Physical Layer Performance (Chapter 11)

Harri Holma, Senior Research Engineer

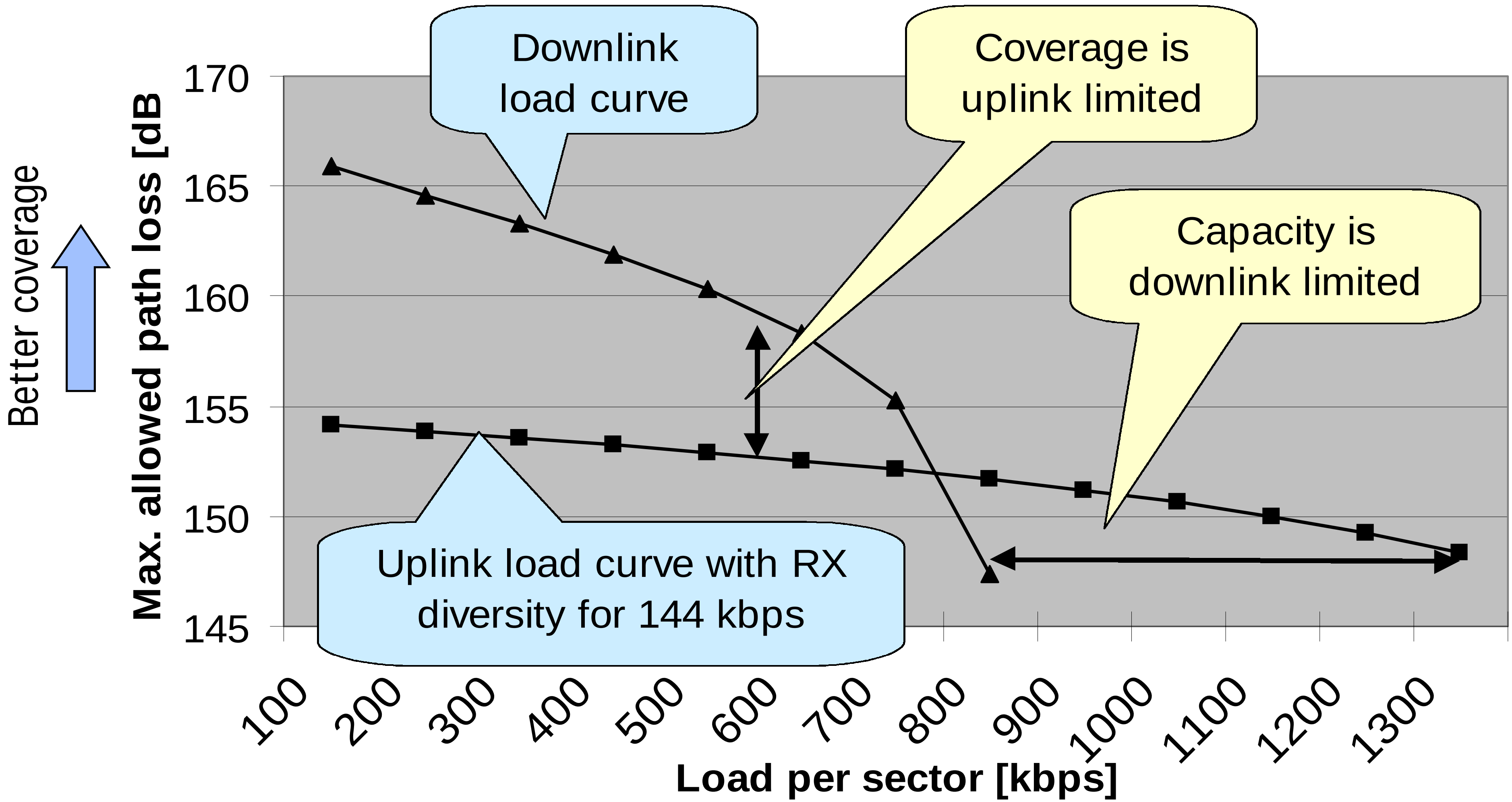
IP Mobility Networks

Nokia Networks

