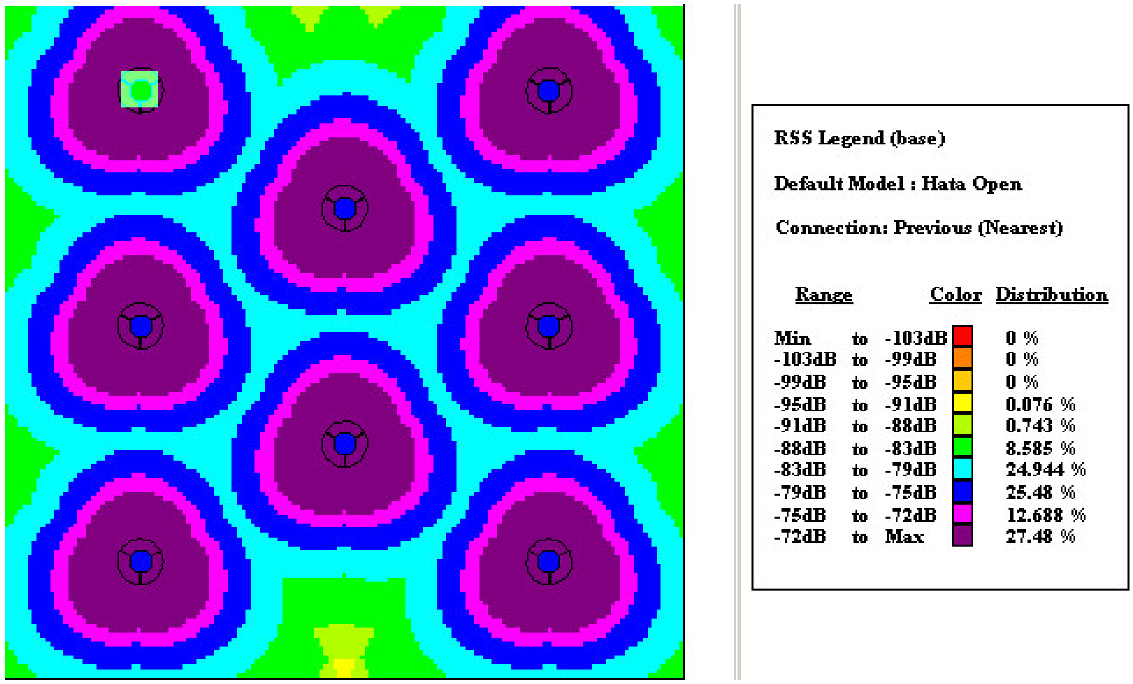
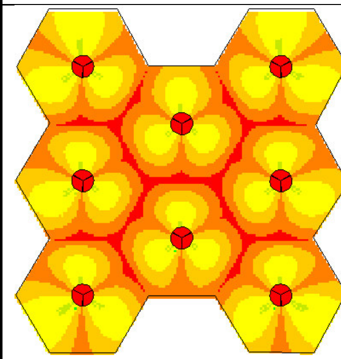
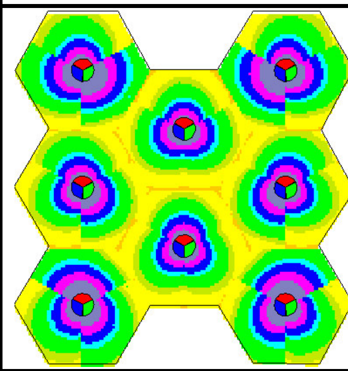
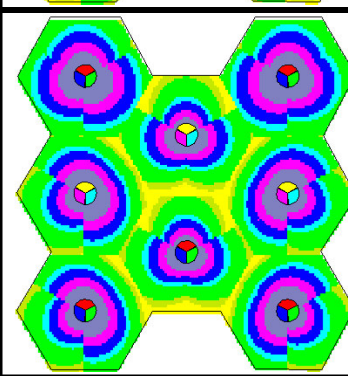


