
Literatur

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[COST321] COST Action 231: Digital mobile radio towards future generation systems; final report; COST Telecom Secretariat, European Commission, Brussels, Belgium, 1999

## Lectures

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1. Introduction/ Overview
2. Basics: Radio Transmission
3. Basics: Radio Network Planning
4. Physical Layer
5. Radio Interface Protocols
6. Architecture/ Core Network
7. Release 4/5
8. Applications

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## Outline Part III

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1. Basics of Radio Network Planning
2. Okumura-Hata
3. Coverage Areas
4. Interference in CDMA networks
5. Link Budget
6. Cell Capacity
7. Basic CDMA estimations

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## Repetition: dB/ dBi/ dBm

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Decibels - a ratio of two powers.
Standard dB references include:

- **dBi** - power gain or loss relative to an isotropic antenna
- **dBd** - power gain or loss relative to a dipole antenna (0 dBd = 2.15 dBi)
- **dBm** - power gain or loss relative to 1 milliwatt (1 mW)
- **dB** = 10 log10 (P1/P2)
- **EIRP** = Effective Isotropic Radiated Power

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## Why dB is used?

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- **Simplification of calculations**
  - "big" numbers are transformed to "handy" numbers
    - Instead of factor 1000 → 30 dB
    - Instead of factor 1 Million → 60 dB
    - Instead of factor 1/100 → -20 dB
    - Instead of factor 1/billion → -90 dB
- E.g. free space loss :

$$\alpha = \frac{P_E}{P_S} = \left(\frac{\lambda}{4\pi d}\right)^2 = \left(\frac{c_0}{4\pi df}\right)^2$$

| | |
|---|---|
| $c_0$ | : Speed of light |
| d | : Distance |
| f | : Frequency |

$\alpha$ [dB] = - 92,5dB - 20log f(GHz) - 20log d(km)

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## CDMA Networks

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- CDMA networks are based on a frequency reuse factor of one
- Cells are separated by codes
- Capacity is interference limited
  - thus capacity is shared by several cells

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# Influences to radio coverage

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- External (Outdoor) – cold, heat, rain, atmospheric moisture, lightning etc.
- Vegetation – depending on seasons
- Open – looks like line of site but..
- Cluttered - buildings, street furniture etc.
- Traffic – large and small vehicles moving in the coverage area, maybe obscuring paths.
- Co-located systems

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## Attenuation by Trees

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- Frequency (MHz) Approximate (dB/meter) Attenuation

| Frequency (MHz) | Approximate Attenuation (dB/meter) |
|---|---|
| 432 | 0.10 - 0.30 |
| 1296 | 0.15 - 0.40 |
| 2304 | 0.25 - 0.50 |
| 3300 | 0.40 - 0.60 |
| 5600 | 0.50 - 1.50 |
| 10000 | 1.00 - 2.00 |

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## Rain/ Fog

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- 1.8 to 2.4 GHz signals may be attenuated by up to 0.05 dB/km by torrential rain (100-150mm/hr).
- Thick fog produces up to 0.02 dB/km attenuation.
- Even though rain itself does not cause major propagation problems, rain will collect on the leaves of trees and will produce additional attenuation until it evaporates.

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# Radio Network Planning

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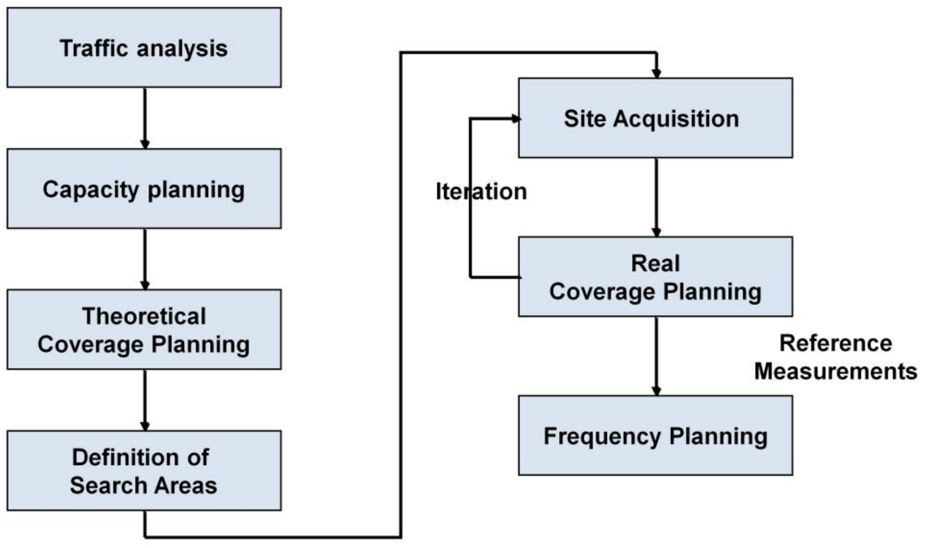


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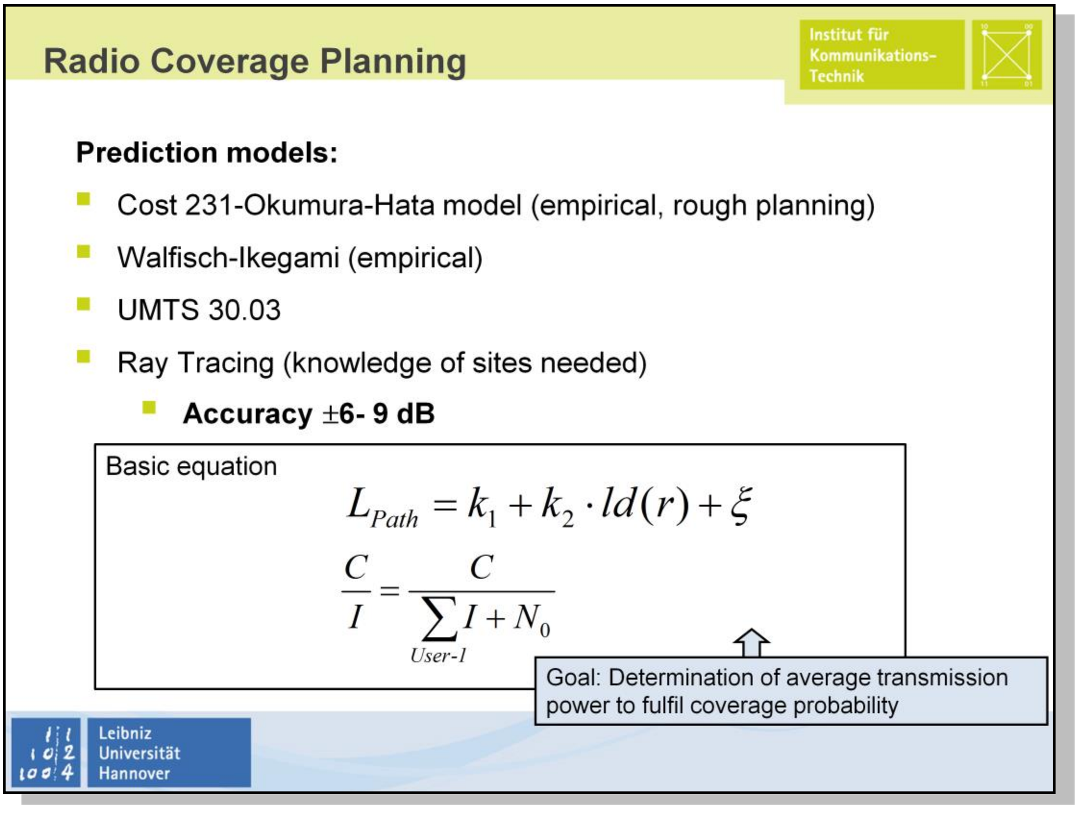


$L_{Pfad}$ = Pfadverlust
r = Abstand zum Sender
C = Empfangsleistung Nutzsignal
I = Störleistung
k = Konstanten abhängig von der Umgebung, der Frequenz, der Sender- und Empfängerhöhe

Für die weiteren Betrachtungen ist es notwendig, den Zusammenhang zwischen Entfernung und Ausbreitungsdämpfung von Funkwellen zu verstehen: je weiter ein Empfänger von einem Sender entfernt ist, desto geringer ist der Anteil der ausgestrahlten Leistung, die beim Empfänger noch ankommt (vgl. Abbildung XXX).

Es gibt eine Vielzahl von mathematischen Modellen, die diese Abhängigkeit beschreiben. Der genaue Zusammenhang ist abhängig vom Frequenzbereich, von der Art der eingesetzten Antennen, von der Beschaffenheit der Umgebung etc. Das bekannteste Modell ist das Modell von Okumura-Hata , dass für einen Frequenzbereich von 500MHz bis 2GHz gültig ist. Das Modell basiert auf Messungen und kennt zwei Geländetypen und drei Arten von Bebauung.

Der UMTS-Standard enthält ebenfalls ein Dokument (ETSI TR 101 112, kurz UMTS 30.03), das verschiedene Szenarien und Modelle für die Leistungsbewertung von UMTS-Systemtechnik enthält. Dort werden auch Ausbreitungsmodelle für Gebäude angegeben.

Da die Dämpfung in einem weiten Bereich variieren kann, stellt man den Dämpfungsfaktor oft logarithmisch (in dB) dar. Da es sich um Leistungen handelt, rechnet man den logarithmischen Wert wie folgt in die lineare Darstellung um:

\begin{math}
D_{linear}=10^(D_{logarithmisch}/10)
\end{math}

Umgekehrt kommt man über die Formel
\begin{math}
D_{logarithmisch}=10*log(D_{linear})
\end{math}

von einem linearen Wert zu einem Dämpfungsfaktor.