Outline

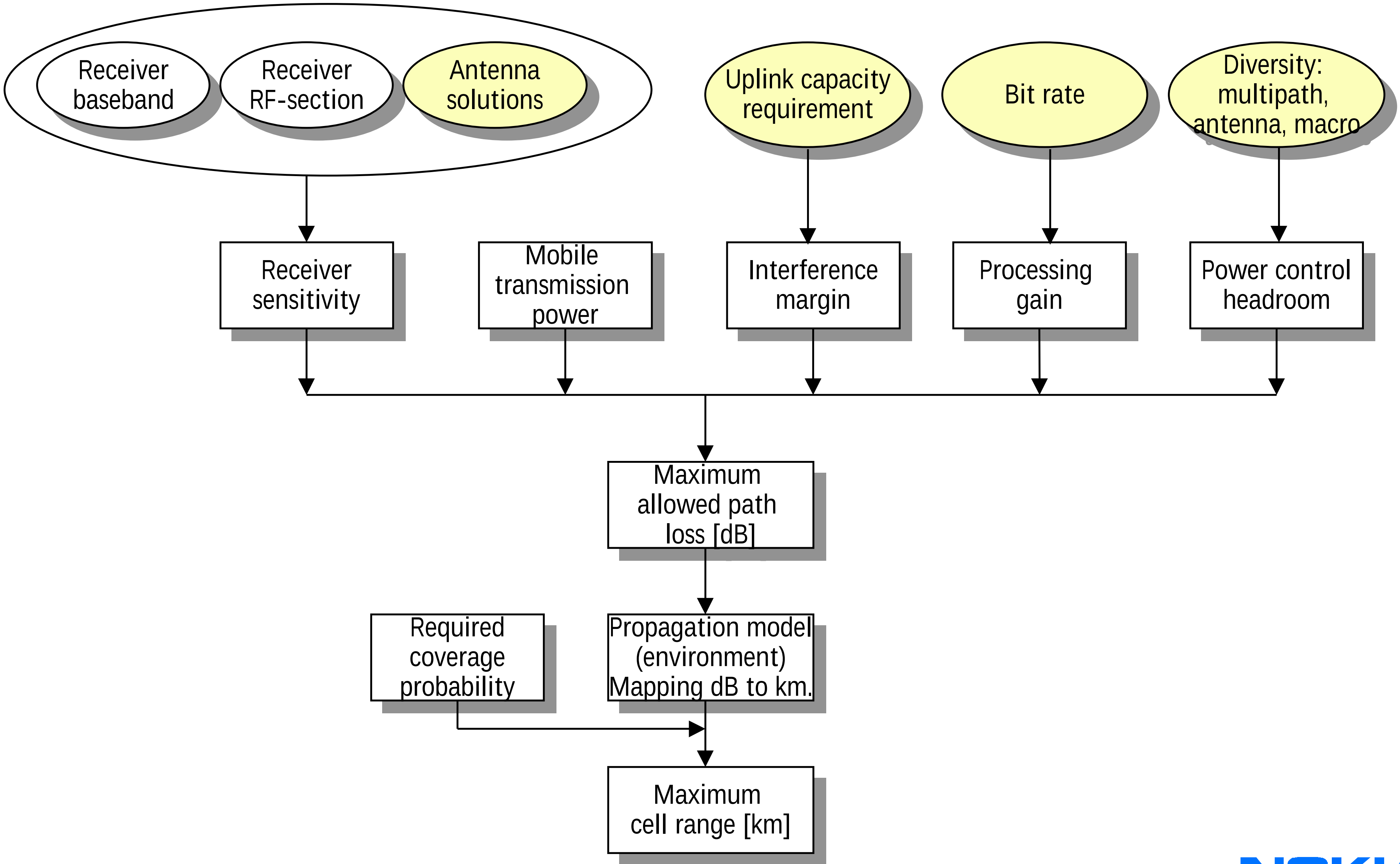
- Coverage
- Capacity
- High bit rates
- Diversity gain (antenna, multipath, macro)
- Packet data
- Compressed mode

