Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Coverage simulations for OFDMA PHY mode**
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Re:	Call for inputs IEEE 802.16e-03/01
Abstract	Coverage simulation results
Purpose	Validate the suitability of the OFDMA PHY mode for mobile operation
Notice	
Release	
Patent Policy and Procedures	

Coverage and Capacity simulations for OFDMA PHY

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1 Simulated system

Coverage simulations have been prepared using the channel model specified by IEEE 802.16a [1], and by ITU-R recommendation M.1225 [2]. Three different scenarios where analyzed,

1) Pedestrian (outdoor to outdoor)
2) Vehicular
3) Outdoor to indoor

All simulations where done for an OFDMA system with 2K FFT and 192 sub-channels. The simulations where done for a scenario where the mobile station transmit power is limited to 20dBm with the ITU model, and 17dBm with the IEEE model. To maintain bi-directional communication the base station transmit power has been set to mobile transmit power plus the OFDMA concentration gain. The OFDMA concentration gain is up to 22.8dB in this case, and therefore the BS transmission power has been set at 40dBm for ITU model and 37dBm for IEEE model. The simulations include use of antenna diversity that can be achieved either by using the STC option, or by maximal-ratio-combining (MRC) at the receiver.

Under these conditions, the simulations have been performed only for the downlink, as the downlink is supposed to suffer worse interference than the uplink. The results therefore apply for the downlink channel, or for a single OFDMA uplink channel.

The simulated system summary is

- 5MHz Rayleigh channel at 2.6GHz
- Convolutional Turbo Coding FEC scheme with threshold BER of 10^{-5}
- The SS antenna is omni-directional with gain of 0dBi
- The BS antenna has beam-width of 60 degrees and gain of 18dBi (see **Error! Reference source not found.**)
- Transmit power from the BS is 40dBm for the ITU model and 37dBm for IEEE model
- Use of antenna diversity (either STC or MRC)
- Receiver noise-figure of 4dB

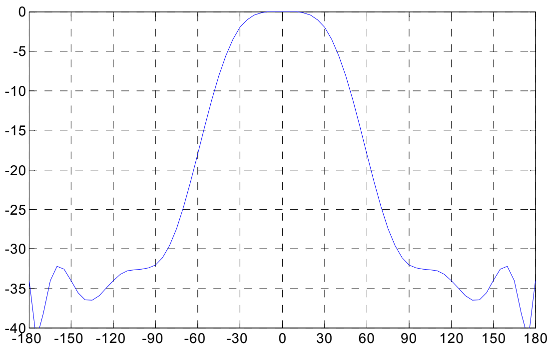

Figure 1: BS sector antenna pattern

Table 1 has been used for capacity calculations (with GI=1/32),

Modulation	Code rate	Sensitivity threshold S/N (Rayleigh)	Guard Interval			
			1/4	1/8	1/16	1/32
QPSK	1/2	6.6 dB	0.686	0.762	0.807	0.831
16QAM	1/2	10.5 dB	1.371	1.524	1.613	1.662
64QAM	2/3	15.3 dB	2.743	3.048	3.227	3.325
64QAM	3/4	20.8 dB	3.086	3.429	3.63	3.740

Table 1: Net PHY bit/sec/Hz and sensitivity with fixed Rayleigh channel

2 Propagation models

This section compares the various propagation models that are used (or might be used) for coverage and capacity simulations. For the graphs below, BS height = 15m and SS height = 1.5m.

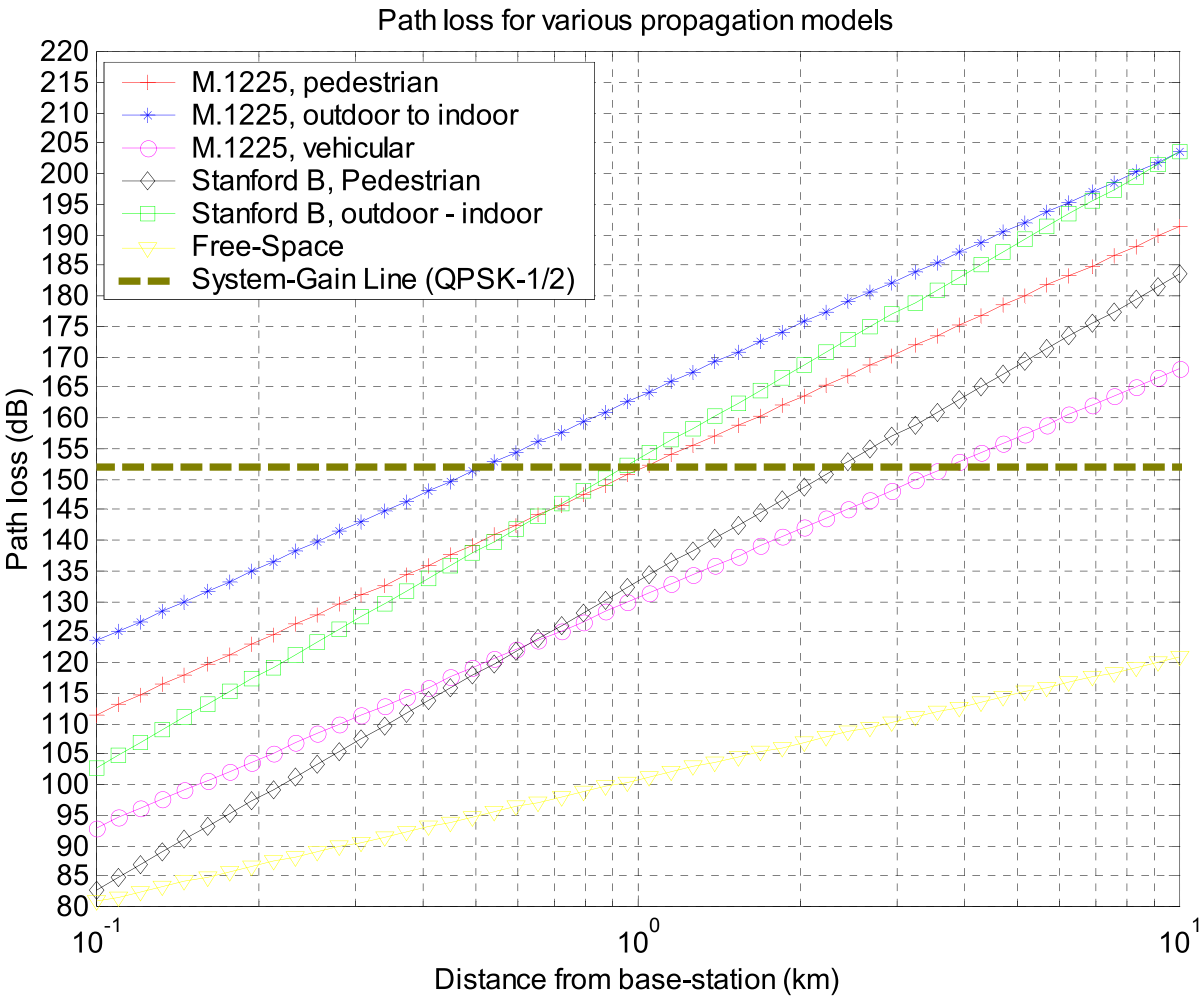

Figure 2: Various path loss models

3 Outdoor/Pedestrian model (ITU-R M.1225)

3.1 Path loss and system model

The path loss model used is taken from ITU-R recommendation M.1225. The path loss is given by the formula,

$$\text{Path-Loss} = 40\cdot\log_{10}(d) + 30\cdot\log_{10}(f) + 49 + S$$

Where,
d is the distance in km
f is the frequency (2.6GHz)
S is the lognormal distributed shadowing random variable, with standard deviation of 10dB

3.2 Single cell

In this section the performance of a single cell has been simulated **without use of forward APC**.

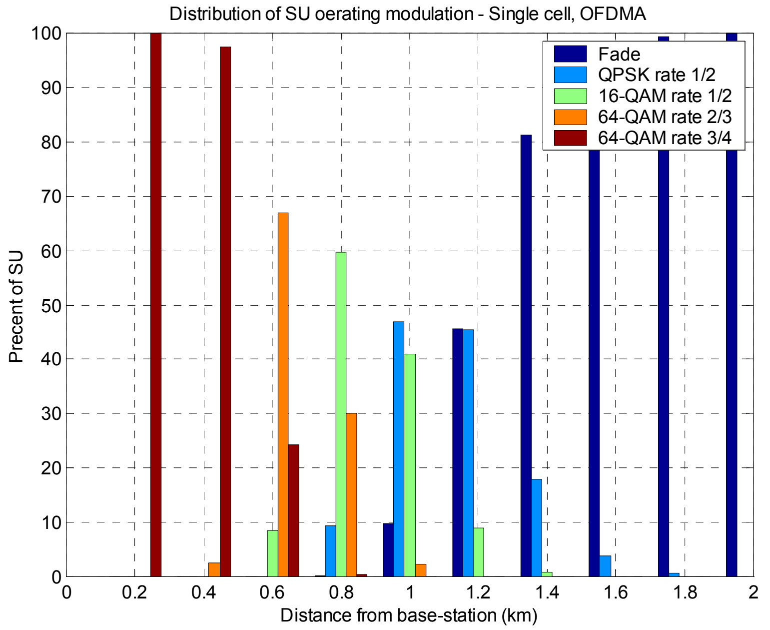

Figure 3: Distribution of SU operating mode in a single cell (M.1225, pedestrian)

3.3 Multiple cells

The objective of the situation simulated was to demonstrate good coverage and good capacity. Figure 4 shows the simulated geometry where 6 sectors are used per BS. Each frequency is used twice in each cell. The coverage is enhanced by utilizing four forward APC rings. The simulation is done in the downlink, because this is the limiting case for the capacity calculation. Note that this simulation does NOT include adaptive antennas, which have a potential of further increasing the coverage and capacity. Each sector has been sub-divided into regions with different forward APC settings, in order to minimize interference.