## Path-loss

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**Basic Law:**

$$Pr\ [dBm] = Ps\ [dBm] + G_{Ant1}\ [dBi] + G_{Ant2}\ [dBi] - L\ [dB] - M\ [dB]$$

with

- Pr Power received
- Ps Power send
- $G_{Ant\,I}$ Directive Antenna gain
- L Path loss
- M Protection margin slow fading (due to moving obstacles and buildings) and fast fading (due to multi-path reception)
- d Distance in meters/km

**Free space transmission loss** is

$$L\ [dB] = 20 \log_{10}(4 \cdot \pi \cdot d\ [m] / \lambda[m])$$

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## Okumura-Hata Model (1/x)

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- The Hata model has been developed by Masahura Hata in 1980.
- It is based on empirically determined measurements of field strength in certain distances and different environments.
- The Model has been modified several times to eliminate several disadvantages e.g. restriction in frequency range and distance.
- Nowadays an ITU model is used:
  - ITU Specification ITU-R P.529-3
  - Usable at frequencies >600MHz and distances up to 60km

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## Okumura-Hata-Modell (2/x)

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- Assumptions: uniform surface
- Three basic formulas for different coverage areas:
  - Urban (town)
  - Suburban
  - Rural
- Basic Okumura- Hata model is usable with following restrictions:
  - Frequency range ($f$): 150 - 1500 MHz
  - Height (sender) ($h_b$): 30 - 200 m
  - Height receiver ($h_m$): 1 - 10 m
  - Distance ($d$): 1 - 20 km
- Other models allow higher frequency ranges:
  - COST 231

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## Okumura Hata

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**Path-loss formula:**

$$L[dB] = 69.55 + 26.16 \cdot \log_{10}(f) - 13.82 \cdot \log_{10}(h_b) + (44.9 - 65.5 \cdot \log_{10}(h_b)) \cdot \log_{10}(d) - A_{hm}$$

Where
L = Path Loss from base station to the mobile unit;
*f* = Carrier Frequency in MHz;
$h_b$ = Base Station Antenna height in metres above the ground level in the range 3-10km from the base station; $h_b$ may therefore vary slightly with the direction of the mobile from the base;
R = Distance between base station and mobile in kilometres
$h_m$= mobile antenna height in metres

Correction for small and medium sized towns:

$$A_{hm} = (1.1 \cdot \log_{10}(f) - 0.7) \cdot h_m - (1.56 \cdot \log_{10}(f) - 0.8)$$

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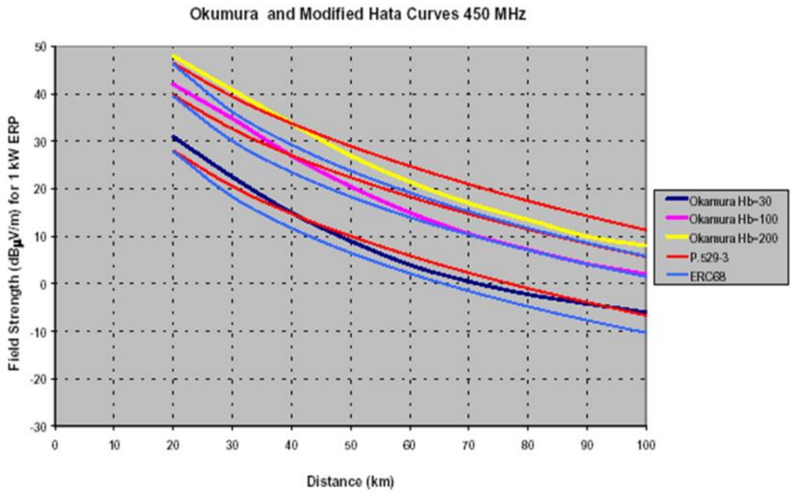
## Examples: Field Strength Graphs





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## Coverage Probability

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$$P(p_R > P_{R\min}) = \int_{P_{R\min}}^{\infty} p(p_R)\, dp_R$$

Propability, that the received power $p_R$ will exceed the lowest possible level $P_{Rmin}$

$$P_{CPixel} = 1 - \prod_{j=1}^{Count_{BS}} \left[1 - P(p_R > P_{R\min})\right]$$

Coverage probability in a small area (pixel) covered by several base stations

$$P_{CA} = \frac{1}{A} \sum_{A} \Delta A_i \cdot P_{CPixeli}$$

Coverage probability for an area $A$

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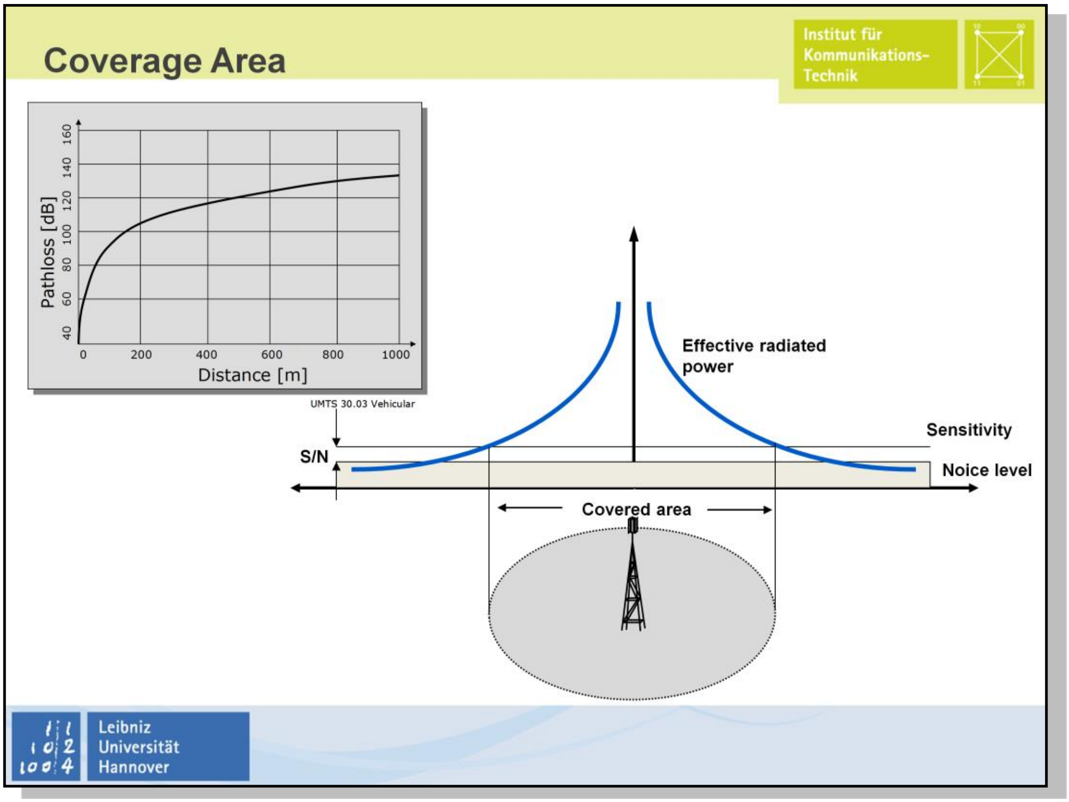
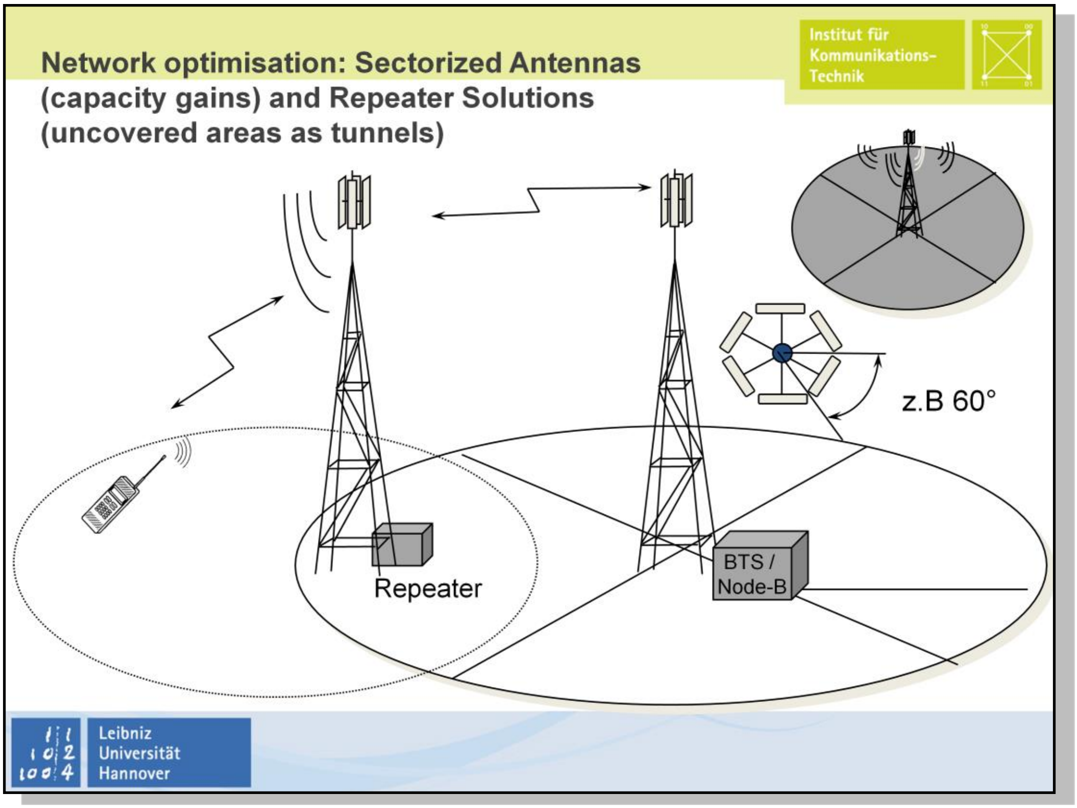
Ist die Wahrscheinlichkeitsdichtefunktion *p* (*pE*) für einen Pixel mit der Empfangsfeldstärke *pE* und dem Mittelwert *PE,mittel* bekannt, kann die Versorgungswahrscheinlichkeit *P* (*pE>PE min*) für ein Flächenelement mit dem Mindestpegel *PE min* berechnet werden




The coverage in an area is given, when the signal level is higher than the sensitivity. The sensitivity must have the signal to noise distance to the noise level.

This is an example for a noise limited coverage.




Repeater erhöhen die Reichweite des Systems, aber nicht die Verkehrskapazität! Sie sind allerdings wesentlich kostengünstiger als eine BTS.