144 kbps Coverage / Capacity Trade-off in Macro Cells



Uplink Coverage

Uplink Coverage



GSM Co-siting

	GSM900 / speech	GSM1800 / speech	WCDMA / speech	WCDMA / 144 kbps	WCDMA / 384 kbps
Mobile transmission power	33 dBm	30 dBm	21 dBm	21 dBm	21 dBm
Receiver sensitivity[1]	–110 dBm	–110 dBm	–124 dBm	–117 dBm	–113 dBm
Interference margin[2]	1.0 dB	0.0 dB	2.0 dB	2.0 dB	2.0 dB
Fast fading margin[3]	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB
Base station antenna gain[4]	16.0 dBi	18.0 dBi	18.0 dBi	18.0 dBi	18.0 dBi
Body loss[5]	3.0 dB	3.0 dB	3.0 dB	—	—
Mobile antenna gain[6]	0.0 dBi	0.0 dBi	0.0 dBi	2.0 dBi	2.0 dBi
Relative gain from lower frequency compared to UMTS frequency[7]	11.0 dB	1.0 dB	—	—	—
Maximum path loss	**164.0 dB**	**154.0 dB**	**156.0 dB** **SRC : 158.5 dB**	**154.0 dB** **SRC: 156.5 dB**	**150.0 dB** **SRC : 152.5 dB**

[1]WCDMA sensitivity assumes 4.0 dB base station noise figure and E_b/N_0 of 5.0 dB for 12.2 kbps speech, 1.5 dB for 144 kbps and 1.0 dB for 384 kbps data. GSM sensitivity is assumed to be –110 dBm with receive antenna diversity.

[2]The WCDMA interference margin corresponds to 37% loading of the pole capacity. An interference margin of 1.0 dB is reserved for GSM900 because the small amount of spectrum in 900 MHz does not allow large reuse factors.

[3]The fast fading margin for WCDMA includes the macro diversity gain against fast fading.

[4]The antenna gain assumes three-sector configuration in both GSM and WCDMA.

[5]The body loss accounts for the loss when the terminal is close to the user's head.

[6]A 2.0 dBi antenna gain is assumed for the data terminal.

[7]The attenuation in 900 MHz is assumed to be 11.0 dB lower than in UMTS band and in GSM1800 band 1.0 dB lower than in UMTS band.