Figure 5 and Figure 6 show the coverage simulation results for a scenario optimized for coverage, with a cell radius of **1.5km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 100%, and the average capacity per sector is 1.24 Bit/sec/Hz, and for the entire cell it is 2.48 Bit/sec/Hz.

Figure 7 and Figure 8 show the coverage simulation results for a scenario optimized for capacity, with a cell radius of **1.0km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 99%, and the average capacity per sector is 1.71 Bit/sec/Hz, and for the entire cell it is 3.43 Bit/sec/Hz.

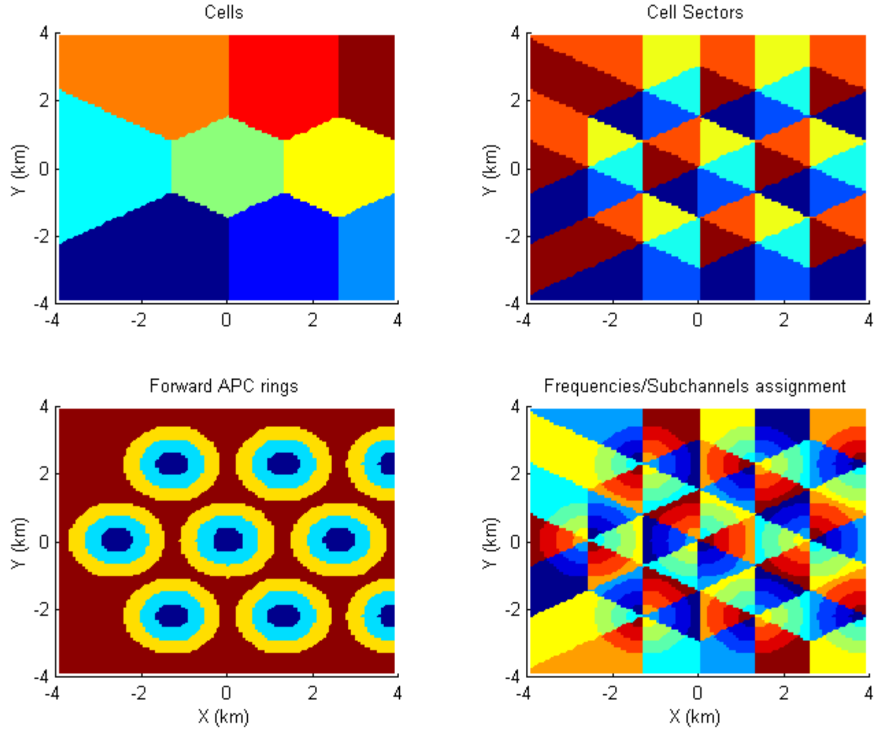

Figure 4: Cell and sector assignment plan, 6 sectors per cell, 3 frequencies per cell, 4 APC rings, M.1225

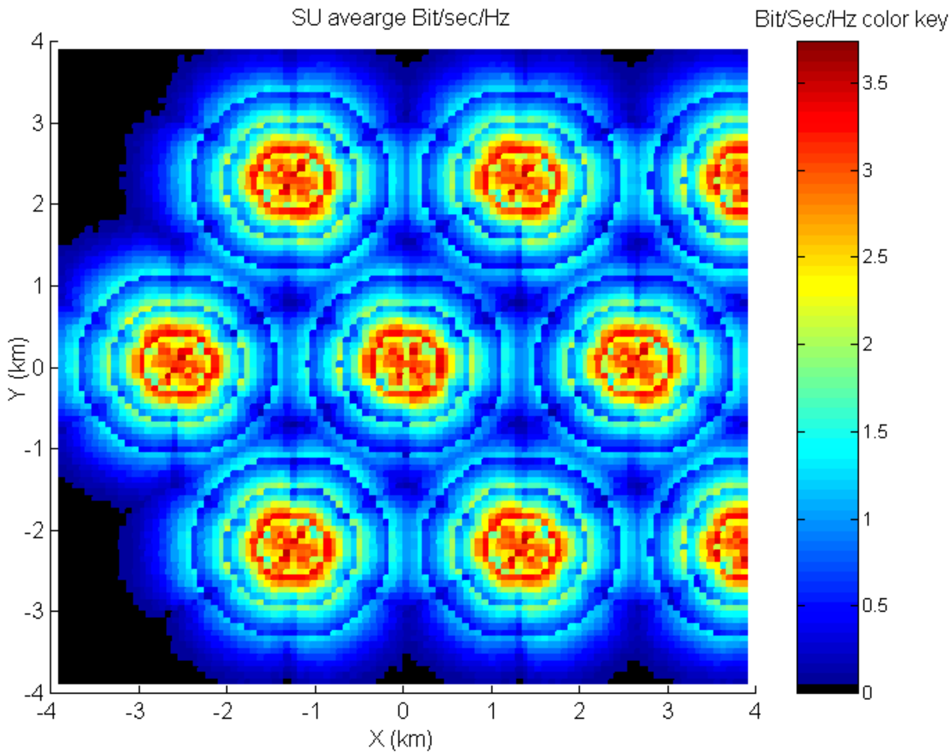

Figure 5: Outdoor-Pedestrian coverage (M.1225, optimized for better coverage)

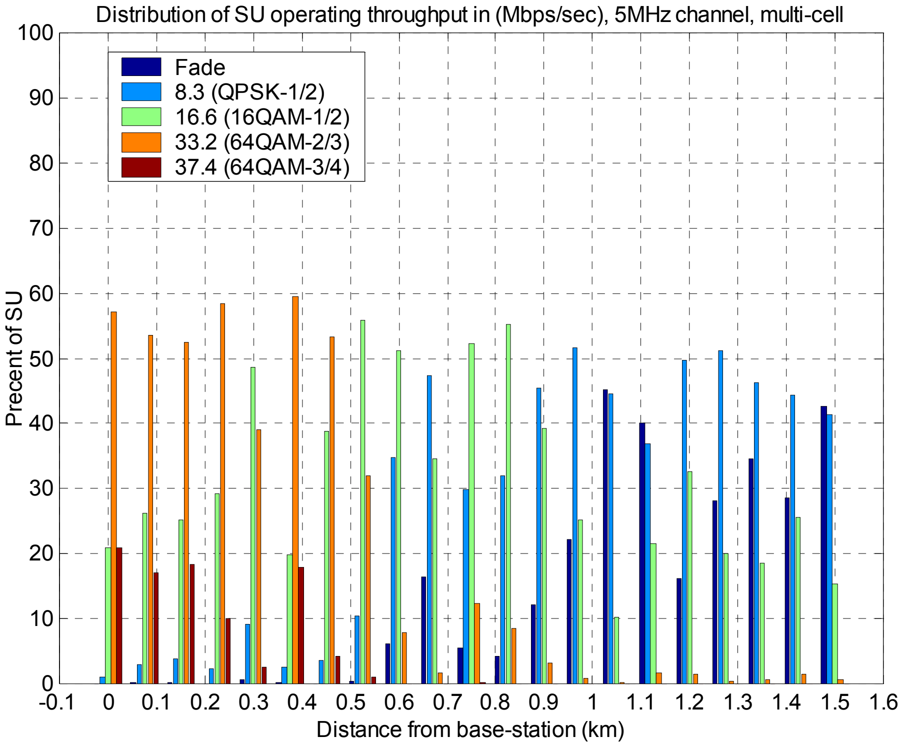

Figure 6: Distribution of SS throughput in the cell, pedestrian (M.1225, optimized for better coverage)

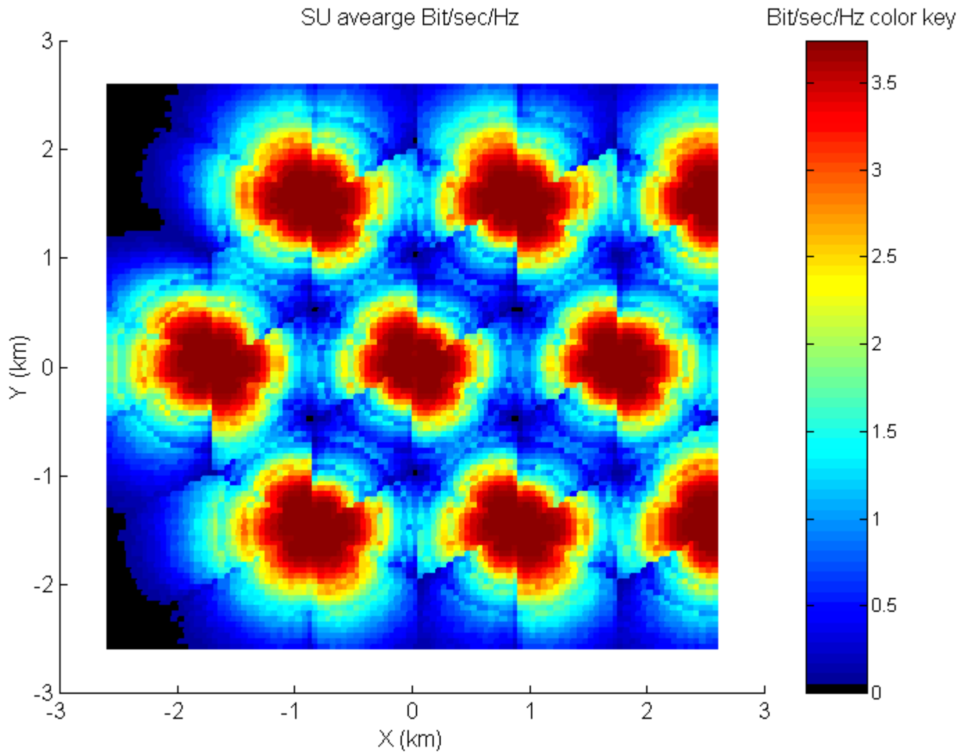

Figure 7: Outdoor-Pedestrian coverage (M.1225, optimized for better capacity)