Durch Sektorisierung, d.h. dem Einsatz von gerichteten Antennen, kann sowohl die Reichweite (höherer Antennengewinn) als auch die Kapazität des Systems verbessert werden.

Gegebenfalls verringern sich auch die Frequenzwiederholabstände.

Das Bild zeigt die Bildung von Clustern bei der Planung von Frequenzwiederholabständen.

## Ideale Antenne

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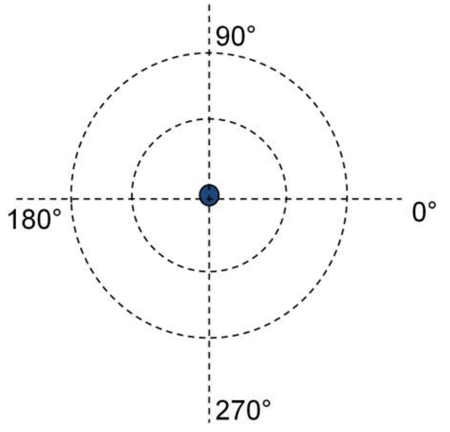
**Isotroper Punktstrahler:**

- gleichmäßige Abstrahlung in alle Richtungen
- horizontale und vertikale Abstrahlcharakteristik gleich

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## Antennengewinn

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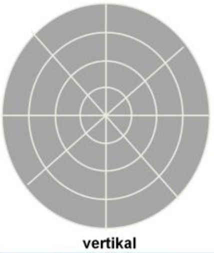
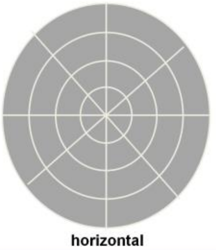
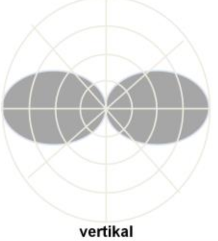
- Es findet keine tatsächliche Verstärkung, sondern die Bündelung der abgestrahlten Leistung in eine Vorzugsrichtung statt.
- Der Antennengewinn wird in dBi oder dBd angegeben:
  - Der Antennengewinn in dBi bezieht sich auf einen (rein theoretischen) isotropen Strahler.
  - Der Antennengewinn in dBd bezieht sich auf einen Dipol.
  - Ein Dipol hat im Vergleich zum isotropen Strahler einen Gewinn von 2,15 dBi.

**Isotroper Strahler**


vertikal


horizontal

**Dipol**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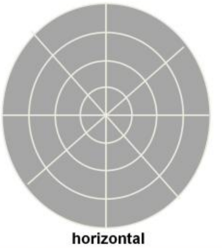
horizontal

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## Patchantenne/ Panelantenne

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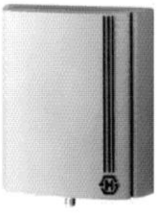
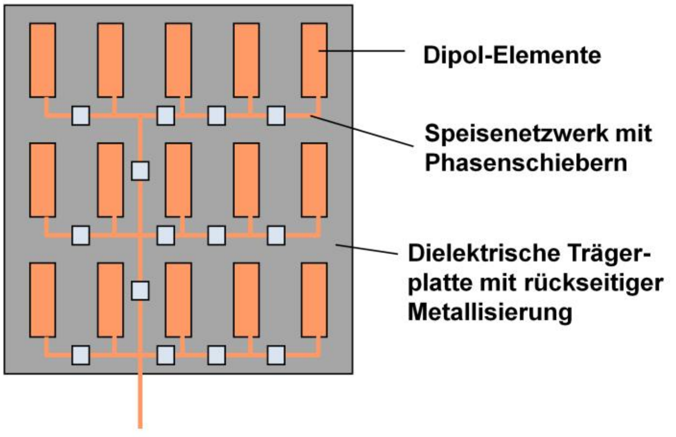
- Dipol-Array in Form einer gedruckten Schaltung



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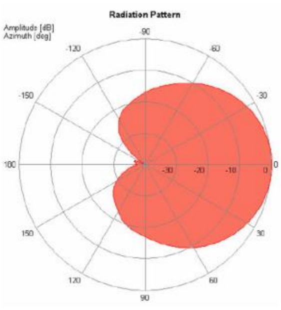
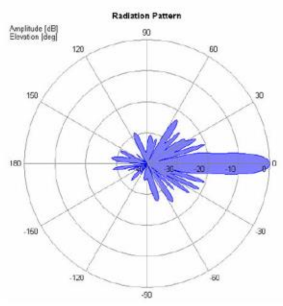
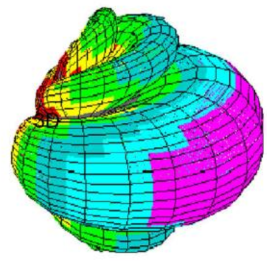
# Beispiel: Strahlungsdiagramm mit 3D-Darstellung

horizontal




vertikal



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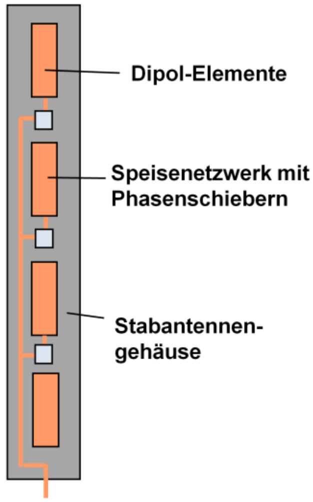
# Down-Tilt



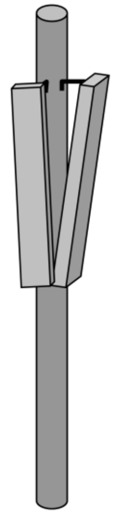
- **Neigung der Antenne:**
  - Vermeidung von Überreichweiten
  - Optimierung der Ausleuchtung
  - Reduktion von Interferenz
- **Unterscheidung:**
  - Mechanischer Down-Tilt
  - Elektronischer Down-Tilt



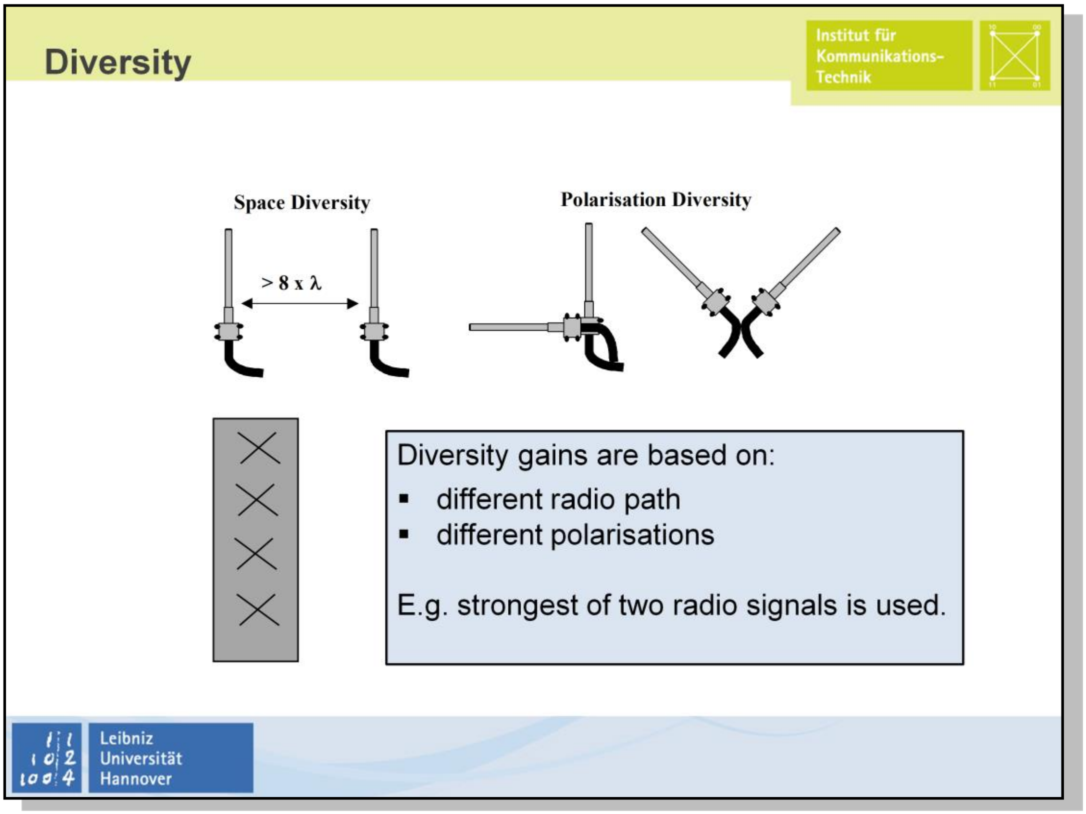
**Vertikale Ebene einer Stabantenne mit elektronischem Down-Tilt**




**Aufbau Stabantenne omnidirektional mit elektronischem Down-Tilt**



**Panelantenne mit Down-Tilt durch geneigte Befestigung**



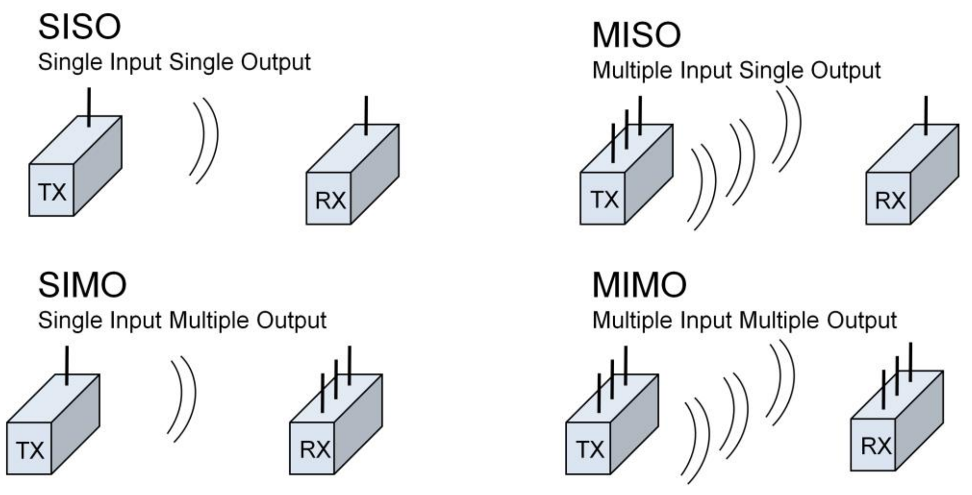

Short-range radio communications can be susceptible to the phenomenon of multi-path fading. This occurs when reflected signals arrive at a receiver over different paths and the difference in path length is long enough to result in a phase difference causing partial or complete signal cancellation. Multi-path fading is a well-known and significant problem for mobile/portable radio devices. As users or devices change position they pass in and out of 'dead spots'. To counter this many systems make use of antenna diversity, a technique that involves equipping one end of the link with two antennas and an antenna switch. If multi-path cancellation is being experienced at one antenna, this will reduce the signal strength, so the receiver will switch automatically to the other.