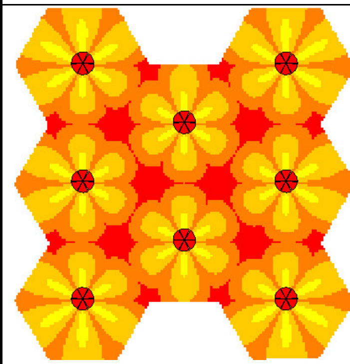
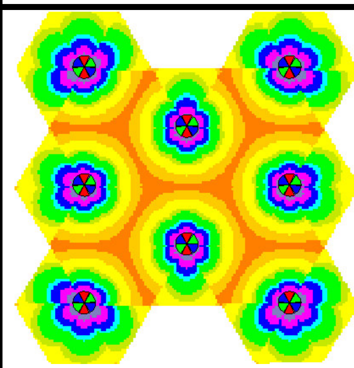
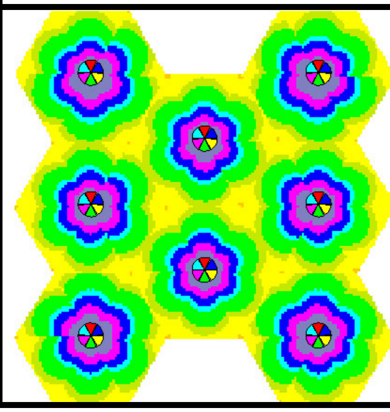
Figure 2: OFDMA coverage in a Multi cell configuration

The next table describes the C/I distribution in the hexagonal configuration as a function of the number of frequency channels used (instead of using different frequency channels, logical channels could also be created by dividing the Sub-Channels into logical entities, each consisting several Sub-Channels), together with a typical pattern of the C/I ratio. The corresponding values for the colors can be seen in the legend adjacent to each of the plots. The various channels are indicated by a color code in the "pie chart" in the center of each cell. The table does not include the effect of forward APC, which improves the C/I.

The second column in the table indicates the average capacity carried by a sector and the corresponding efficiency. The capacity was calculated as the weighted sum of the capacity that can be carried in each of the C/I intervals. The spectral efficiency was based on 10MHz channels, and 3 sectors per base station, considering a Rayleigh channel.

No. of Channel	Mbps/Cell Bps/Hz Bps/Hz/Cell	C/I Distribution	C/I Distribution Pattern
1	13.8489 0.5554 1.6662	Min to -2dB 5.565 % -2dB to 2dB 29.182 % 2dB to 6dB 33.722 % 6dB to 11dB 30.105 % 11dB to 13dB 1.408 % 13dB to 18dB 0.016 % 18dB to 20dB 0 % 20dB to 24dB 0 % 24dB to 29dB 0 % 29dB to Max 0 %	
3	85.0510 3.4109 3.4109	Min to -2dB 0 % -2dB to 2dB 0 % 2dB to 6dB 1.408 % 6dB to 11dB 19.315 % 11dB to 13dB 13.051 % 13dB to 18dB 29.95 % 18dB to 20dB 8.035 % 20dB to 24dB 11.301 % 24dB to 29dB 8.041 % 29dB to Max 8.894 %	
6	100.4085 4.0268 2.0134	Min to -2dB 0 % -2dB to 2dB 0 % 2dB to 6dB 0 % 6dB to 11dB 4.338 % 11dB to 13dB 6.216 % 13dB to 18dB 33.429 % 18dB to 20dB 12.331 % 20dB to 24dB 17.379 % 24dB to 29dB 12.373 % 29dB to Max 13.932 %	

The table below presents a similar analysis with 6-sector configuration

No. of Channel	Mbps/Sector	Bps/Hz	Bps/Hz/Cell	C/I Distribution	C/I Distribution Pattern
1	8.2236	0.1649	0.9894	Min to -2dB 9.879 % -2dB to 2dB 38.281 % 2dB to 6dB 42.421 % 6dB to 11dB 9.417 % 11dB to 13dB 0 % 13dB to 18dB 0 % 18dB to 20dB 0 % 20dB to 24dB 0 % 24dB to 29dB 0 % 29dB to Max 0 %	
3	123.3438	2.4733	4.9466	Min to -2dB 0 % -2dB to 2dB 9.056 % 2dB to 6dB 13.754 % 6dB to 11dB 21.487 % 11dB to 13dB 11.761 % 13dB to 18dB 20.546 % 18dB to 20dB 5.272 % 20dB to 24dB 7.658 % 24dB to 29dB 6.037 % 29dB to Max 4.427 %	
6	171.6679	3.4423	3.4423	Min to -2dB 0 % -2dB to 2dB 0 % 2dB to 6dB 0.249 % 6dB to 11dB 16.454 % 11dB to 13dB 16.581 % 13dB to 18dB 31.85 % 18dB to 20dB 8.099 % 20dB to 24dB 10.703 % 24dB to 29dB 7.663 % 29dB to Max 8.397 %	