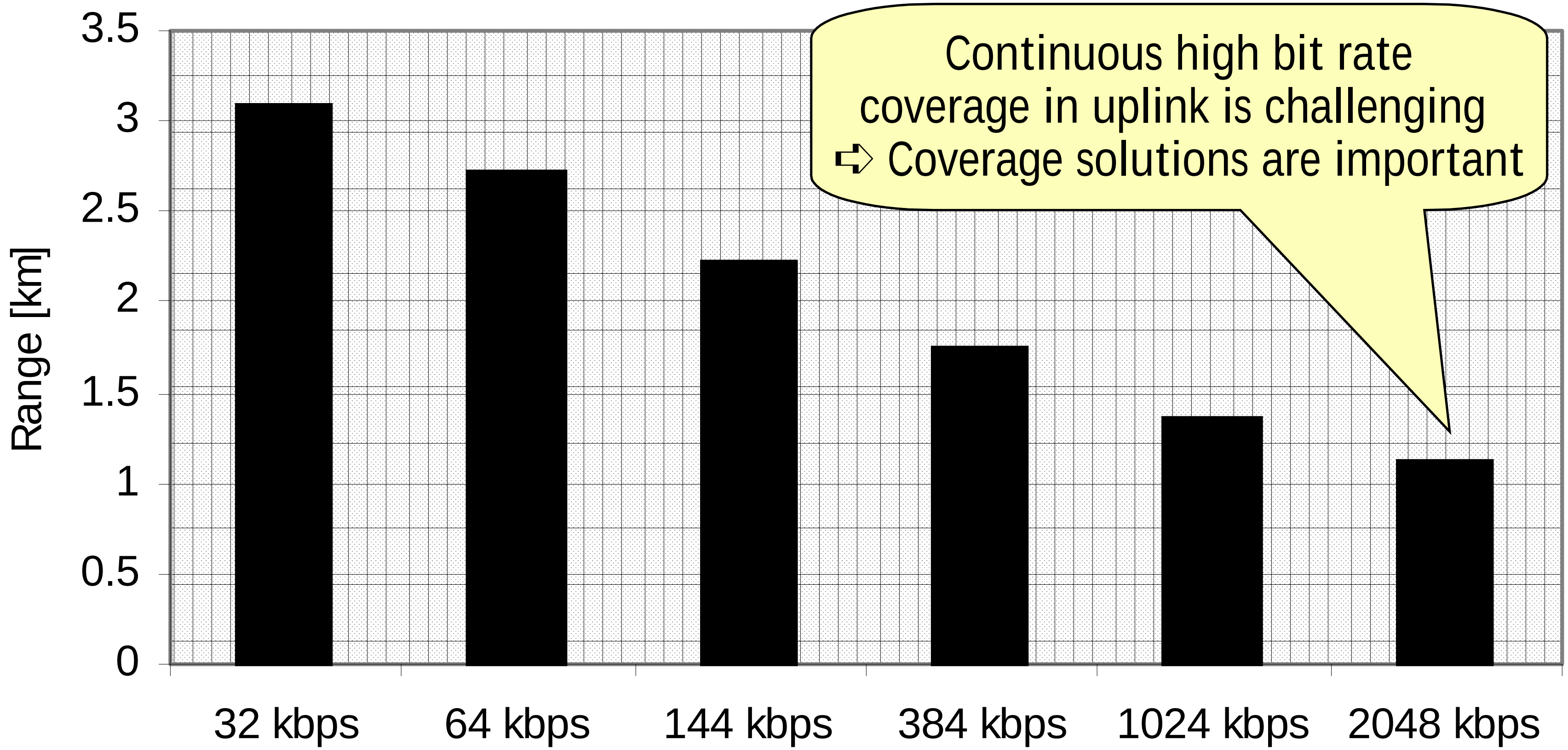
144 kbps full coverage with GSM1800 sites

Downlink coverage of high bit rates is better than uplink coverage

SRC = Nokia's Smart Radio Concept

NOKIA

Uplink Coverage of Different Bit Rates



Suburban area with 95% outdoor location probability

Multipath Diversity Gain for Coverage

- Simulation parameters
  - Required received Eb/N0 shown
  - 2 branch receiver diversity assumed in the base station
  - FER=1% with speech
  - Full constant power (at the cell edge)
  - ITU Vehicular A has more multipath than ITU Pedestrian A

	E_b/N_0
ITU Pedestrian A (less multipath diversity)	11.3dB
ITU Vehicular A (more multipath diversity)	8.5dB
Multipath diversity gain	2.8dB

- Multipath diversity gain in this case 2.8 dB gain in uplink coverage
- The amount of multipath diversity depends on the chip rate
  - ITU Vehicular A with WCDMA may be equal to ITU Pedestrian A with narrowband CDMA

Macro Diversity Gain for Coverage

- Simulation parameters
  - Required received Eb/N0 shown
  - 2 branch receiver diversity assumed in the base station
  - FER=1% with speech
  - Full constant power (at the cell edge)
  - Two cases:
    - the same average attenuation to both base station (best case)
    - 3dB difference between the base stations

E_b/N_0	ITU Pedestrian A	ITU Vehicular A
Single link	11.3 dB	8.5 dB
Macro diversity result Best case / 3 dB difference	7.3 dB / 8.6 dB	6.3 dB / 7.7 dB
Macro diversity gain Best case / 3 dB difference	4.0 dB / 2.7 dB	2.2 dB / 0.8 dB

- Macro diversity gain for uplink coverage
  - ITU Pedestrian A: 2.7 - 4.0 dB
  - ITU Vehicular A: 0.8 - 2.2 dB

NOKIA

BS Antenna Diversity Gain for Coverage

- Simulation parameters
  - Required received Eb/N0 shown
  - FER=1% with speech
  - Full constant power (at the cell edge)