Two principle diversity mechanisms can be differentiated

Space diversity uses two antennas with the same orientation in a certain distance (more than 50% than a wavelength) whereas

Polarisation diversity uses the effect that the reception level will be different for different orientations of the antenna. In theory a vertical oriented dipole antenna will result in a better reception level at another vertical oriented antenna at the receiving end. But reflections cause changes in polarisation thus polarisation diversity works.

# Mehrwegetechniken



## Vorteile und Anwendung der Mehrwegetechniken

- SIMO
  - Diversityempfang
  - z. B. bei TETRA Basisstationen
- MISO
  - Elektronische Ausrichtung von Antennendiagrammen
  - z. B. militärische Radarsysteme und WiMAX
- MIMO
  - Ausnutzung von Mehrwegeausbreitung zur Erhöhung der Datenrate
  - z. B. IEE 802.11n

## MIMO

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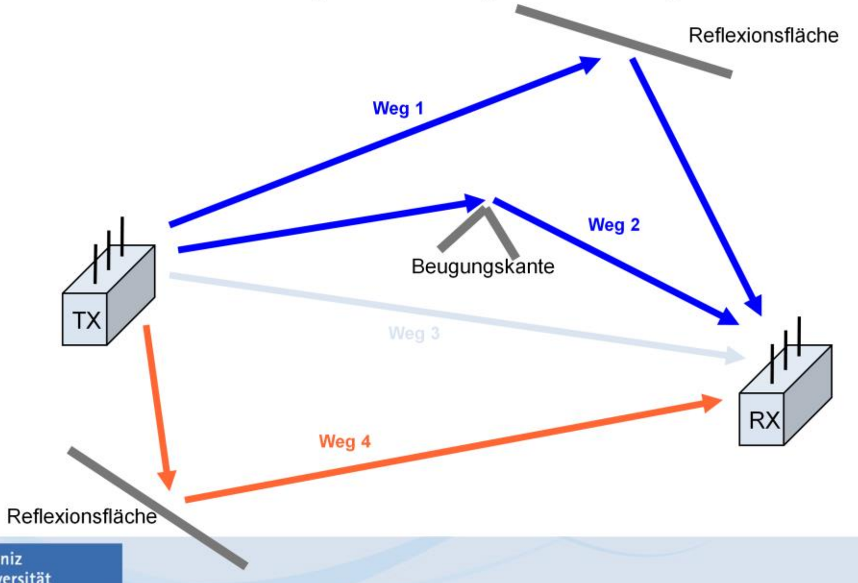
- Ausnutzen der Mehrwegeausbreitung zur Erhöhung der Datenrate:

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## MIMO

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- Mehrwegeausbreitung wird genutzt, um verschiedene Inhalte zeitgleich auf derselben Frequenz zu übertragen.
- Das System ermittelt (Zeitdifferenz), welche verschiedenen Ausbreitungspfade zwischen Sender und Empfänger zur Verfügung stehen.
- Durch mehrere, einzeln ansteuerbare Antennen werden
  - am Sender Signale in verschiedene Richtungen abgestrahlt,
  - am Empfänger Signale den verschiedenen Richtungen (Ausbreitungspfade) zugeordnet.
- In einer Freien Fläche ohne Reflexionen und Beugung kann durch MIMO keine Erhöhung der Punkt-zu-Punkt Nutzerdatenrate erreicht werden.

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## Datendurchsatz MIMO und mehrstufige Modulation

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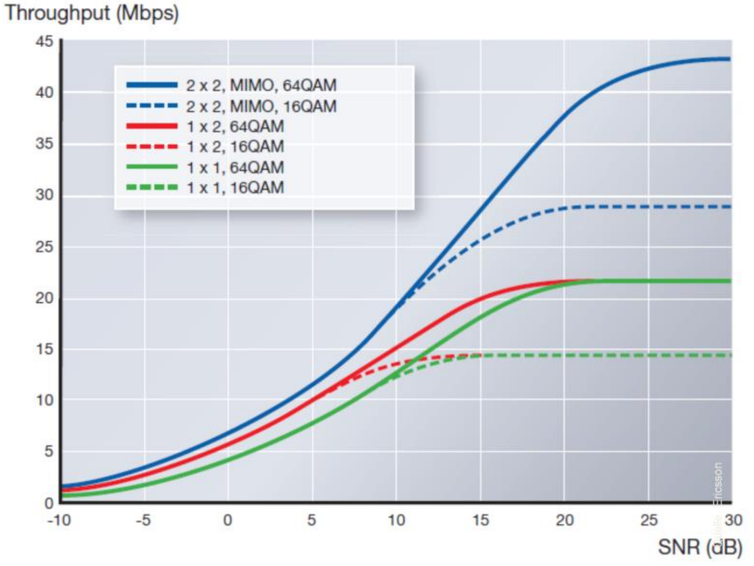


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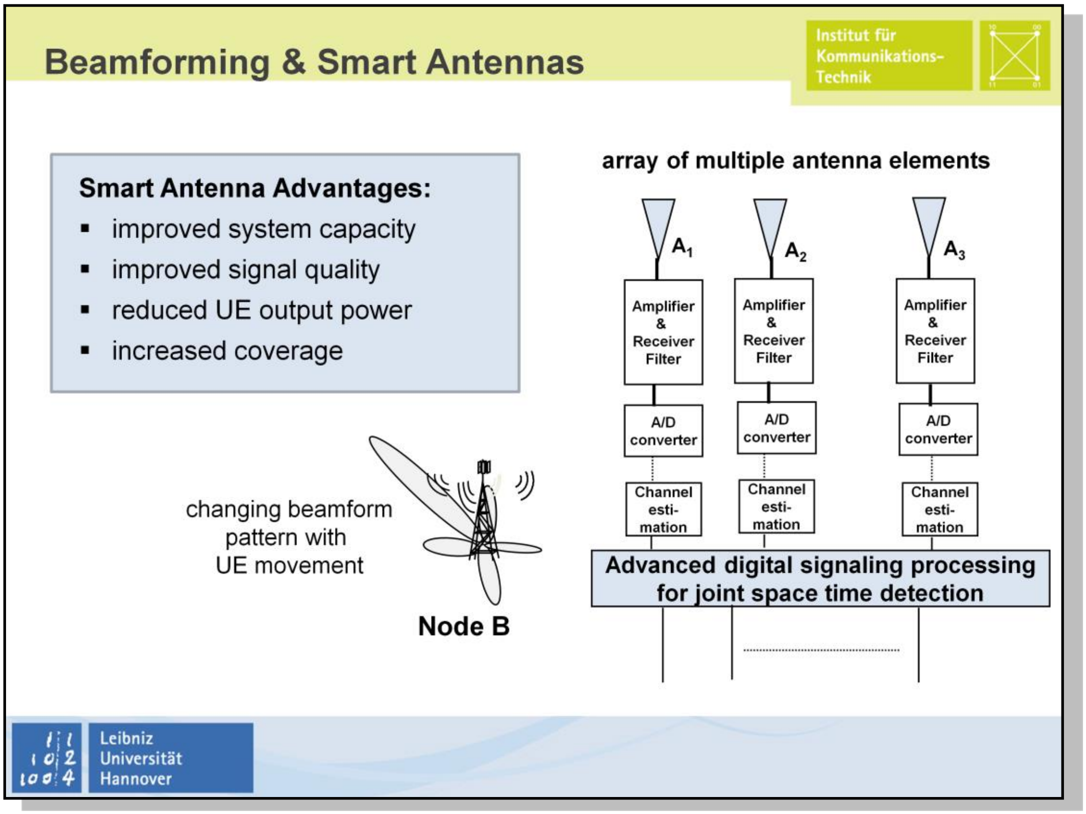



Beamforming and Smart Antennas[2]

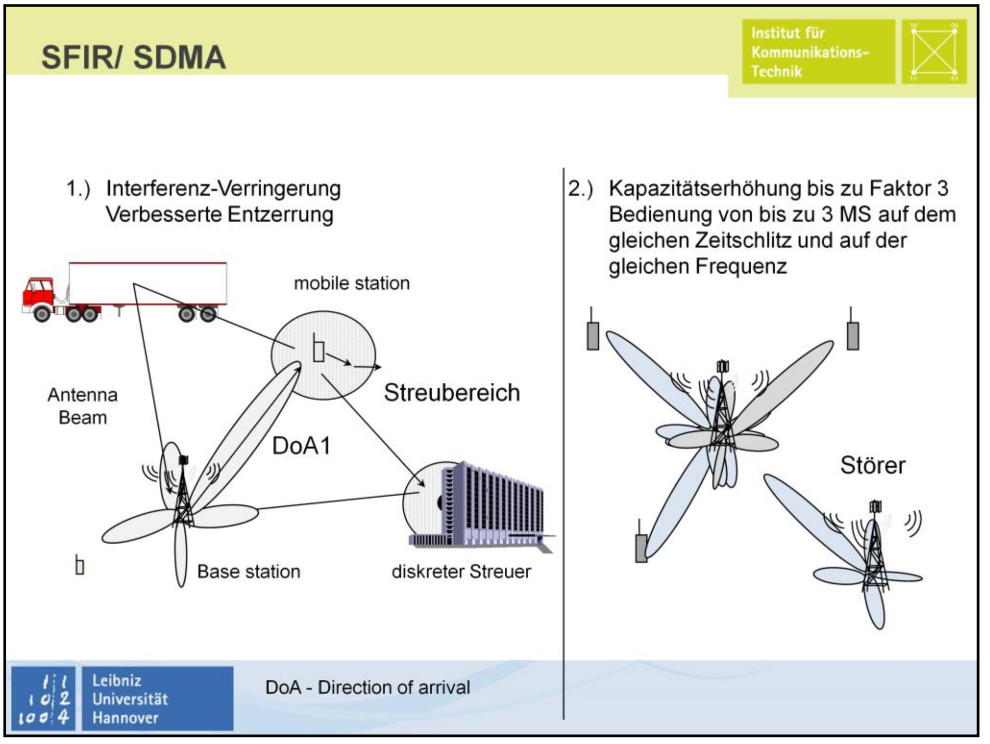
With low chip rate TDD, the two leading technologies of an advanced TDMA system is combined with synchronous CDMA. One of the advanced technologies are smart antennas. With smart antennas,

- the system capacity can be improved,
- the signal quality can be improved,
- the UE´s transmission power can be reduced, and
- the coverage can be increased.