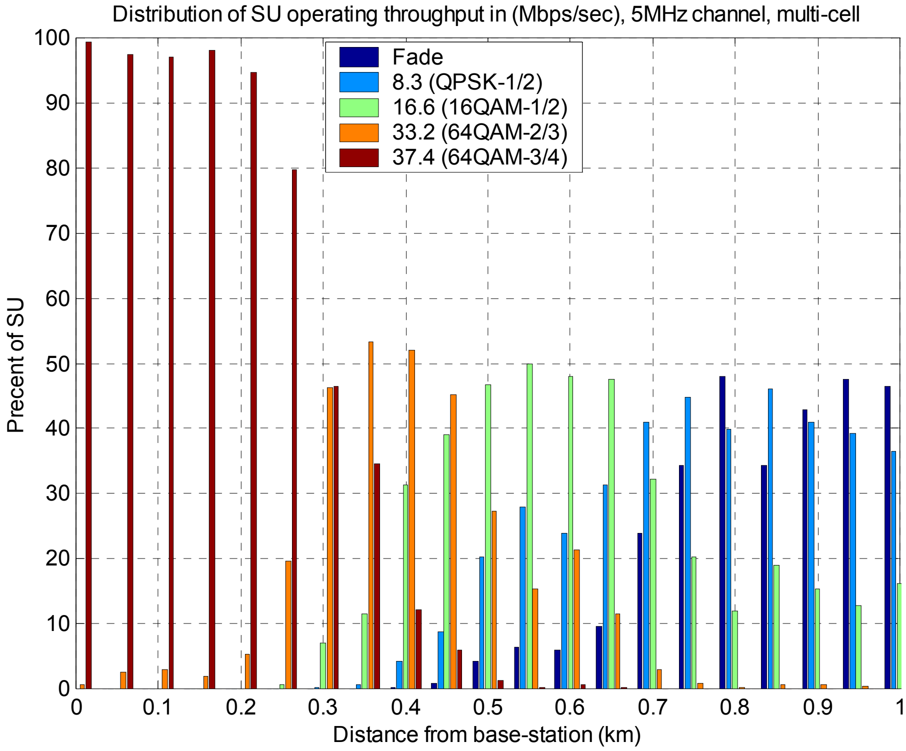

Figure 8: Distribution of SS throughput in the cell, pedestrian (M.1225, optimized for better capacity)

4 Outdoor/Pedestrian model (IEEE, Stanford B)

4.1 Path loss and system model

Coverage simulations have been prepared using the IEEE channel model (Stanford B),

$$PathLoss = 20 \cdot \log_{10}(\frac{4\pi d_0}{\lambda}) + 10 \cdot (a - b \cdot h_b + \frac{c}{h_b}) \cdot \log_{10}(\frac{d}{d_0}) + s + Modifications$$

$$Modifications = 6 \cdot \log_{10}(\frac{f}{2000}) - 10.8 \cdot \log_{10}(\frac{h_u}{2})$$

Where,

h_b, h_u Are the BS and SU antenna heights respectively (15m, 1.5m)

d_0 is a normalization factor (100m)

S is the lognormal distributed shadowing random variable, with standard deviation of 10dB

a, b, c are derived from the terrain type (a=4, b=0.0065, c=17.1)

f is the frequency (2.6GHz)

4.2 Single cell

In this section the performance of a single cell has been simulated **without use of forward APC**.

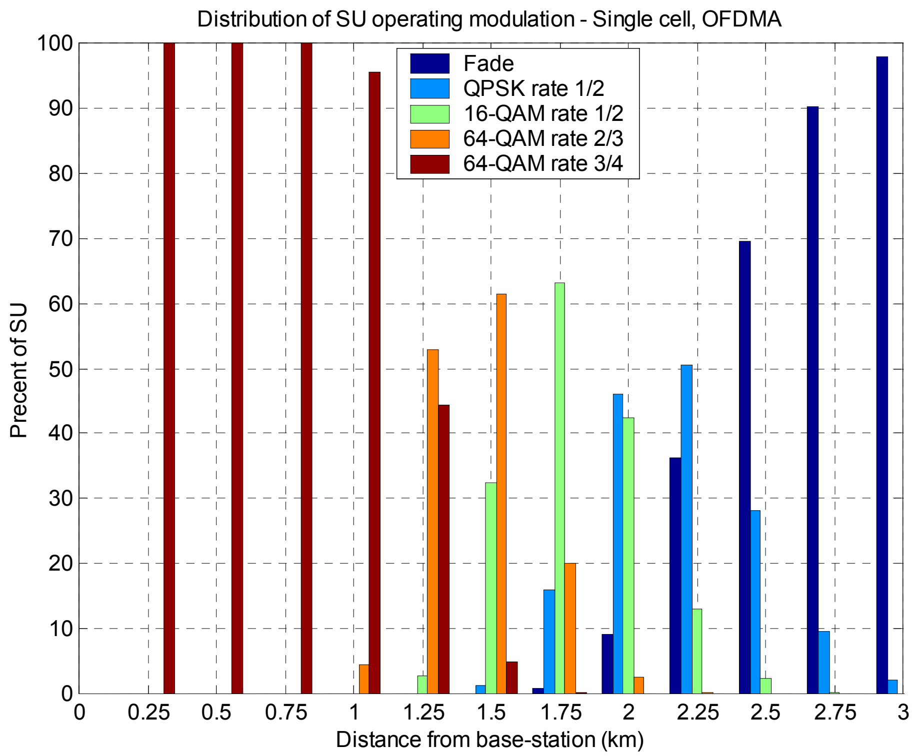

Figure 9: Distribution of SU operating mode in a single cell (Stanford B, pedestrian)

4.3 Multiple cells

The objective of the situation simulated was to demonstrate good coverage and good capacity. Figure 10 shows the simulated geometry where 6 sectors are used per BS. Each frequency is used twice in each cell. The

coverage is enhanced by utilizing four forward APC rings. The simulation is done in the downlink, because this is the limiting case for the capacity calculation. Note that this simulation does NOT include adaptive antennas, which have a potential of further increasing the coverage and capacity. Each sector has been sub-divided into regions with different forward APC settings, in order to minimize interference.
Figure 11 and Figure 16 show the coverage simulation results for a scenario optimized for coverage, with a cell radius of **2.5km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 100%, and the average capacity per sector is 2.15 Bit/sec/Hz, and for the entire cell it is 4.31 Bit/sec/Hz.

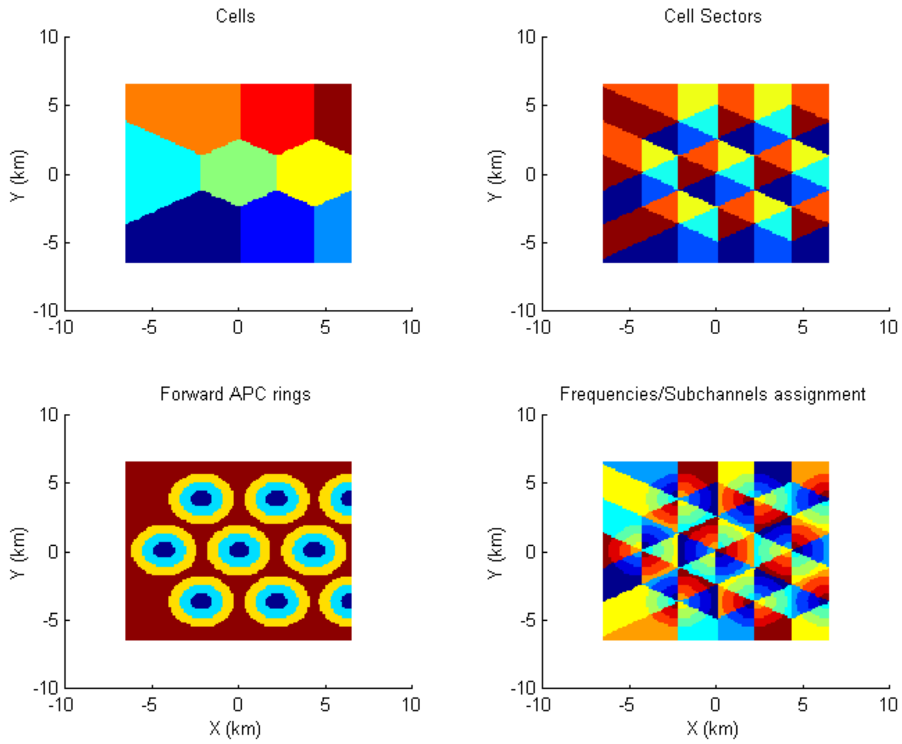

Figure 10: Cell and sector assignment plan, 6 sectors per cell, 3 frequencies per cell, 4 APC rings, Stanford B

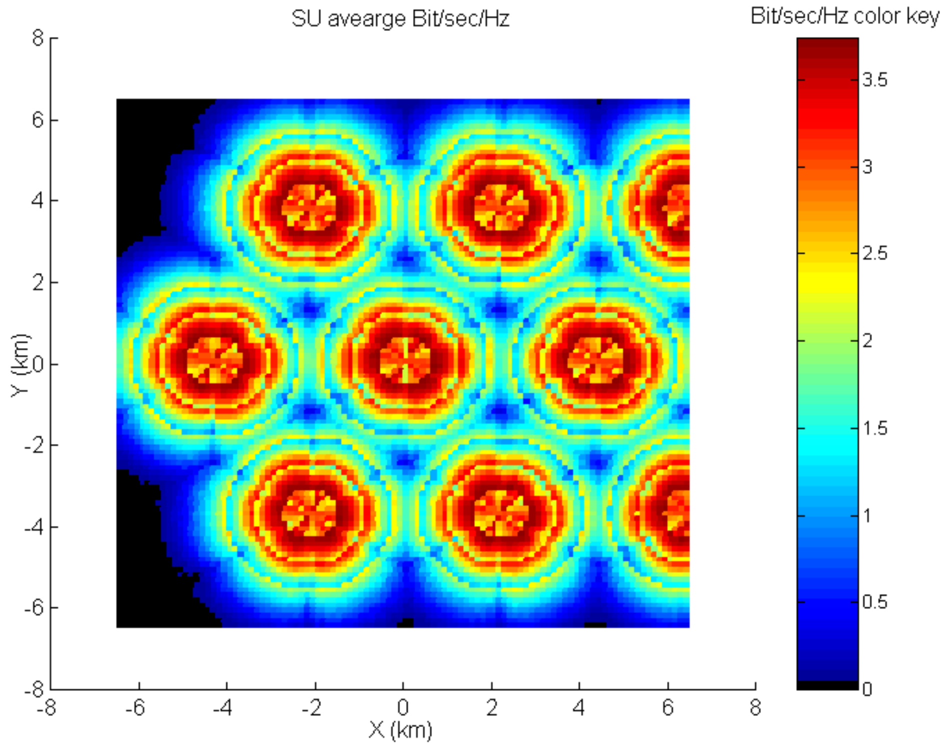

Figure 11: Outdoor-Pedestrian coverage (Stanford B, optimized for better coverage)