E_b/N_0	ITU Pedestrian A	ITU Vehicular A
With one receiver antenna	18.8 dB	12.8 dB
With receiver antenna diversity	11.3 dB	8.5 dB
Antenna diversity gain	7.5 dB	4.3 dB

- With antenna diversity
  - 3dB gain because coherent combining for signals and non-coherent for noise
  - +diversity gain
- Antenna diversity gain
  - ITU Pedestrian A: 7.5dB
  - ITU Vehicular A: 4.3dB

NOKIA

Example Performance Verification in Field Measurements - Four Branch Antenna Diversity

Suburban, urban, dense urban

Field Measurements

- Measurements done with Nokia WCDMA experimental system in Espoo / Finland and in Singapore
- Environment: urban / sub-urban in Espoo and dense urban in Singapore

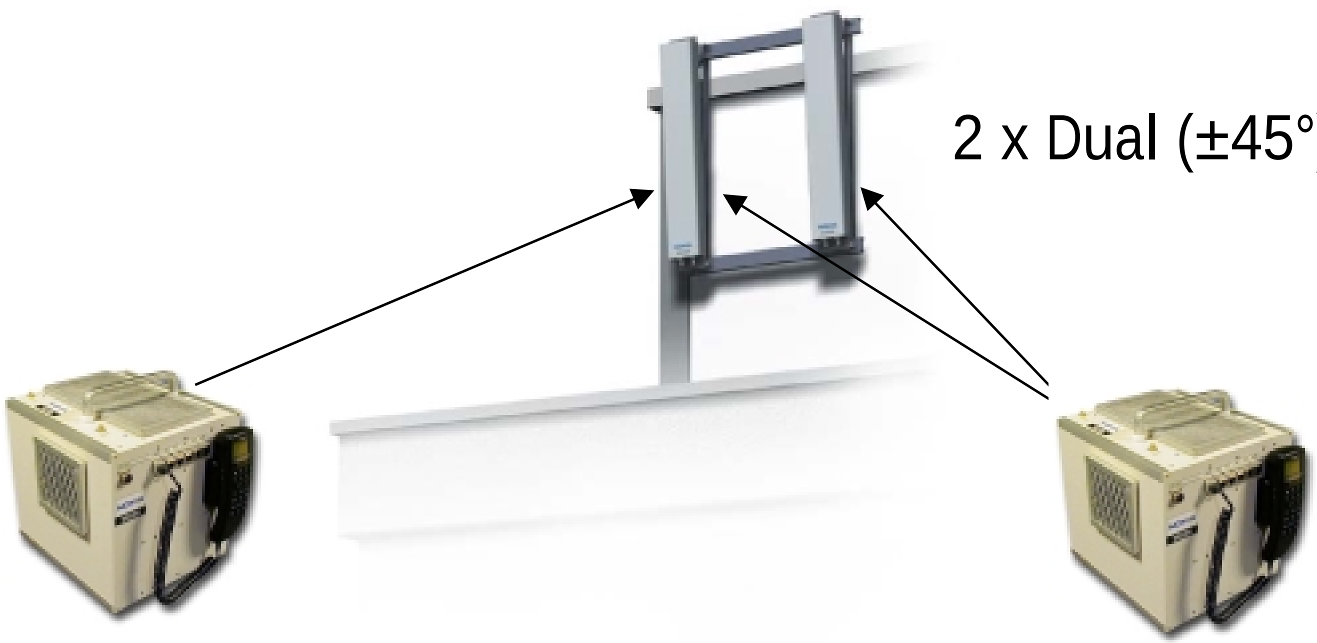
Antenna separation ~1.0 m

2 x polarization diversity ±45°

NOKIA

Field Measurements

- What is the coverage gain of 4-branch diversity over normal 2-branch receiver diversity?
- We measured the reduction of WCDMA mobile transmission power with 4-branch reception compared to 2-branch reception