The Node B is equipped with a smart antenna and baseband DSPs (Digital Signaling Processors). A smart antenna cpnsists of an array of K antenna elements, K feed cables, and K coherent RF transceiver in the RF part. All modules belong to the analogue part of the Node B. Analogur/Digital (A/D) converters are used to make the analogue-digital conversation.

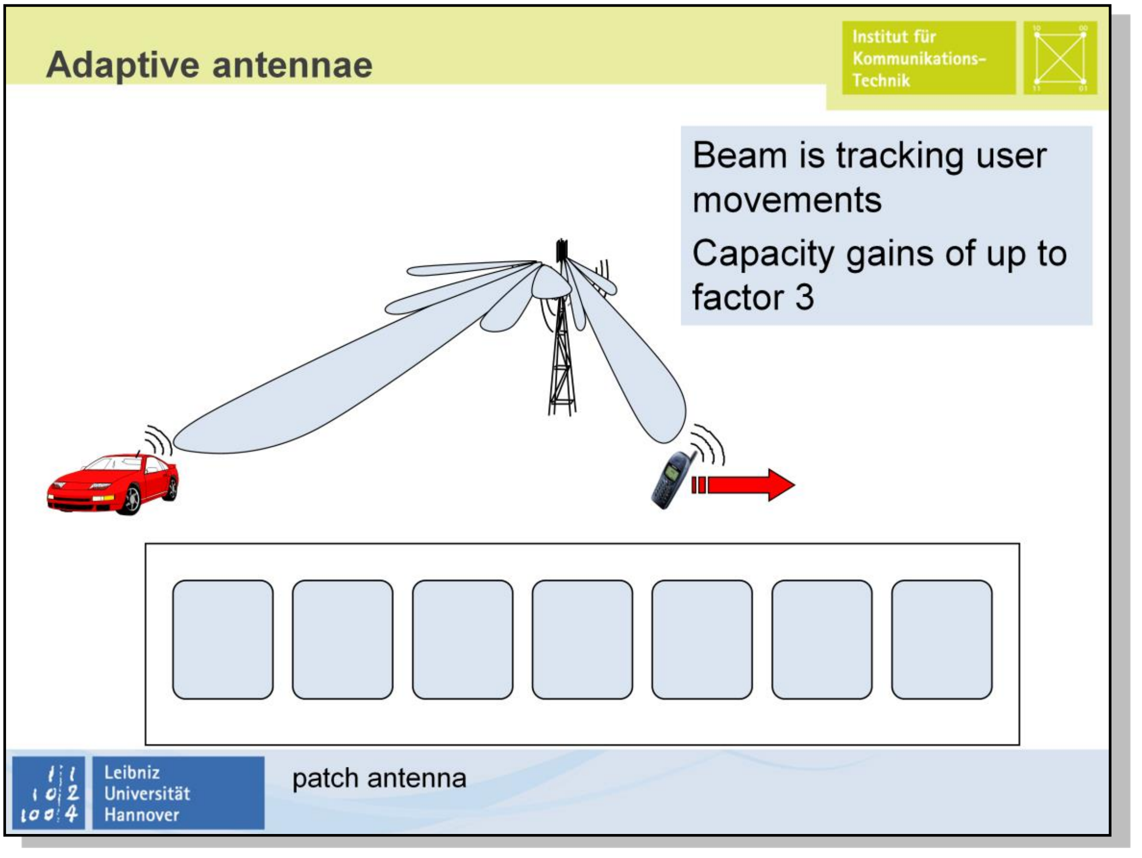
When a signal is transmitted from one UE, each antenna element and coherent RF transceiver will get it. The antenna elements are spatially separated. Thus, each of them will the incoming signal with a different amplitude, phase, and delay. This is also true in the case of a multipath propagation situation. The signals of all antenna elements will be digitalized and sent with phase and amplitude information to the digital signaling processor. Here the de-spreading takes place, and a combination of the individual de-spreaded signals may take place. Hereby, the target is to get the best possible Signal-to-Interference Radio for the combined signal.

In the TDD mode, uplink and downlink are realized on the same carrier bandwidth. Therefore, the characteristics of each signal arriving at the individual antenna elements can be used for downlink beamformind. The 5 ms sub-frames were introduced to allow hereby a fast beamforming. As an alternative, Tx Diversity can be used.




1.) Verringerung des Einflusses von Mehrwegepfaden und Interferenz: Die störenden einfallenden Wellenfronten werden in die Nullrichtungen der adaptiven Antenne gelegt.

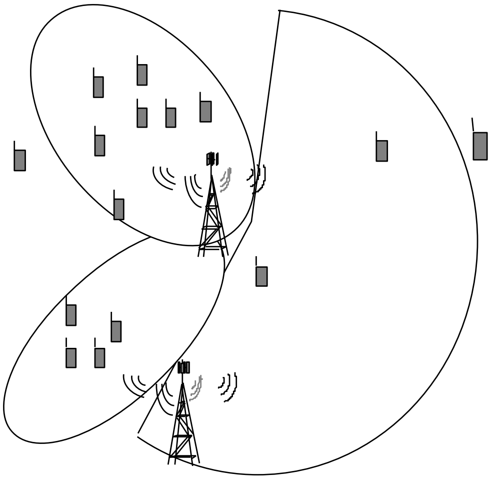
2.) Eine Kapazitätserhöhung von einem Faktor $\leq 3$ ist durch SDMA (Space Diversity Multiple Access) möglich. Dieses geschieht durch die Richtungstrennung der Strahlungskeulen. Allerdings sind aufwendige Algorithmen zur Steuerung der Antennen und zur Verwaltung der einzelnen sich bewegenden Teilnehmer notwendig.



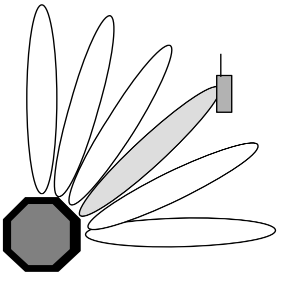

„Adaptive“Antennen lassen sich auf zwei Arten erreichen. Die einfachste Antenne schaltet einfach zwischen verschiedenen Strahlungsrichtungen um. Bei Patch-Antennen sind aufwendige Algorithmen notwendig, die die einzelnen Antennenarrays phasenunterschiedlich zur Steuerung der Beams ansteuern.

Damit ist dann auch eine unterschiedliche Ausformung des Sektors, z.B. abhängig von Lastzuständen, möglich.

variable Sektoren



Switched Beam



## Outline Part III

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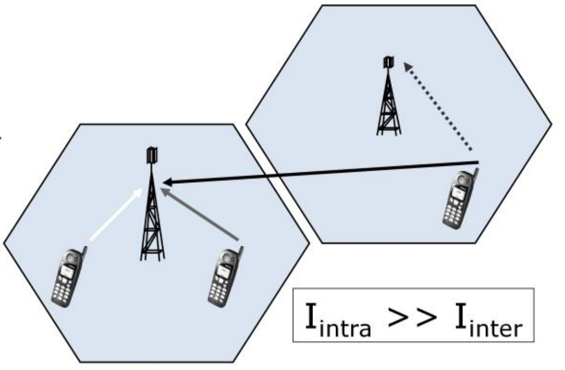
# Interference

**Intracell**: due to transmitters within the same cell and within the same frequency channel (Multiple Access Interference)

**Intercell**: due to transmitters in other cells and with the same frequency channel

$$C/I = \frac{C}{I_{intra} + I_{inter}}$$

typically < 0 dB

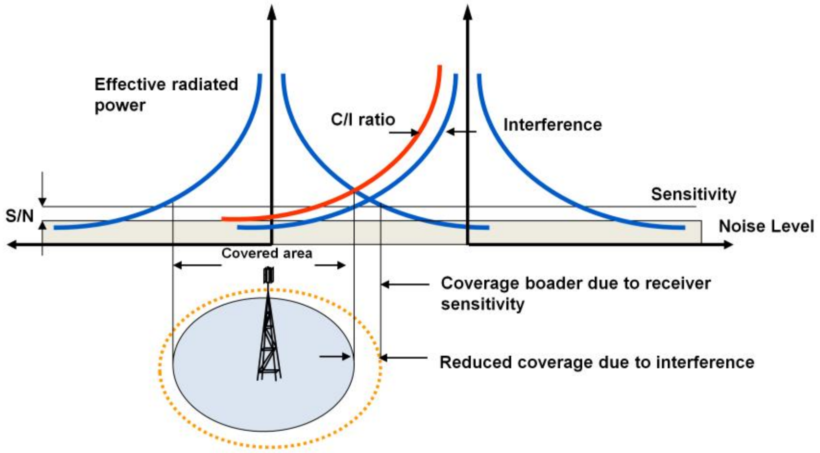


$I_{intra} >> I_{inter}$

## Interference



The carrier to interference ratio is called C/I:






Receiver only can cope on two signals of the same frequency when signals have a difference of C/I in level.

This is an example for interference limited coverage.