5. Handoff Sub-channels

In OFDMA dedicated handoff channels can be used to cover badly covered areas between cells and to serve the mobile while moving between cells. Consider the 3 frequencies 6 sector case. In this case, which is the most spectrally efficient, there is still about 22% of the area not covered (C/I<6dB). An additional handoff channel can cover this area, which is active randomly in each base station. With OFDMA technology soft handoff can be applied to provide additional diversity gains in problematic areas. As the handoff area is concentrated mainly

in the outer border of the cells, the expected signal strength in the handoff area may look like figure 4. It is expected that the handoff channel be dynamically assigned to different users in different base stations without causing interference between cells. It is further assumed that 2 such channels can be assigned in each cell without causing any interference.
Using those assumptions we can show that the extra capacity carried by the handoff channel will boost the spectral efficiency. In scenarios where only a single handoff channel can be assigned to each cell, or in case two channels have to be used for soft handoff and hence carry the same information, it is expected that the spectral efficiency per cell will be to 4.84 bps/Hz/Cell (very much the same as for a regular 6 sectors 3 channel configuration, although some Sub-Channels are used only for handoff – making the handoff process very efficient and secure).

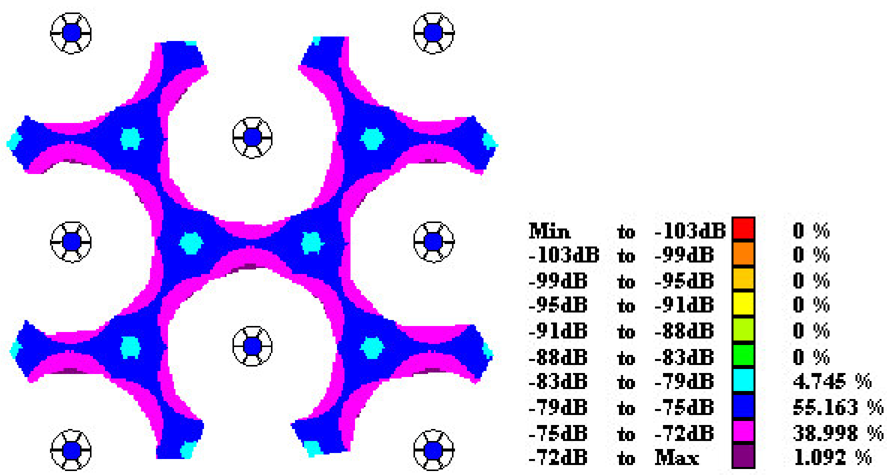


Figure 3: Handoff Sub-channel Coverage

6. Performance in a Real-Scenario

The analysis performed previously involved synthetic flat terrain with 8 base stations covering hexagonal cells. The effects in real environment, such as shadowing can be modeled mathematically, but it is certainly preferable to perform a simulation with real terrain data to demonstrate the real performance. The following Figure describes a terrain of a real urban area. This is a digital terrain map with 10m resolutions and 1m-height accuracy. The figure shows buildings as well as hills. In addition one can observe the base station, located in a similar configuration to that performed above, and the coverage area, similar to the one used in the previous analysis. Please note that the base station locations were moved somewhat from the previous hexagonal grid in order to place them in an acceptable location in the area (on a top of the building and not in the middle of a street). As the available map is not complete the coverage area was distorted in order to exclude the unavailable areas (shown in blue).