(1) Record mobile tx power with 2-rx base station reception

(2) Record mobile tx power with 4-rx base station reception

Measurements Parameters

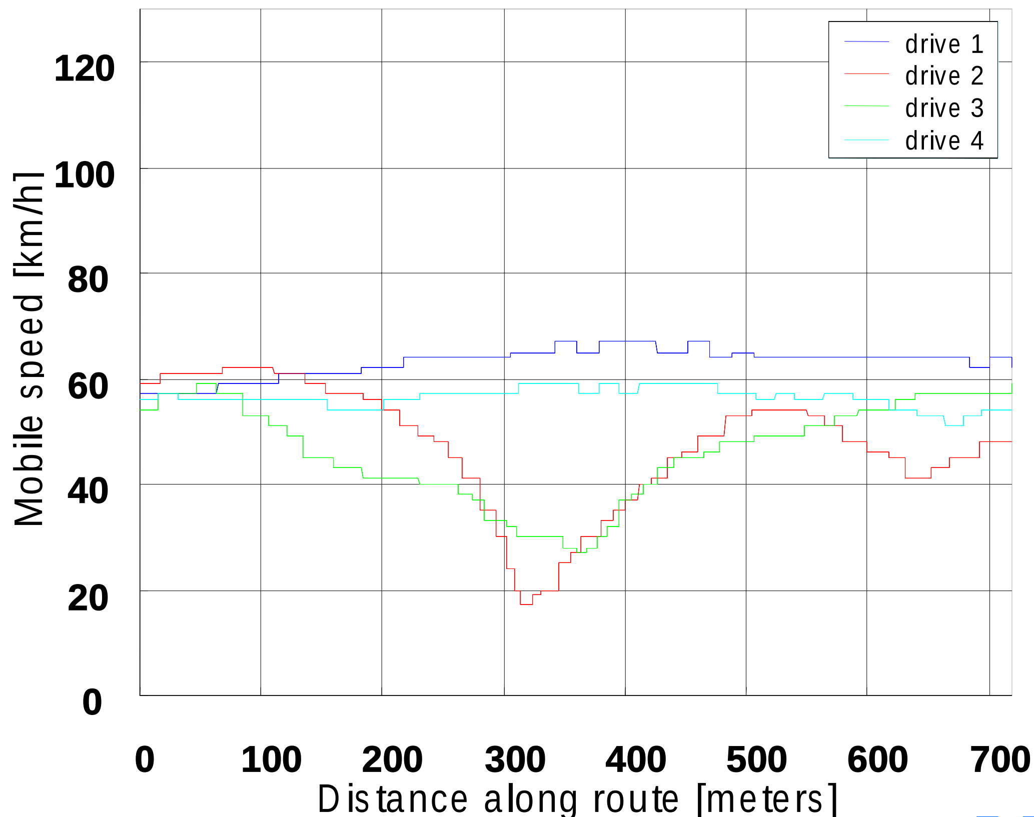
Bit rate	8 kbps
FER target in the outer loop	1%
Channel estimation and Rake allocation	From pilot symbols
Number of Rake fingers per connection	8
Interleaving depth	10 ms, 1 radio frame
Base station antennas	Espoo: ±45° with 15.5 dBi gain (Aerial) Singapore: ±45° with 18 dBi gain (Kathrein)
Mobile station antenna	Within measurement van, vertical

Measurement Routes in Espoo

Route A	up to 40 km/h in Leppävaara / Lintuvaara
Route B	up to 70 km/h on Ring I
Route C	below 10 km/h in Mäkkylä

Example mobile speeds on Route B

Differential GPS is used to make the iterations comparable



Measurement Results in Espoo

Route A

Antenna separation	2-rx	4-rx	4-rx gain
1 m separation	6.95 dBm	4.44 dBm	2.5 dB
No separation	6.95 dBm	4.83 dBm	2.1 dB

Route B

Antenna separation	2-rx	4-rx	4-rx gain
1 m separation	7.90 dBm	4.59 dBm	3.3 dB
No separation	7.90 dBm	4.86 dBm	3.1 dB

Route C

Antenna separation	2-rx	4-rx	4-rx gain
1 m separation	5.63 dBm	2.54 dBm	3.0 dB

NOKIA

Measurement Results in Singapore

- Singapore measurements are done in China town
- Measurement environment is dense urban