You remember we already saw a noise limited coverage,

## Link Budget

**(Example FDD UL, speech, 8 kbit/s)**

| | |
|---|---|
| UE EIRP [dBm] | 21 |
| | |
| Receiver Noise Floor [dBm] | -103 |
| Interference Power [dBm] | -98.26 |
| Total (Noise + Interference) [dBm] | -97 |
| | |
| Required C/I [dB] | -20.9 |
| Receiver Sensitivity [dBm] = | -117.9 |
| | |
| Gains and Losses at the BS [dB] | 11 |
| Maximum Pathloss [dB] (=Z1+Z6+Z7) | 149.9 |
| | |
| Fading Margin [dB] | 12.3 |
| Handover Gain [dB] | 3 |
| Link Budget [dB] | 140.7 |

=f(n)

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# Radio Link Budget - uplink

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| | Service A | Service B | Service C | |
|---|---|---|---|---|
| **Transmitter (mobile)** | | | | |
| Max. mobile transmission power [W] | 0.125 | 0.25 | 0.25 | |
| As above in dBM | 21 | 24 | 24 | a |
| Mobile antenna gain [dBi] | 0 | 2 | 2 | b |
| Body loss [dB] | 3 | 0 | 0 | c |
| Equivalent Isotropic Radiated Power | 18 | 26 | 26 | d = a+b+c |
| | | | | |
| **Receiver (base station)** | | | | |
| Thermal noise density [dBm/Hz] | -174 | -174 | -174 | e |
| Base Station receiver noise figure [dB] | 5 | 5 | 5 | f |
| Receiver Noise density [dBm/Hz] | -169 | -169 | -169 | g = e+f |
| Receiver Noise Power [dBm] | -103,2 | -103,2 | -103,2 | h = g+10*log(3840000) |
| Interference Margin [dB] | 3 | 3 | 3 | i |
| Receiver interference Power [dBm] | -103,2 | -103,2 | -103,2 | j = 10*log(10^((h+i)/10)-10^(h/10)) |
| Total effective noise + Interference [dBm] | -100,2 | -100,2 | -100,2 | k = 10*log(10^(h/10)+10^(j/10)) |
| Processing Gain [dB] | 25 | 14,3 | 10 | l = 10*log(3840/Rate) |
| Required Eb/No [dB] | 5 | 1,5 | 1 | m |
| **Receiver Sensitivity** | **-120,2** | **-113** | **-109,2** | n = m-l+k |
| Base Station antenna gain [dBi] | 18 | 18 | 18 | o |
| Cable Loss in the base station [dB] | 2 | 2 | 2 | p |
| Fast Fading margin [dB] | 0 | 4 | 4 | q |
| **Max. path loss [dB]** | **154,2** | **151** | **147,2** | r = d-n+o-p-q |
| Coverage probability [%] | 95 | 80 | 95 | |
| Log normal fading constant [dB] | 7 | 12 | 7 | |
| Propagation model exponent | 3,52 | 3,52 | 3,52 | |
| Log normal fading margin [dB] | 7,3 | 4,2 | 7,3 | s |
| Soft handover gain [dB], multi-cell | 3 | 2 | 0 | t |
| Indoor loss [dB] | 8 | 15 | 0 | u |
| **Allowed propagation loss for cell range [dB]** | **141,9** | **133,8** | **139,9** | v = r-s+t-u |

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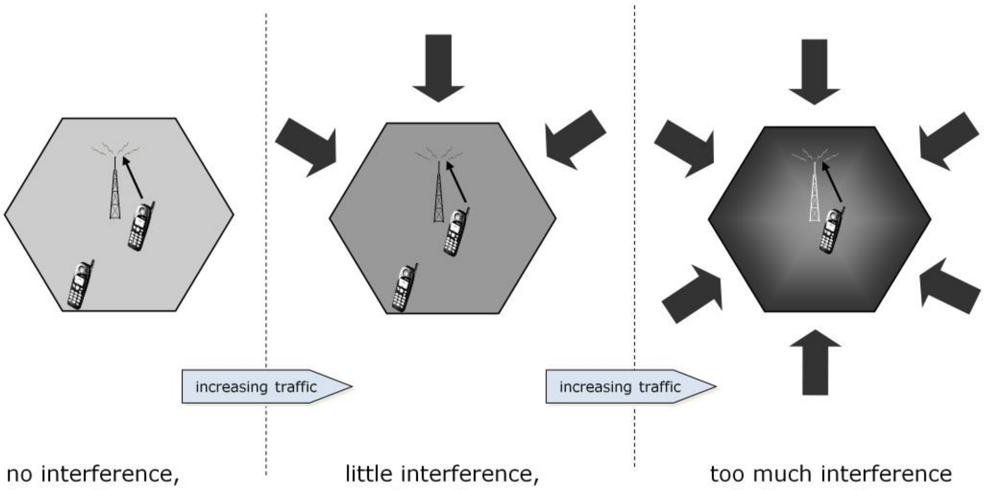
# Cell-Breathing




no interference,
large cells

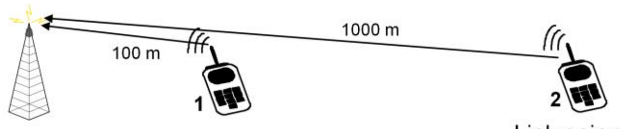
little interference,
smaller cells,
but large enough

too much interference
cells too small

## Near-far problem

- Both users transmit with the same power:

$$(p_{tx,1})_{dB} = (p_{tx,2})_{dB} = 24\,dBm$$




Link gain model

$$g_{ij} \approx d_{ij}^{-4}$$

- Received power:

$(p_{rx,1})_{dB}$ = 24 dBm-80 dBi = -64 dBm

$(p_{rx,2})_{dB}$ = 24 dBm-120 dBi = -104 dBm **Near-far problem.**

Signal received from mobile 1 is 10000 times stronger than the signal from mobile 2.

## Traffic versus Link Budget (FDD)

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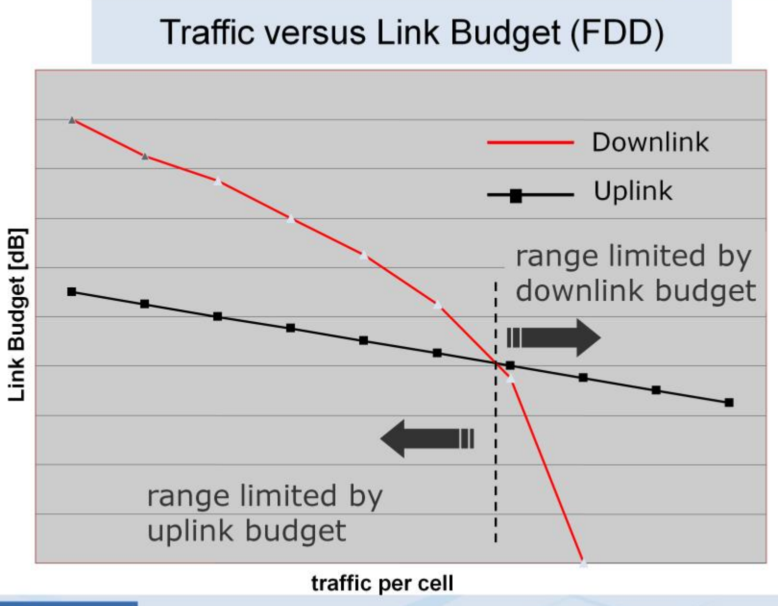


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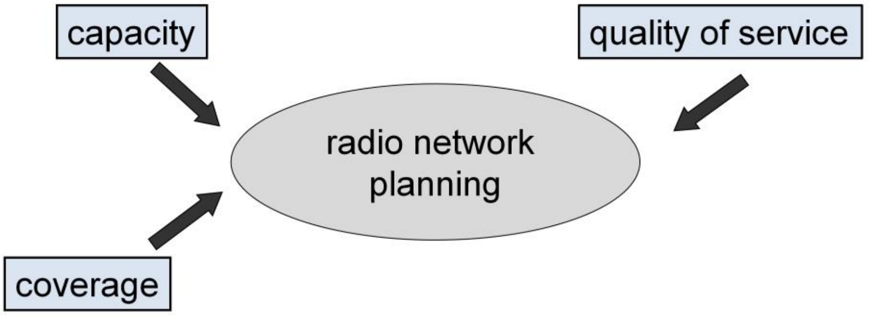
## UMTS Radio Network Planning

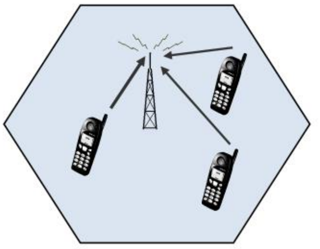
Due to the cell-breathing the cell size depends on the amount and on the type of traffic



## Cell Capacity

**FDD UL:** quasi-orthogonal codes, single-user detector, perfect power control

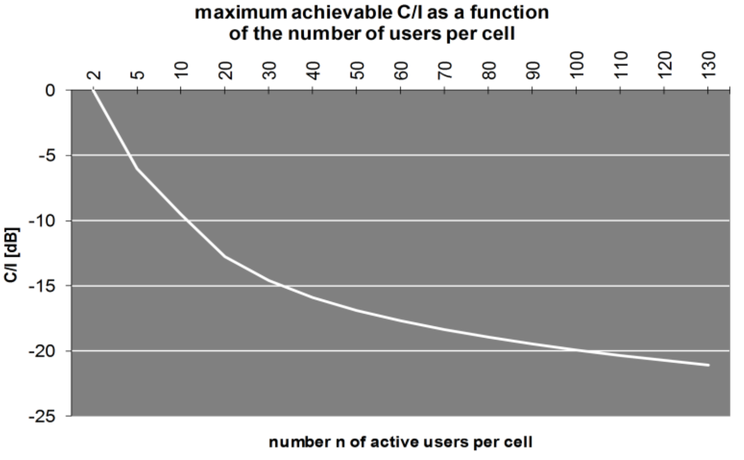
$$\frac{C}{I} = \frac{1*C}{(n-1)*C}$$



n=3 user

# Cell Capacity

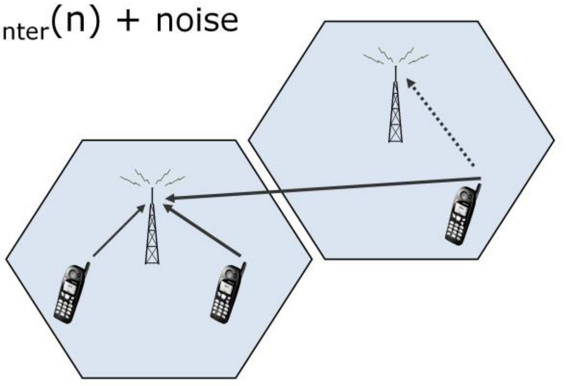





the achievable capacity depends on the required minimum C/I value

## Multi-Cell Capacity

$$\frac{C}{I} = \frac{1*C}{(n-1) * C + I_{inter}(n) + \text{noise}}$$



# Interference within CDMA Systems

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$$\left(\frac{C}{I}\right)_{effective} = \frac{S_{Data}}{\sum_{User} \frac{S_{Interference\,i} \cdot x_{CrossCorrellation} \cdot \nu_i}{G_P} + \frac{N_0}{G_P}}$$