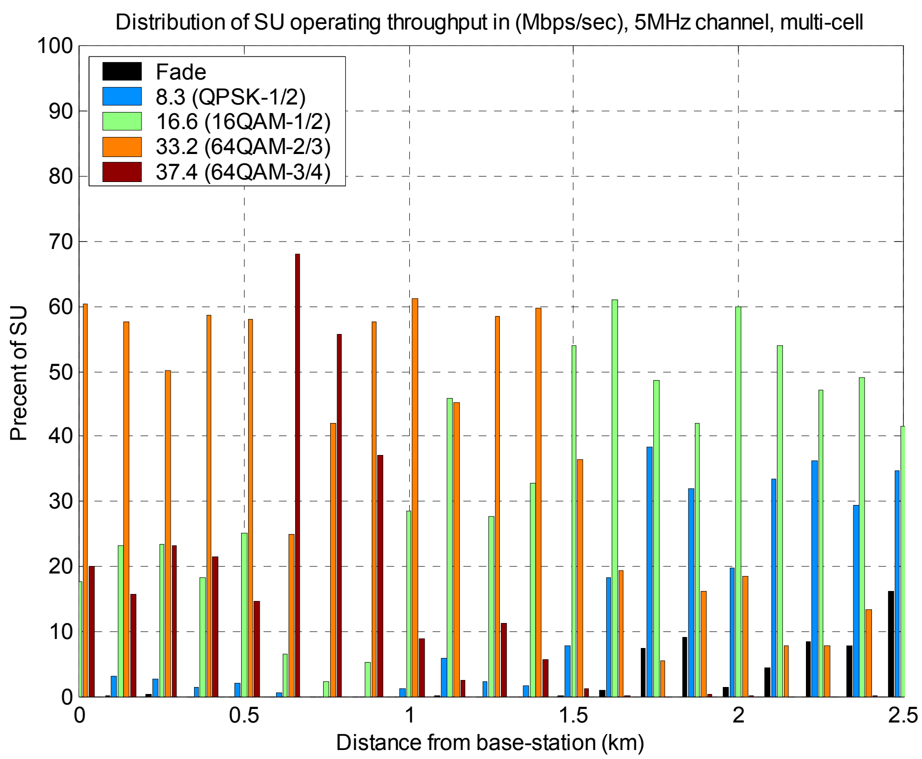

Figure 12: Distribution of SS throughput in the cell, pedestrian (Stanford B, optimized for better coverage)

5 Vehicular model (ITU-R M.1225)

5.1 Path loss and system model

The path loss model used is taken from ITU-R recommendation M.1225. The path loss is given by the formula,

$$\text{Path-Loss} = 40\cdot[1 - 0.004\Delta h_b]\log_{10}(d) - 18\cdot\log_{10}(\Delta h_b) + 21\cdot\log_{10}(f) + 80 + S$$

Where,
d is the distance in km
f is the frequency (2.6GHz)
Δh_b is the BS antenna height above average building level
S is the lognormal distributed shadowing random variable, with standard deviation of 10dB

5.2 Single cell

In this section the performance of a single cell has been simulated **without use of forward APC**.

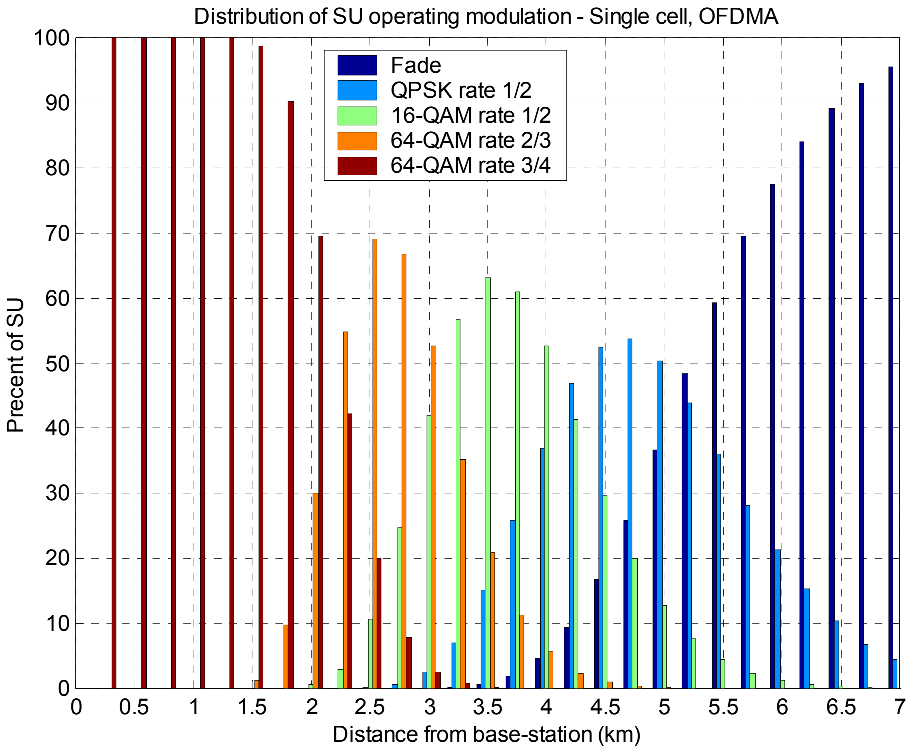

Figure 13: Distribution of SU operating mode in a single cell (M.1225, vehicular)

5.3 Multiple cells

The objective of the situation simulated was to demonstrate good coverage and good capacity. Figure 14 shows the simulated geometry where 6 sectors are used per BS. Each frequency is used twice in each cell. The coverage is enhanced by utilizing three forward APC rings. The vehicular speed used for the simulation is 75km/H. The simulation is done in the downlink, because this is the limiting case for the capacity calculation. Note that this simulation does NOT include adaptive antennas, which have a potential of further increasing the coverage and capacity. Each sector has been sub-divided into regions with different forward APC settings, in order to minimize interference. Figure 15 and Figure 16 show the coverage simulation results for a scenario optimized for maximum coverage, with a cell radius of **5km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 100%, and the average capacity per sector is 1.35 Bit/sec/Hz, and for the entire cell it is 2.71 Bit/sec/Hz.

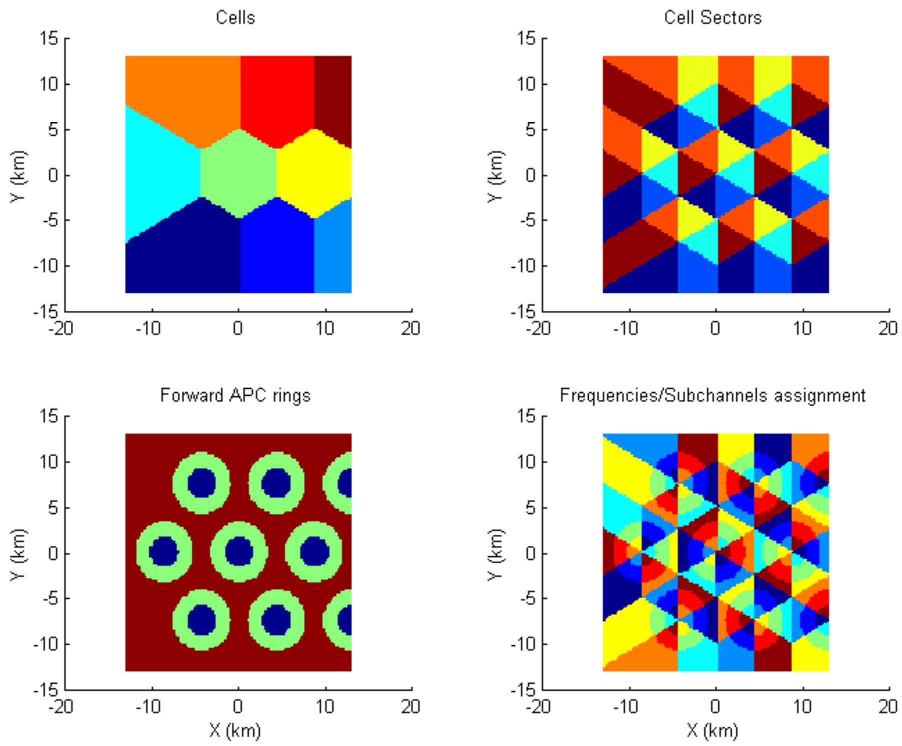

Figure 14: Cell and sector assignment plan, 6 sectors per cell, 3 frequencies per cell, 3 APC rings, M.1225