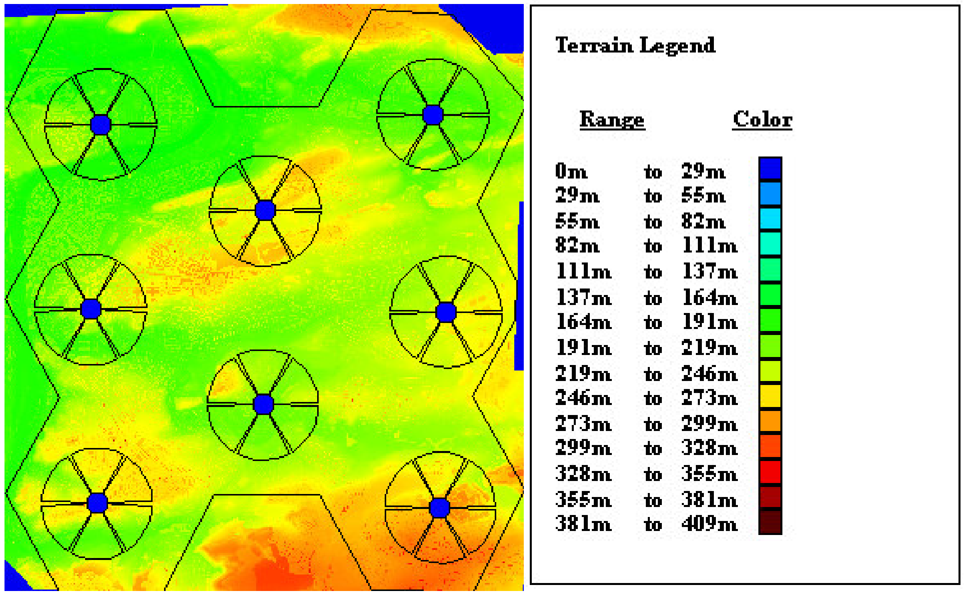


Figure 4: Terrain Map

The received signal strength was calculated for each point in the coverage area (assuming an omni directional antenna at 2m height above ground. A double knife-edge model was used as a model for the propagation lost. This model takes into account the terrain and hence reflects actual shading and obstruction problems. The RSS is given in the next figure below.

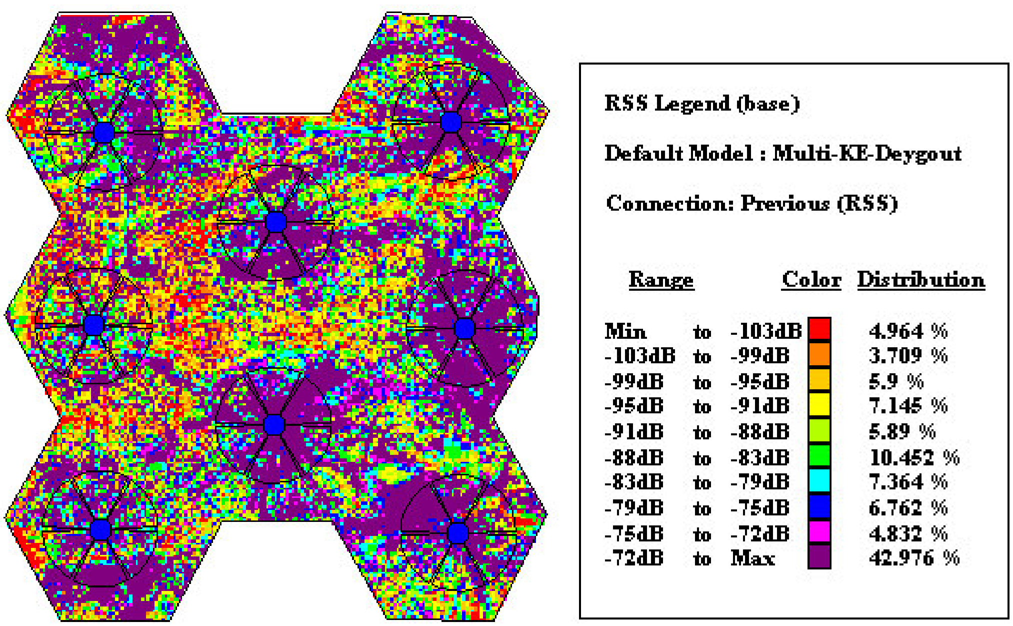


Figure 5: RSS Map of the Covered Terrain

The level depicted is RSS from the strongest base station/ sector, thus assuming handover has taken place to the strongest base station. The area thus covered by each base station is depicted in the following figure:

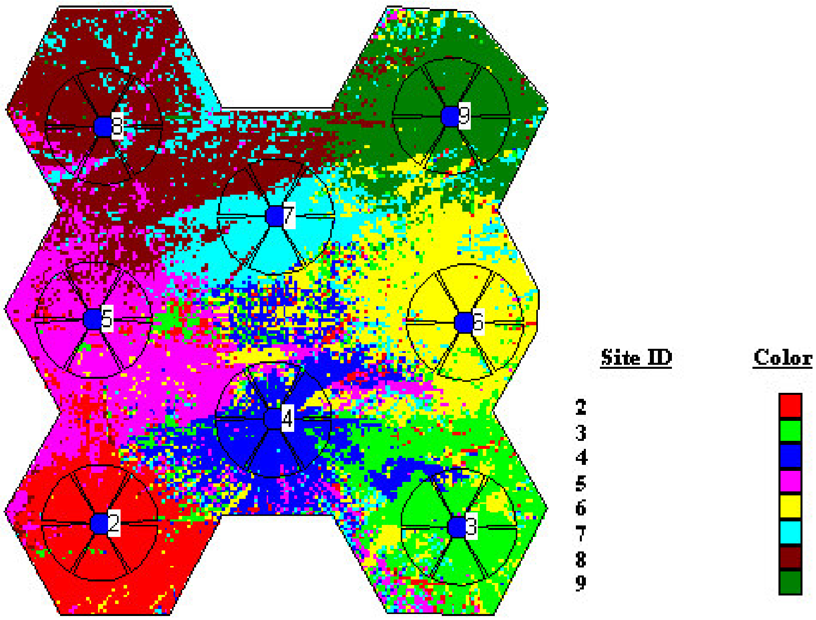


Figure 6: Site connection Map

The actual coverage is given by the C/(I+N) distribution and is shown in the figure 7. The C/(I+N) was calculated using the 3-channel 6-sector frequency pattern, shown in the previous section. Compared to the synthetic scenario, in this case the uncovered area is larger, however the larger area covered with high C/(I+N) compensate for this lack of coverage. The distribution leads to 122.87Mbps/Cell, 2.4638 bps/Hz/sector and 4.9277 bps/Hz/Cell.

It should be noted that while the cell configuration was kept identical to that of the synthetic area, it is by no means optimal, and was given here for demonstration purpose.

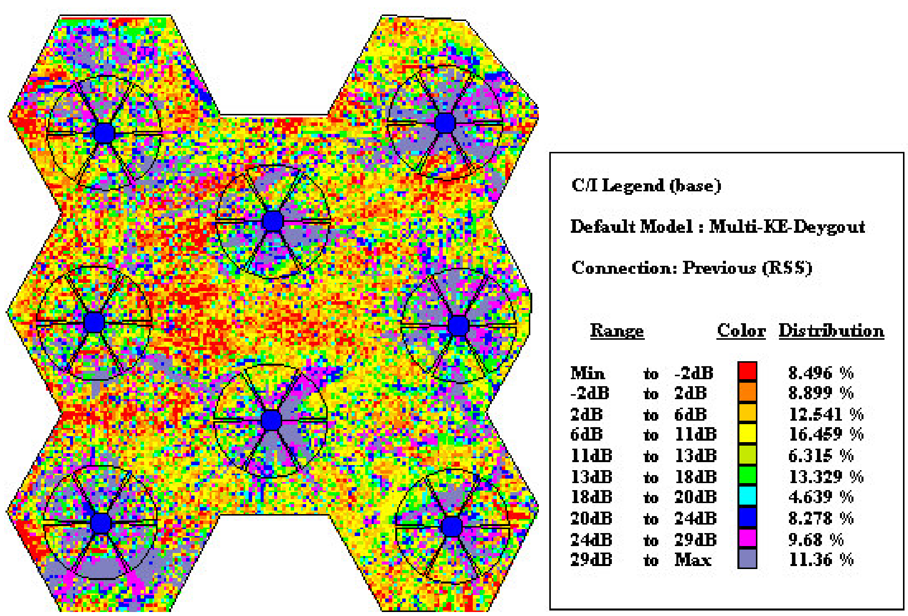


Figure 7: C/(I+N) Distribution