$G_P$ Process gain due to spreading

$x$ Cross Correlation Factor (downlink)

$S$ Received Signal Power in dB

$N_0$ Noise density

$n_i$ Activity

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## Summary

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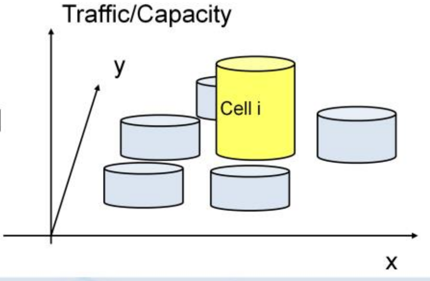
- Frequency planning is simplified:
  - Code planning neccessary (simpler)
  - Coverage planning
  - Load planning
- Bundling gains are achieved due the usage of one air interface (5Mhz) for all services
- „Soft"-Capacity:
  - Influenced by chosen QoS
  - Traffic of neighbouring cells
- Capacity is higher compared to GSM

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## Basic CDMA estimations

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1. Capacity Simple CDMA Case
2. Load factor
3. Network Planning

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## Theoretical Capacity I

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- assuming perfect power control, the received powers from all mobile users are the same.
- M is the total number of active users in a given band.
- The total interference power in the band equals the sum of powers of single users.
- Simple formula for CDMA capacity: $$\frac{S}{N} = \frac{1}{M-1}$$

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Here we look at capacity from the user interference side. To illustrate a basic case, we use the link reference parameter, i.e. *Eb/No,* or energy per pit per noise power density, which later will apply to the link budget frame work.

Picking it up from equation, we consider the generic reverse-link capacity in CDMA as the limitiong factor. Thus, assuming perfect power control for this instance, the received powers from all mobiles users are the same.

## Theoretical Capacity II

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- Now equating the energy per bit to the average modulating signal power

$$E_b = ST = \frac{S}{R}$$

- where S is the average modulating signal power,
- T is bit time duration,
- R is the bit rate, i.e. 1/T
- Then, incorporating the noise power density No, which is the total noise power N divided by the bandwidth B (i.e. No = N/B), we get

$$\frac{E_b}{N_o} = \frac{S}{N}\frac{B}{R} = \frac{1}{(M-1)}\frac{B}{R}$$

*Eb/No,* or energy per pit per noise power density

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## Theoretical Capacity III

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- Solving for M yields

$$M - 1 = \frac{(B / R)}{(E_b / N_o)}$$

- and for large M we get

$$M = \frac{(B / R)}{(E_B / N_0)} = \frac{G_p}{(E_B / N_0)}$$

- Where Gp corresponds to the system processing gain defined in equation,
- M defines the number of projected users in single CDMA cell with omnidirectional antenna without interference from neighbouring cells users transmitting continuously.

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## Theoretical Capacity
### Cell Loading

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- In real 3G mobile networks there always exists more than one cell and more than one sector, thus we need to introduce a loading effect due to interference from neighbouring cells

$$\frac{E_b}{N_o} = \frac{1}{(M-1)}\frac{B}{R}\left(\frac{1}{1+\beta}\right)$$

- where ß is the loading factor (ranging from 0 to 100%) as introduced
- Typical ß values will range from 45 to 50%. The inverse of as (1+ß) has often been defined as the frequency re-use factor, i.e. F=1/(1+ß). The ideal single cell CDMA value of F=1 (i.e. ß=0) decreases as the loading of multi-cell environments increase.

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## Theoretical Capacity
### Influence of Sectorisation

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- Sectorization gain $\lambda$:

$$\lambda = \frac{\int_0^{2\pi} I(\theta)d\theta}{\int_0^{2\pi}\left(\frac{A_G(\theta)}{A_G(0)}\right)I(\theta)d\theta}$$

- Where AG(0) is the peak antenna gain occurring generally at the bore sight (i.e.$\theta$=0), AG($\theta$) is the horizontal antenna pattern of the sector antenna;
- I($\theta$) represents the received interference power from users of other cells as a function of $\theta$.
- In practice $\lambda$ = 2.5 for a three sector configuration and about 5 for a six sector one. Incorporating the sectorization gain in the loading effect, we get:

$$\frac{E_b}{N_o} = \frac{1}{(M-1)}\frac{B}{R}\left(\frac{1}{1+\beta}\right)\lambda$$

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Sectorization can decrease interference from other users in other cells. Thus, instead of deploying only omnidirectional antennas with 360° a majority (if not) all sites can bear at least three sectors (e.g. 120°), and allow thereby the sectorized antenna to reject interference from users outside ist antenna pattern.

## Theoretical Capacity
### Activity and Orthogonality



- Initially for the single cell case, we have assumed continuous transmission. However, this does not occur for voice and some multimedia services; although it does for data. Thus, we will now introduce an activity factor 1/v to reflect this event in the UL loading effect. Then, we get

$$\frac{E_b}{N_o} = \frac{1}{(M-1)}\frac{B}{R}\left(\frac{1}{1+\beta}\right)\lambda\left(\frac{1}{\nu}\right)$$

- where v may range from 40 to 50% for voice and 1% for data. Therefore, the value of v reduces the overall interference of the UL loading effect equation. For the downlink (DL) we need an additional parameter ε to reflect the orthogonality of the transmission. Thus empirically, we can express it as:

$$\frac{E_b}{N_o} = \frac{1}{(M-1)}\frac{B}{R}\left(\frac{1}{(1-\varepsilon)+\beta}\right)\lambda\left(\frac{1}{\nu}\right)$$

## Basic CDMA estimations

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1. Capacity Simple CDMA Case
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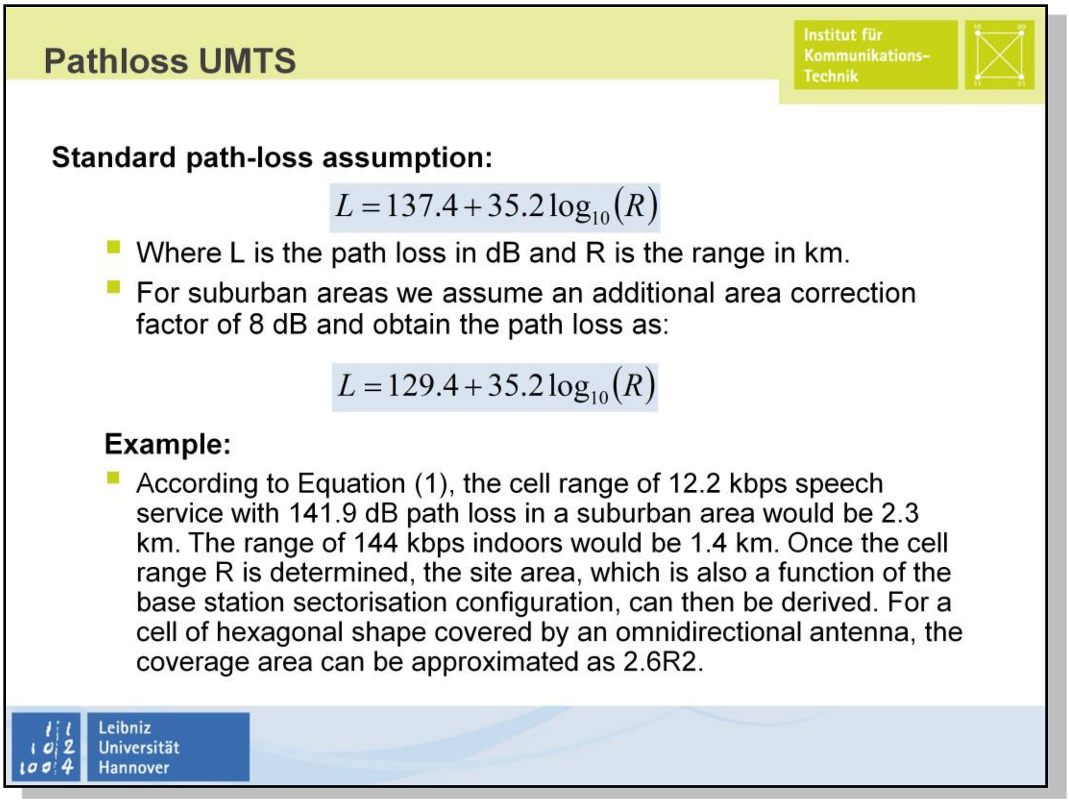


The coverage efficiency of WCDMA is defined by the average coverage area per site, in km²/site, for a predefined reference propagation environment and supported traffic density. From the link budgets above, the cell range R can be readily calculated for a known propagation model, for example the Okumura-Hata model or the Walfish-Ikegami model. The propagation model describes the average signal propatation in that environment, and it converts the maximum allowed propagation loss in dB to the maximum cell range in kilometres. As an example we can take the Okumura-Hata propagation model for an urban macro cell with base station antenna height of 30 m, mobile antenna height of 1.5 m and carrier frequency of 1950 MHz:

## Load Factors and Spectral Efficiency

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- The second phase of dimensioning is estimating the amount of supported traffic per base station site.
- Frequency reuse of a WCDMA system is 1,
  - thus the system is typically interference-limited by the air interface
  - the amount of interference and delivered cell capacity must thus be estimated.
- Uplink Load Factor
  - The theoretical spectral efficiency of a WCDMA cell can be calculated from the load equation whose derivation is shown below.
  - We first define the Eb/N0, energy per user bit divided by the noise spectral density:

$$\left(E_b / N_0\right)_j = \text{Processing gain of user } j * \frac{\text{Signal of user } j}{\text{Total received power}(\text{excl. own signal})} \quad (1)$$

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Based on H. Holma, A. Toskala: *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications*; J. Wiley, 2001

## Uplink Load Factor (I)

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This can be written:

$$(E_b/N_0)_j = \frac{W}{\upsilon_j R_j} * \frac{P_j}{I_{total} - P_j} \quad (2)$$

Solving for $P_j$ gives:

$$P_j = \frac{1}{1 + \frac{W}{(E_b/N_0)_j * R_j * \upsilon_j}} I_{total} \quad (3)$$

W is the chip rate,
$P_j$ is the received signal power from user j,
$\upsilon_j$ is the activity factor of user j,
$R_j$ is the bit rate of user j,
$I_{total}$ is the total received wideband power including thermal noise power in the base station.