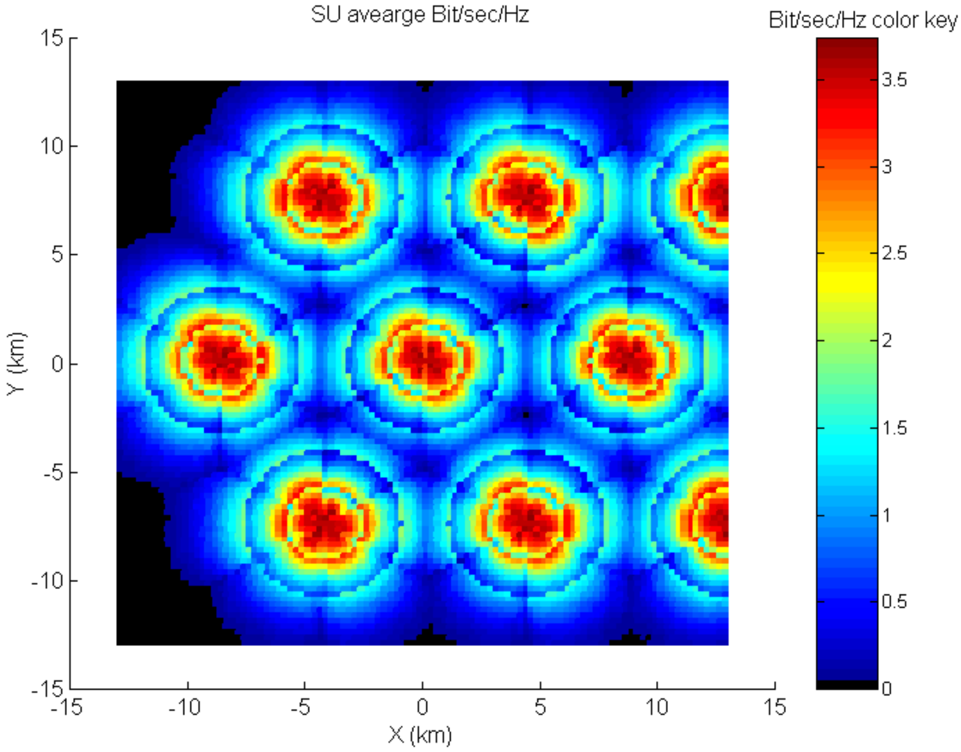

Figure 15: Outdoor-Vehicular coverage (M.1225, optimized for better coverage)

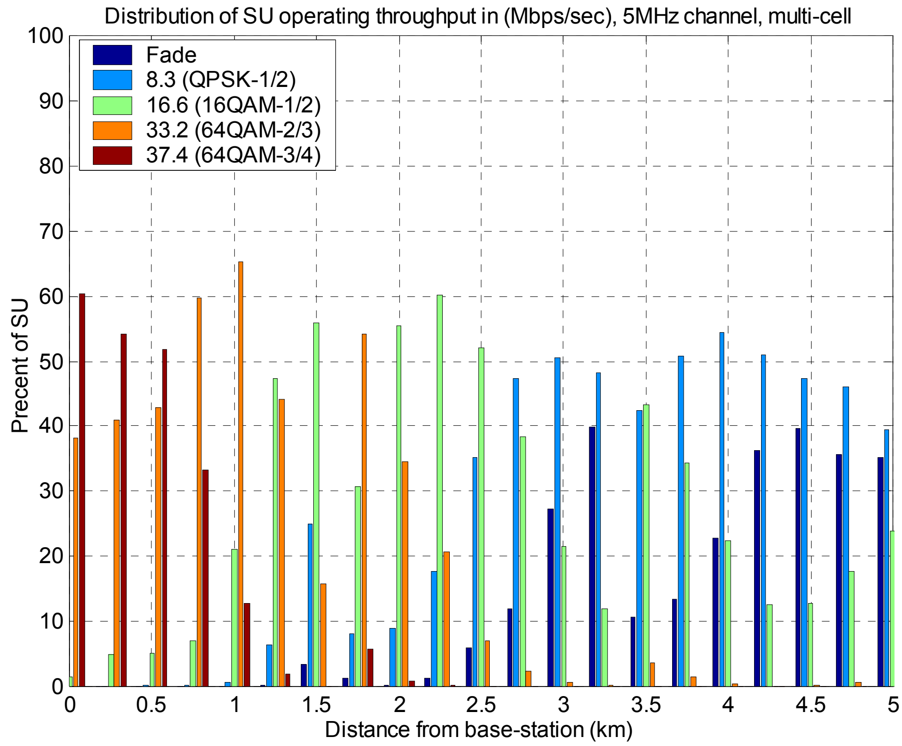

Figure 16: Distribution of SS throughput in the cell, vehicular (M.1225, optimized for better coverage)

6 Vehicular model (IEEE, Stanford B)

6.1 Path loss and system model

Coverage simulations have been prepared using the IEEE channel model (Stanford B),

$$PathLoss = 20 \cdot \log_{10}(\frac{4\pi d_0}{\lambda}) + 10 \cdot (a - b \cdot h_b + \frac{c}{h_b}) \cdot \log_{10}(\frac{d}{d_0}) + s + Modifications$$

$$Modifications = 6 \cdot \log_{10}(\frac{f}{2000}) - 10.8 \cdot \log_{10}(\frac{h_u}{2})$$

Where,

h_b, h_u Are the BS and SU antenna heights respectively (15m, 1.5m)

d_0 is a normalization factor (100m)

S is the lognormal distributed shadowing random variable, with standard deviation of 10dB

a, b, c are derived from the terrain type (a=4, b=0.0065, c=17.1)

f is the frequency (2.6GHz)

6.2 Single cell

In this section the performance of a single cell has been simulated **without use of forward APC**.

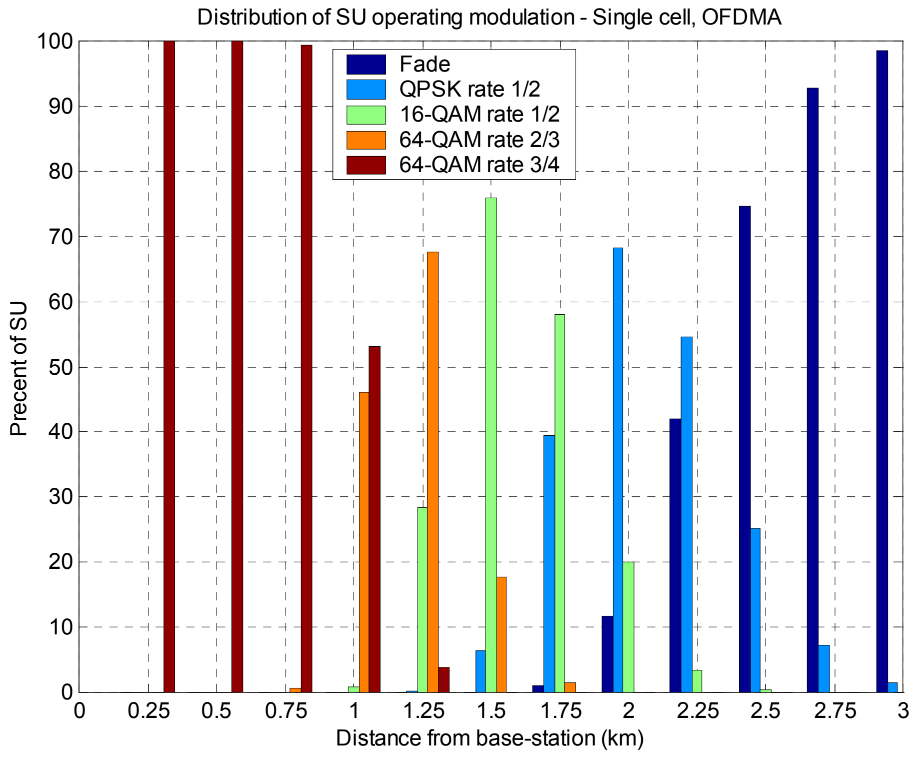

Figure 17: Distribution of SU operating mode in a single cell (Stanford B, vehicular)

6.3 Multiple cells

The objective of the situation simulated was to demonstrate good coverage and good capacity. Figure 18 shows the simulated geometry where 6 sectors are used per BS. Each frequency is used twice in each cell. The coverage is enhanced by utilizing four forward APC rings. The vehicular speed used for the simulation is

75km/H. The simulation is done in the downlink, because this is the limiting case for the capacity calculation. Note that this simulation does NOT include adaptive antennas, which have a potential of further increasing the coverage and capacity. Each sector has been sub-divided into regions with different forward APC settings, in order to minimize interference. Figure 19 and Figure 20 show the coverage simulation results for a scenario optimized for maximum coverage, with a cell radius of **5km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 100%, and the average capacity per sector is 1.69 Bit/sec/Hz, and for the entire cell it is 3.38 Bit/sec/Hz.

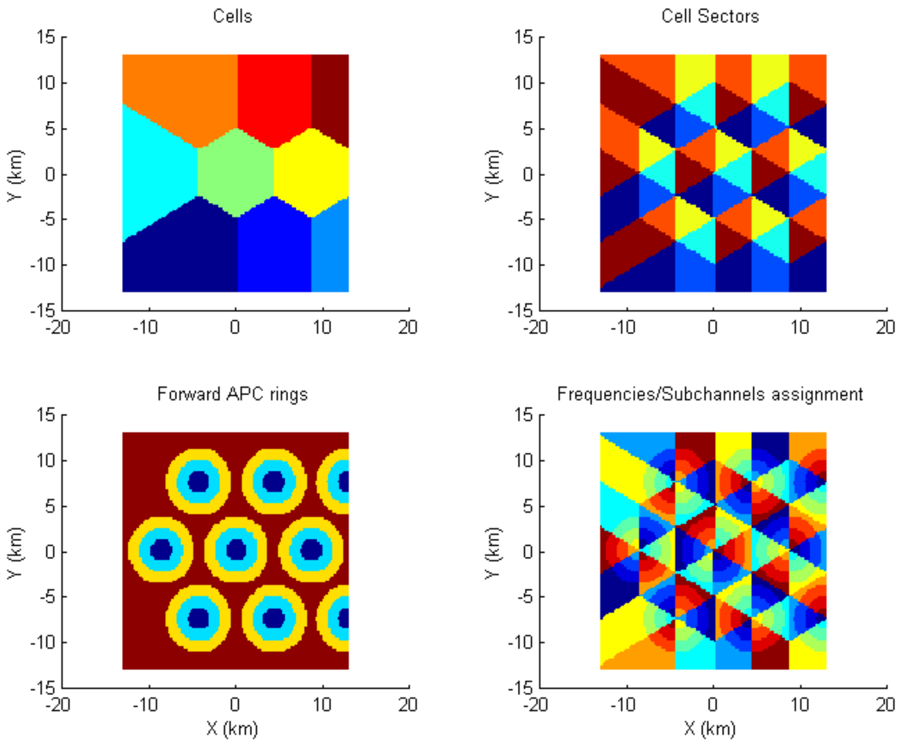

Figure 18: Cell and sector assignment plan, 6 sectors per cell, 3 frequencies per cell, 4 APC rings, Stanford B