Antenna separation	2-rx	4-rx	4-rx gain
1 m separation	17.26 dBm	14.56 dBm	2.7 dB
No separation	17.26 dBm	14.76 dBm	2.5 dB

NOKIA

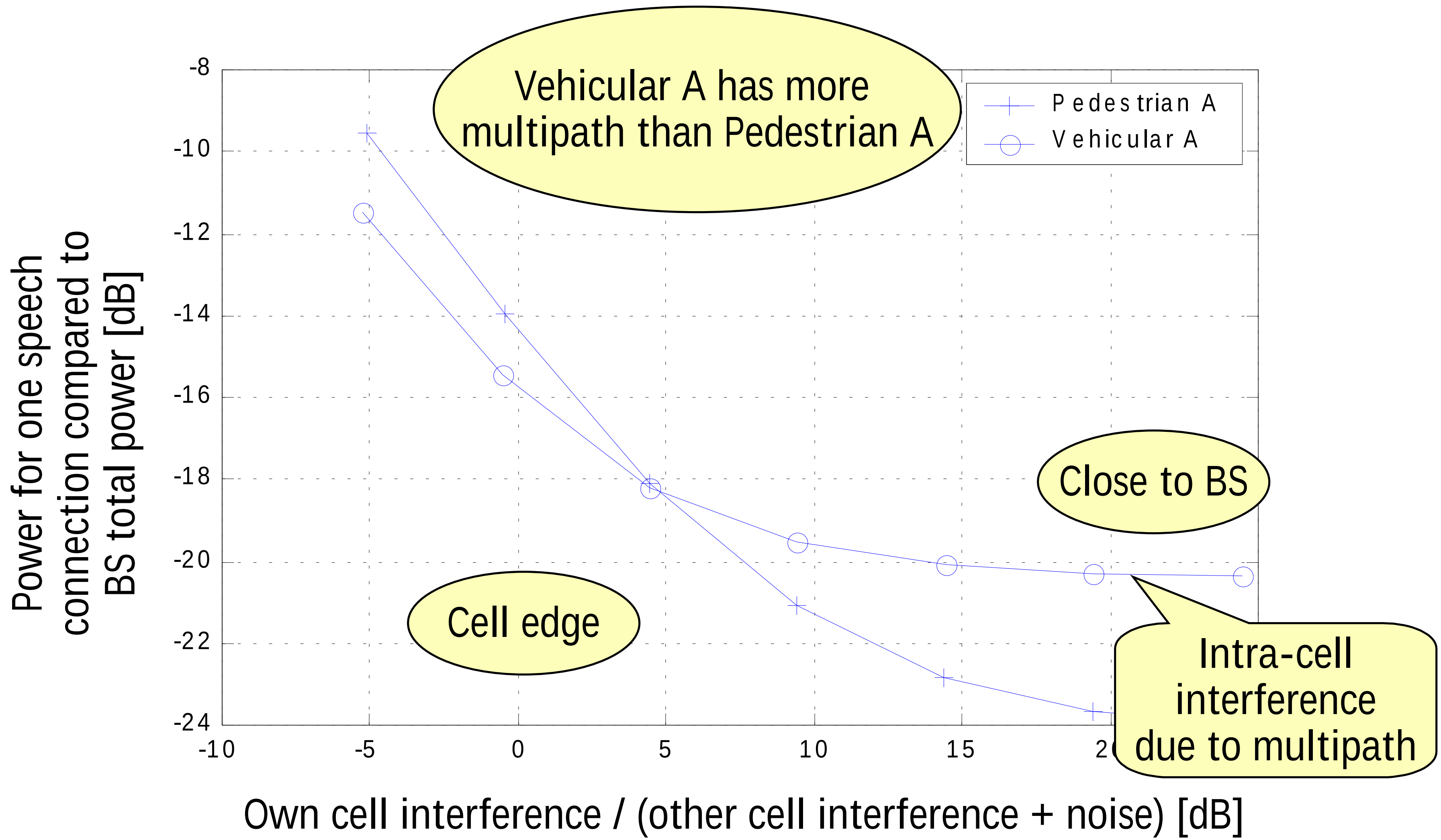
Simulations vs. Measurements

	Simulation	Measurement
Reduction of MS tx power with 1.0 m separation	2.9 dB	2.5-3.3 dB
Reduction of MS tx power without any separation	0.5 dB less gain	0.2-0.4 dB less gain