We define $P_j = W_j * I_{total}$ and obtain the load factor $L_j$ of one connection:

$$\Omega_j = \frac{1}{1 + \frac{W}{(E_b/N_0)_j * R_j * \upsilon_j}} \quad (4)$$

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## Uplink Load Factor (II)

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The total received interference, excluding the thermal noise $P_N$, can be written as the sum of the received powers from all N users in the same cell.

$$I_{total} - P_N = \sum_{j=1}^{N} P_j = \sum_{j=1}^{N} \Omega_j * I_{total} \quad (5)$$

The noise rise is defined as the ratio of the total received wideband power to the noise power.

$$Noiserise = \frac{I_{total}}{P_N} \quad (6)$$

and using Equation (5) we can obtain

$$Noise\ rise = \frac{I_{total}}{P_N} = \frac{1}{1 - \sum_{j=1}^{N} \Omega_j} = \frac{1}{1 - \eta_{UL}} \quad (7)$$

where we have defined the load factor $\eta_{UL}$ as

$$\eta_{UL} = \sum_{j-1}^{N} \Omega_j \quad (8)$$

When $\eta_{UL}$ becomes close to 1, the corresponding noise rise approaches to infinity and the system has reached it‘s pole capacity.

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## Uplink Load Factor (III)

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Additionally, in the load factor the interference from the other cells must be taken into account by the ratio of other cell to own cell interference, *i*:

$$i = \frac{other\,cell\,interference}{own\,cell\,interference} \quad (9)$$

The uplink load factor can then be written as

$$\eta_{UL} = (1+i) * \sum_{j=1}^{N} \Omega_j = (1+i) * \sum_{j=1}^{N} \frac{1}{1 + \frac{W}{(E_b/N_0)_j * R_j * \upsilon_j}} \quad (10)$$

- The load equation predicts the amount of noise rise over thermal noise due to interference.
- The noise rise is equal to -10*log10 (1-ηUL).
- The interference margin in the link budget must be equal to the maximum planned noise rise.
- The required Eb/N0 can be derived from link level simulations and from measurements.

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## Uplink Load Factor (IV)

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$$\frac{W}{E_b / N_0 * R * \upsilon} >> 1$$

$$\eta_{UL} = \frac{E_b / N_0}{W / R} * N * \upsilon * (1+i)$$

Simplification for a classical all-voice-service network, where all N users in the cell have a low bit rate of R.

Example: Parameters used in uplink load factor calculation:

| | Definitions | Recommended values |
|---|---|---|
| *N* | Number of users per cell | |
| *υj* | Activity factor of user j at physical layer | **0.67** for speech, assumed 50% voice activity and DPCCH overhead during DTX<br>**1.0** for data |
| *Eb/N0* | Signal energy per bit divided by noise spectral density that is required to meet a predefined Quality of Service (e.g. bit error rate). Noise includes both thermal noise and interference | Speech: 4 dB<br>Data 16-32kbit/s: 3 dB<br>Data 64kbit/s: 2 dB<br>Data 144kbit/s: 1,5 dB |
| *W* | WCDMA chip rate | **3.84 Mcps** |
| *Rj* | Bit rate of user j | Dependent on service |
| *i* | Other cell to own cell interference ratio seen by the base station receiver | Macro cell with omnidirectional antennas: **55%** |

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# Example uplink noise rise

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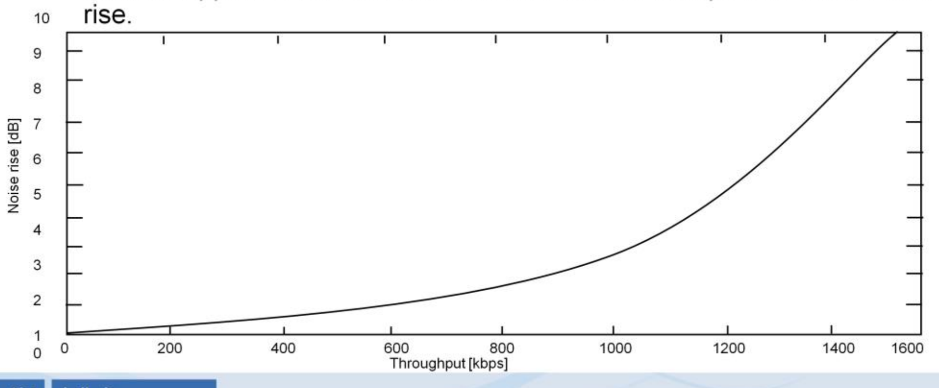
**Assumptions:**

- Eb/N0 requirement of 1.5 dB and i=0.65. The noise rise of 3.0 dB corresponds to a 50% load factor, and the noise rise of 6.0 dB to a 75% load factor.
- Instead for showing the number of users N, the total data throughput per cell of all simultaneous users is shown. In this example, a throughput of 860 kbps can be supported with 3.0 dB noise rise, and 1300 kbps with 6.0 dB noise rise.

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# Downlink Load Factor



The downlink load factor, $h_{DL}$, can be defined based on a similar principle as for the uplink, although the parameters are slightly different:

$$\eta_{DL} = \sum_{j=1}^{N} \upsilon_j * \frac{(E_b / N_0)_j}{W / R_j} * \left[ (1 - \alpha_j) + i_j \right]$$

$\alpha_j$ Orthogonality factor, typical values 0.4 to 0.9 in multipath channels
Orthogonal codes are used for user separation in downlink.

# Parameters used in downlink load factor calculation

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| | Definitions | Recommended values for dimensioning |
|---|---|---|
| *N* | Number of connections per cell = number of users per cell * (1+soft handover overhead) | |
| $\upsilon j$ | Activity factor of user j at physical layer | **0.67** for speech, assumed 50% voice activity and DPCCH overhead during DTX **1.0** for data |
| *Eb/N0* | Signal energy per bit divided by noise spectral density that is required to meet a predefined Quality of Service (e.g. bit error rate). Noise includes both thermal noise and interference | Dependent on service, bit rate, multipath fading channel, transmit antenna diversity, mobile speed, etc. |
| *W* | WCDMA chip rate | **3.84 Mcps** |
| *Rj* | Bit rate of user j | Dependent on the multipath propagation 1: fully orthogonal 1-path channel 0: no orthogonality |
| *aj* | Orthogonality of channel of user j | Dependent on service |
| *ij* | Ratio of other cell to own cell base station power, received by user j | Each user sees a different ij, depending on its location in the cell and log-normal shadowing |
| $\bar{\alpha}$ | Average orthogonality factor in the cell | ITU Vehincular A channel: ~ **60%** ITU Pedestrian A channel: ~ **90%** |
| $\bar{\iota}$ | Average ratio of other cell to own cell base station power received by user. Own cell interference is here wideband | Macro cell with omnidirectional antennas: **55%** |

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Note: The own cell is defined as the best serving cell. If a user is in soft handover, all the other base stations in the active set are counted as part of the „other cell“.

## Soft Capacity

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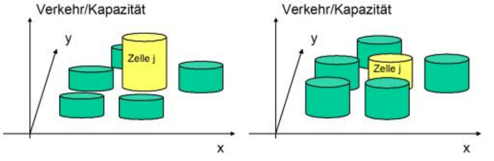
$$Traffic\ density\,[Erlang] = \frac{Call\ arrival\ rate\,[calls/s]}{Call\ departure\ rate\,[calls/s]}$$

$$Soft\ capacity = \frac{Erlang\ capacity\ with\ soft\ blocking}{Erlang\ capacity\ with\ hard\ blocking} - 1$$




$$i + 1 = \frac{other\ cell\ interference}{own\ cell\ interference} + 1 = \frac{other\ cell\ interference + own\ cell\ interference}{own\ cell\ interference}$$

$$= \frac{isolated\ cell\ capacity}{multicell\ capacity}$$

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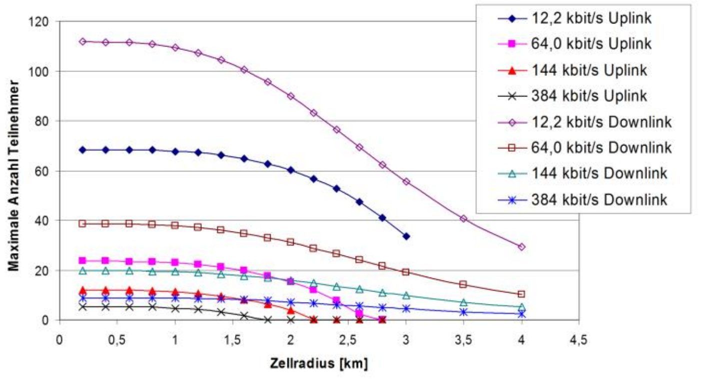
# Capacity




Maximale Anzahl Teilnehmer
120
100
80
60
40
20
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
Zellradius [km]
12,2 kbit/s Uplink
64,0 kbit/s Uplink
144 kbit/s Uplink
384 kbit/s Uplink
12,2 kbit/s Downlink
64,0 kbit/s Downlink
144 kbit/s Downlink
384 kbit/s Downlink