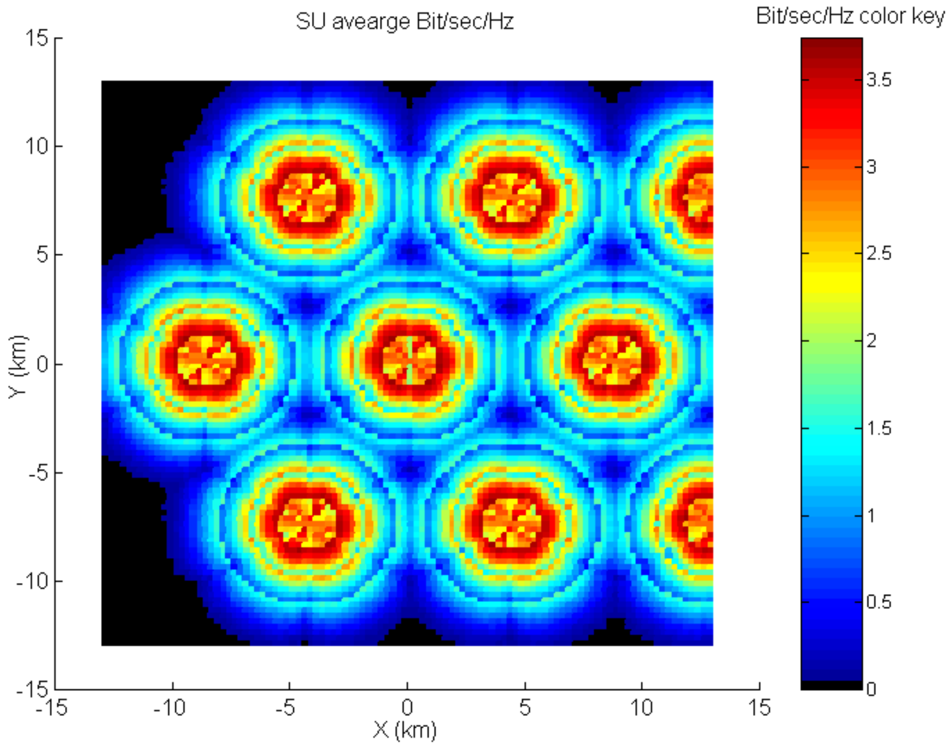

Figure 19: Outdoor-Vehicular coverage (Stanford B, optimized for better coverage)

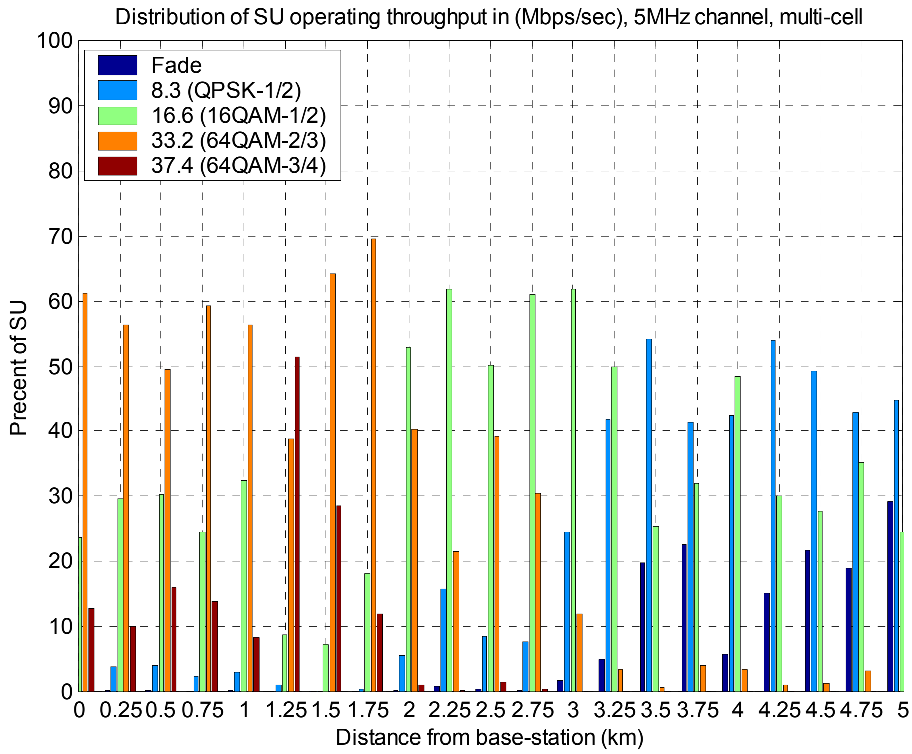

Figure 20: Distribution of SS throughput in the cell, vehicular (Stanford B, optimized for better coverage)

7 Outdoor to indoor model (ITU-R M.1225)

7.1 Path loss and system model

The path loss model used is taken from ITU-R recommendation M.1225. The path loss is given by the formula,

$$\text{Path-Loss} = 40\cdot\log_{10}(d) + 30\cdot\log_{10}(f) + 49 + PL_{indoor\text{-}loss} + S$$

Where,
d is the distance in km
f is the frequency (2.6GHz)
S is the lognormal distributed shadowing random variable, with standard deviation of 14.4dB
$PL_{indoor\text{-}loss}$ is the outdoor to indoor penetration loss of 12dB

7.2 Single cell

In this section the performance of a single cell has been simulated **without use of forward APC**.

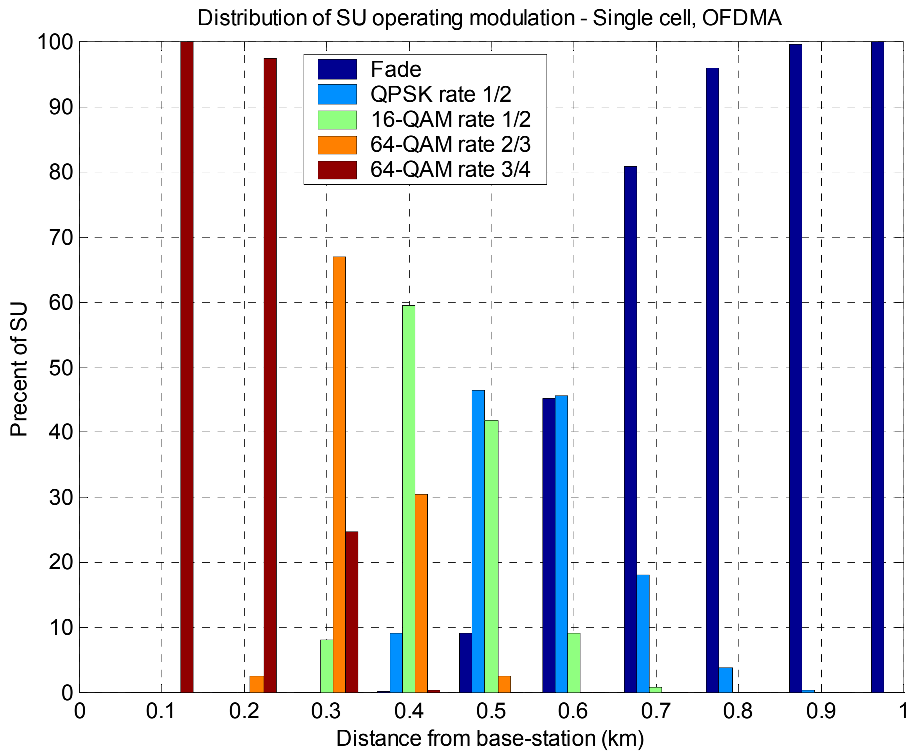

Figure 21: Distribution of SU operating mode in a single cell (M.1225, outdoor to indoor)

7.3 Multiple cells

The objective of the situation simulated was to demonstrate good coverage and good capacity. Figure 22 shows the simulated geometry where 6 sectors are used per BS. Each frequency is used twice in each cell. The coverage is enhanced by utilizing four forward APC rings. The simulation is done in the downlink, because this is the limiting case for the capacity calculation. Note that this simulation does NOT include adaptive antennas, which have a potential of further increasing the coverage and capacity. Each sector has been sub-divided into regions with different forward APC settings, in order to minimize interference. Figure 23 shows the coverage simulation results for a scenario optimized for maximum coverage, with a cell radius of **0.75km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 100%, and the average capacity per sector is 1.24 Bit/sec/Hz, and for the entire cell it is 2.48 Bit/sec/Hz.

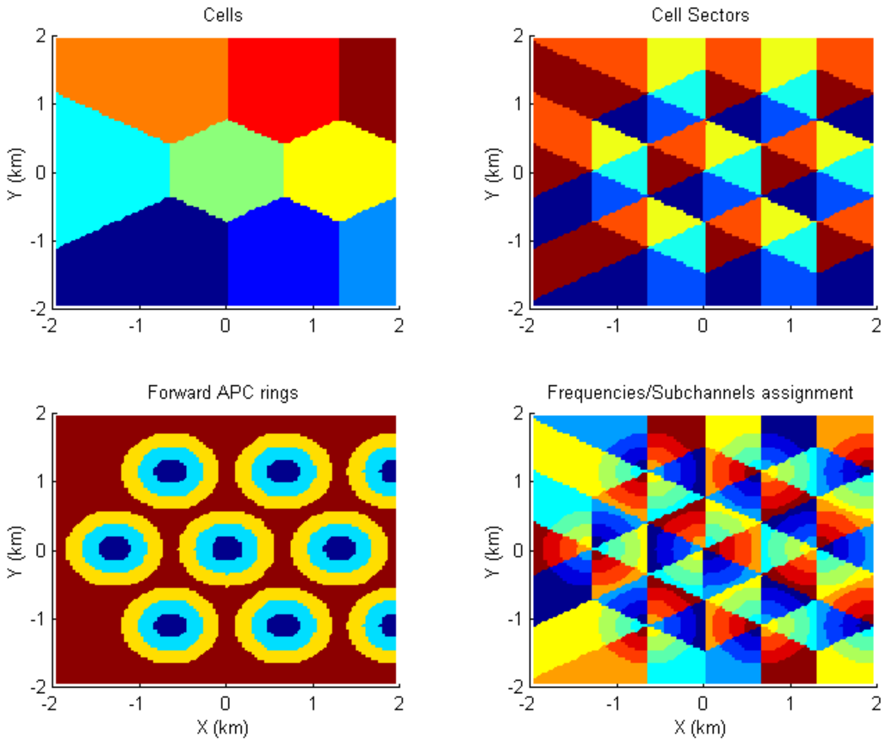

Figure 22: Cell and sector assignment plan, 6 sectors per cell, 3 frequencies per cell, 4 APC rings, M.1225

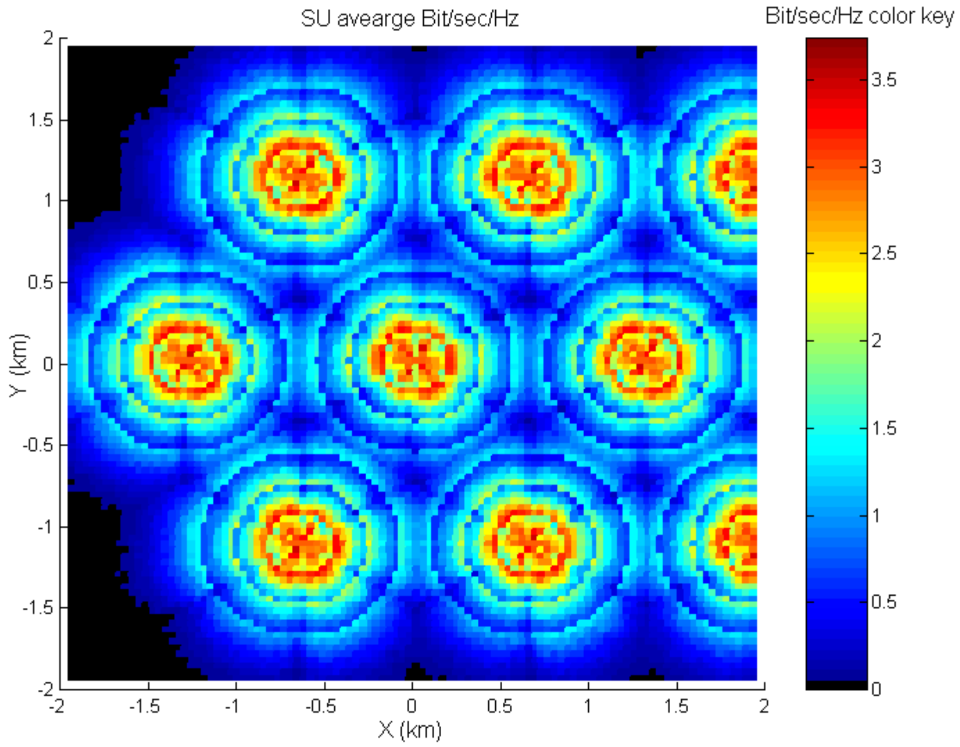

Figure 23: Outdoor to indoor coverage (M.1225, optimized for better coverage)

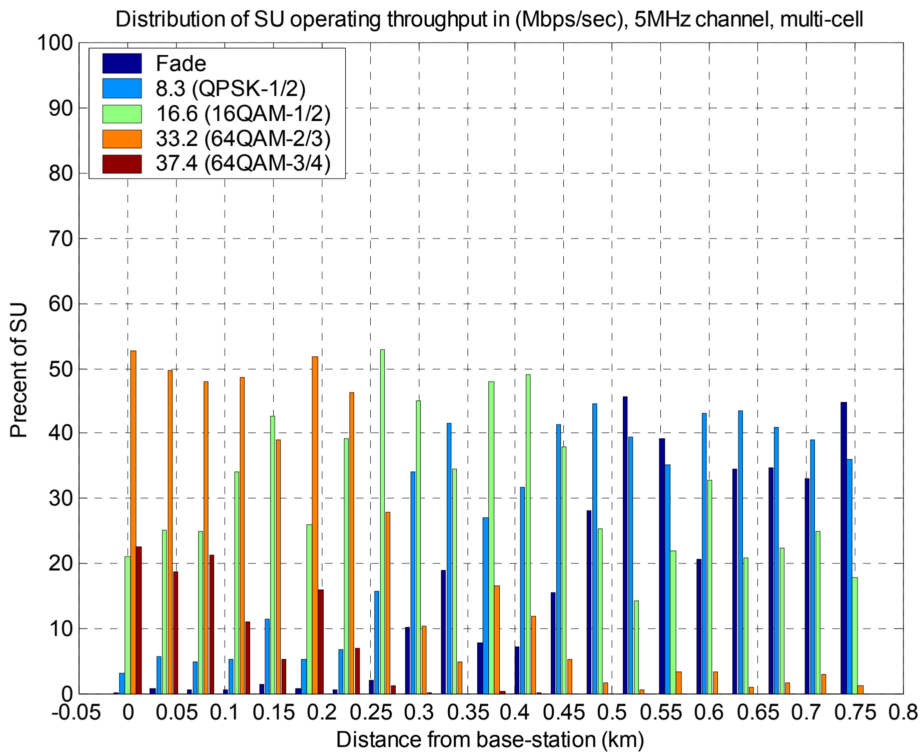

Figure 24: Distribution of SS throughput in the cell, outdoor to indoor (M.1225, optimized for better coverage)

8 Outdoor to indoor model (IEEE, Stanford B)

8.1 Path loss and system model

Coverage simulations have been prepared using the IEEE channel model (Stanford B),

$$PathLoss = 20 \cdot \log_{10}(\frac{4\pi d_0}{\lambda}) + 10 \cdot (a - b \cdot h_b + \frac{c}{h_b}) \cdot \log_{10}(\frac{d}{d_0}) + s + Modifications$$

$$Modifications = 6 \cdot \log_{10}(\frac{f}{2000}) - 10.8 \cdot \log_{10}(\frac{h_u}{2}) + PL_{Indoor}$$

Where,

h_b, h_u Are the BS and SU antenna heights respectively (15m, 1.5m)

d_0 is a normalization factor (100m)

S is the lognormal distributed shadowing random variable, with standard deviation of 14.4dB

a, b, c are derived from the terrain type (a=4, b=0.0065, c=17.1)

f is the frequency (2.6GHz)

PL_{Indoor} is the indoor to outdoor penetration loss of 20dB

8.2 Single cell

In this section the performance of a single cell has been simulated **without use of forward APC**.

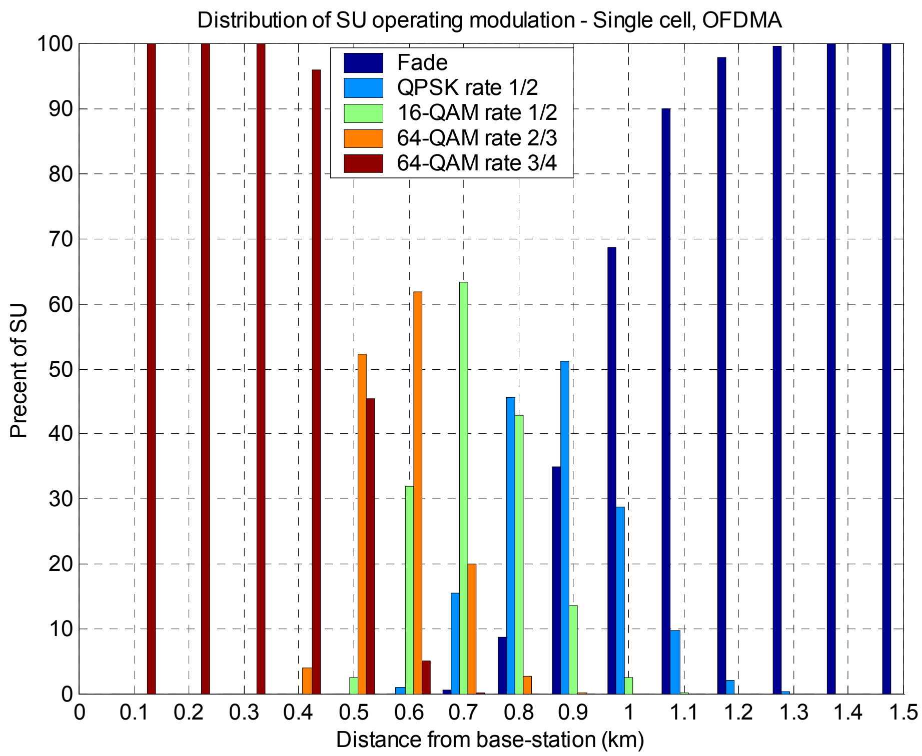

Figure 25: Distribution of SU operating mode in a single cell (Stanford B, outdoor to indoor)

8.3 Multiple cells

The objective of the situation simulated was to demonstrate good coverage and good capacity. Figure 26 shows the simulated geometry where 6 sectors are used per BS. Each frequency is used twice in each cell. The

coverage is enhanced by utilizing four forward APC rings. The simulation is done in the downlink, because this is the limiting case for the capacity calculation. Note that this simulation does NOT include adaptive antennas, which have a potential of further increasing the coverage and capacity. Each sector has been sub-divided into regions with different forward APC settings, in order to minimize interference.
Figure 27 and Figure 28 show the coverage simulation results for a scenario optimized for coverage, with a cell radius of **1.1km**. Areas where the average capacity has dropped below 0.1Bit/sec/Hz are marked in black as non-covered. The cell coverage by this criterion is 100%, and the average capacity per sector is 1.79 Bit/sec/Hz, and for the entire cell it is 3.58 Bit/sec/Hz.

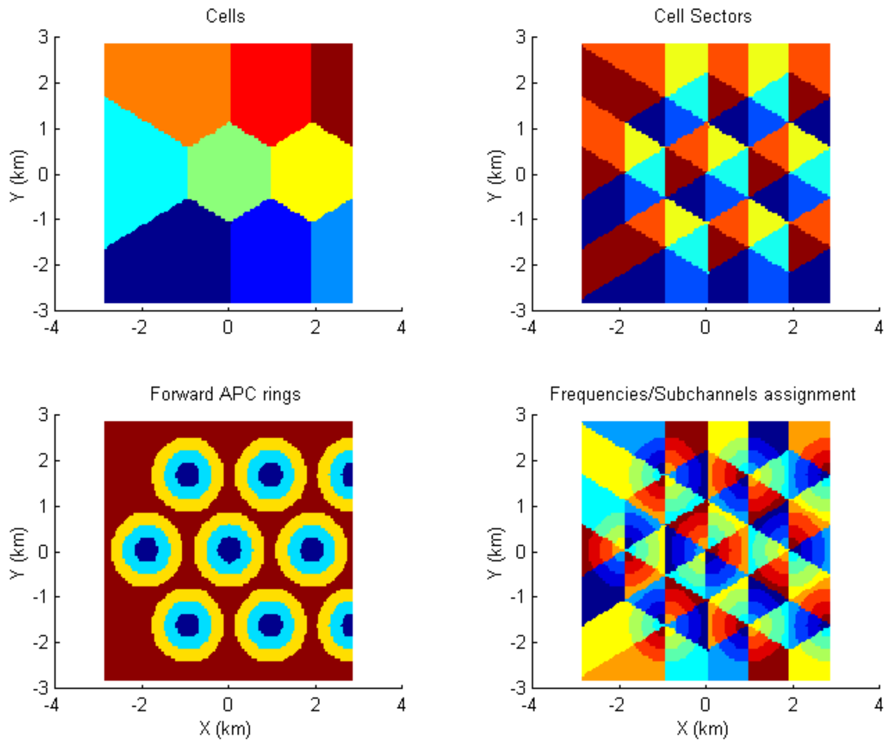

Figure 26: Cell and sector assignment plan, 6 sectors per cell, 3 frequencies per cell, 4 APC rings, Stanford B

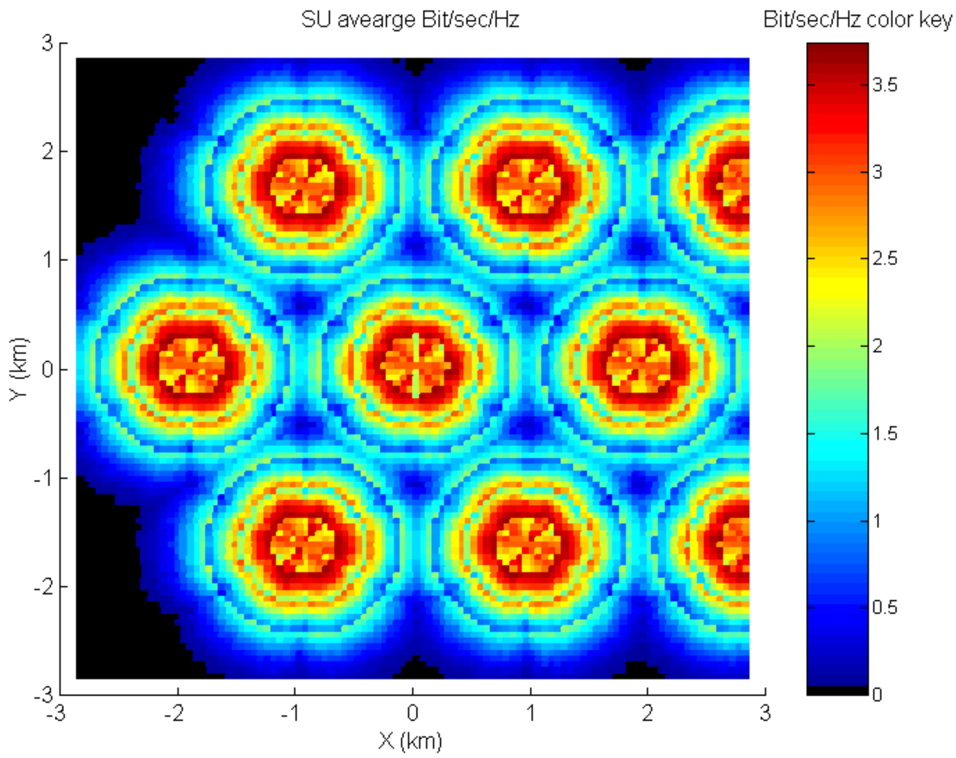

Figure 27: Outdoor to indoor coverage (Stanford B, optimized for better coverage)

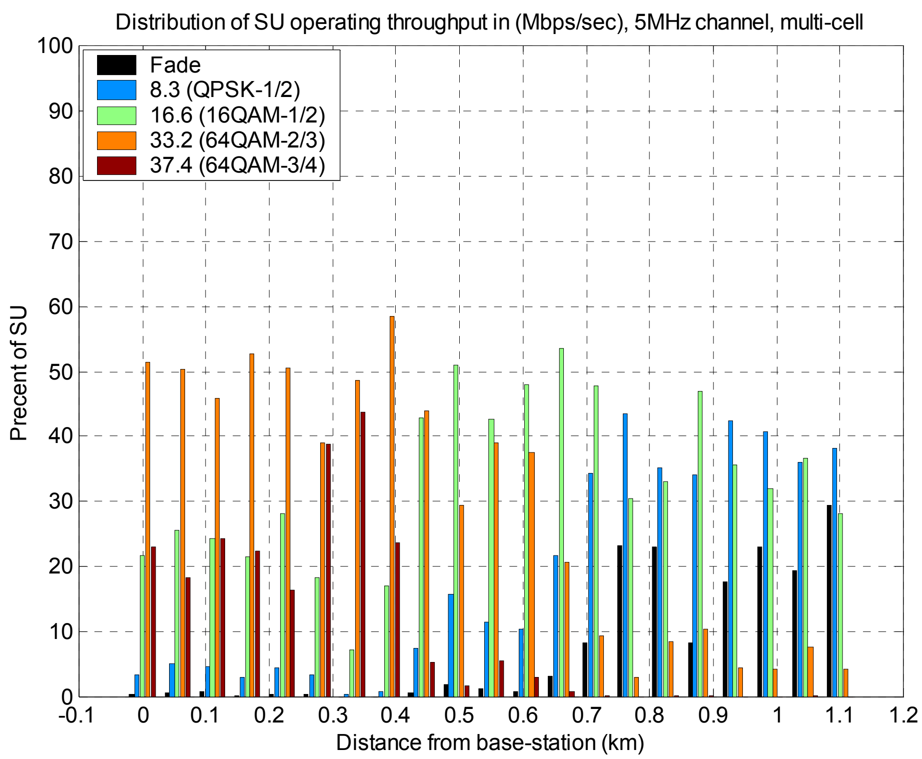

Figure 28: Distribution of SS throughput in the cell, outdoor to indoor (Stanford B, optimized for better coverage)

9 Summary and conclusions

In the previous sections the performance of an OFDMA system in a cellular coverage scenario has been presented. Table 2 summarizes the results. The results demonstrate the suitability of the OFDMA PHY for mobile applications.
The results shown are by no means comprehensive, and leave space for further optimization for coverage or for capacity as necessary, and higher frequency reuse factors. Special attention should be paid to the details of the various propagation modes, and their suitability to the analyzed problem. In particular, the log-normal shadowing has great impact on the results, and should be analyzed using statistical means as shown in the previous sections.
It should be emphasized that the results presented in the previous sections are only valid for situations where the traffic load is equally distributed throughout the cell. Sophisticated scheduling methods as well as use of advanced antenna systems can further improve the presented results.

Scenario	**Model**	**System parameters summary (DL)**						**Cell radius (km)**	**Capacity Bit/sec/Hz Per cell**	**Coverage**
		P_{TX} (dBm)	G_{TX} (dBi)	G_{RX} (dBi)	NF_{RX} (dB)	BW (MHz)	F_C (GHz)			
Outdoor, Pedestrian	ITU-R M.1225	40	18	0	4	5	2.6	1.5	2.48	100%
Outdoor, Pedestrian	IEEE 802.16 Stanford-B	37	18	0	4	5	2.6	2.5	4.31	100%
Outdoor vehicular	ITU-R M.1225	40	18	0	4	5	2.6	5	2.71	100%
Outdoor vehicular	IEEE 802.16 Stanford-B	37	18	0	4	5	2.6	5	3.38	100%
Outdoor to indoor	ITU-R M.1225	40	18	0	4	5	2.6	0.75	2.48	100%
Outdoor to indoor	IEEE 802.16 Stanford-B	37	18	0	4	5	2.6	1.1	3.58	100%

Table 2: Result summary (DL)

<u>Note:</u> The results shown are optimized for coverage, and not for capacity (except section 2 where the two cases were simulated). Capacity increase of about 50% can be obtained when optimizing for capacity at the cost of smaller cell radius.

10 References

[1] IEEE 802.16.3c-01/29r4, Channel models for FWA applications
[2] RECOMMENDATION ITU-R M.1225, GUIDELINES FOR EVALUATION OF RADIO TRANSMISSION TECHNOLOGIES FOR IMT-2000