- These results are with fast power control
- The gain is slightly higher at the edge of the coverage area where the mobile is transmitting close to its full power, up to 0.5 dB more gain in simulations

Downlink Capacity

Downlink Orthogonal Codes



Capacity in Macro vs. Micro Environments

- Packet data throughput, calculated with CDMA capacity formulas

Assumptions

	Macro cell	Micro cell
Downlink orthogonality	0.6	0.95
Other-to-own cell interference ratio i	0.65	0.2
Uplink E_b/N_0	1.5 dB	1.5 dB
Uplink loading	60%	60%
Downlink E_b/N_0	5.5 dB	8.0 dB
Downlink loading	80%	80%

Micro cell: higher orthogonality

Micro cell: higher isolation between cells

Results

	Macro cell	Micro cell
Uplink	1040 kbps	1430 kbps
Downlink	660 kbps	1440 kbps

These figures without transmit diversity

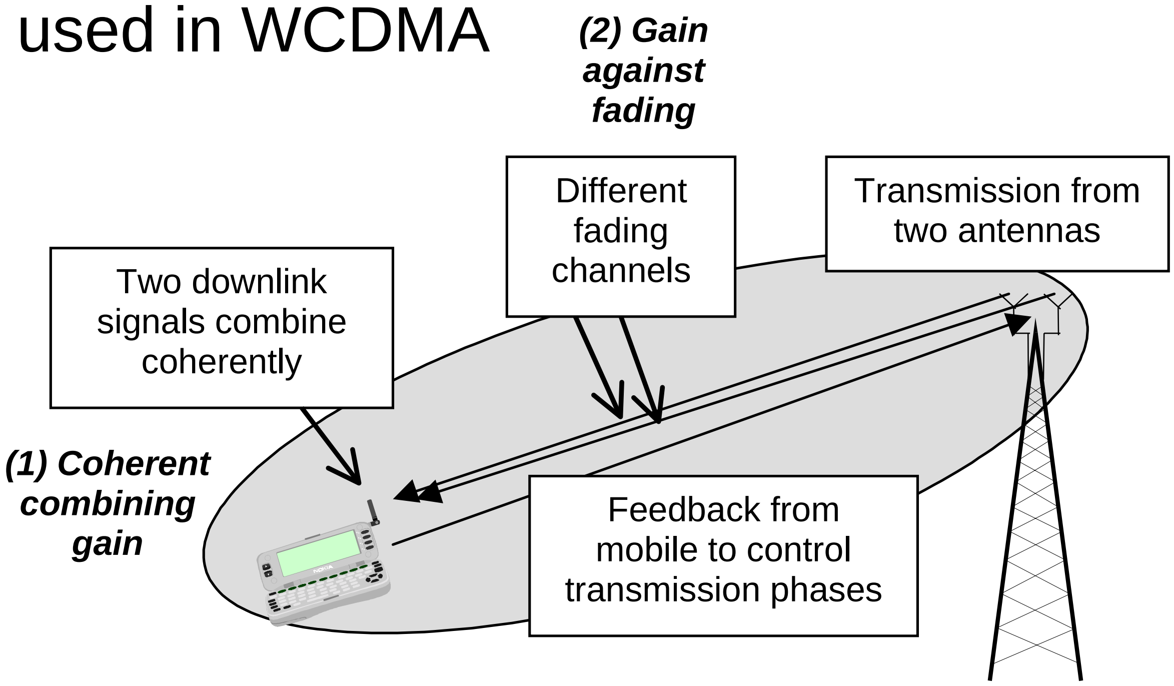
- Downlink capacity is more sensitive to the environment because of orthogonal codes (other cell interference affects more downlink)
- Micro cells provide a higher capacity due to less multipath

NOKIA

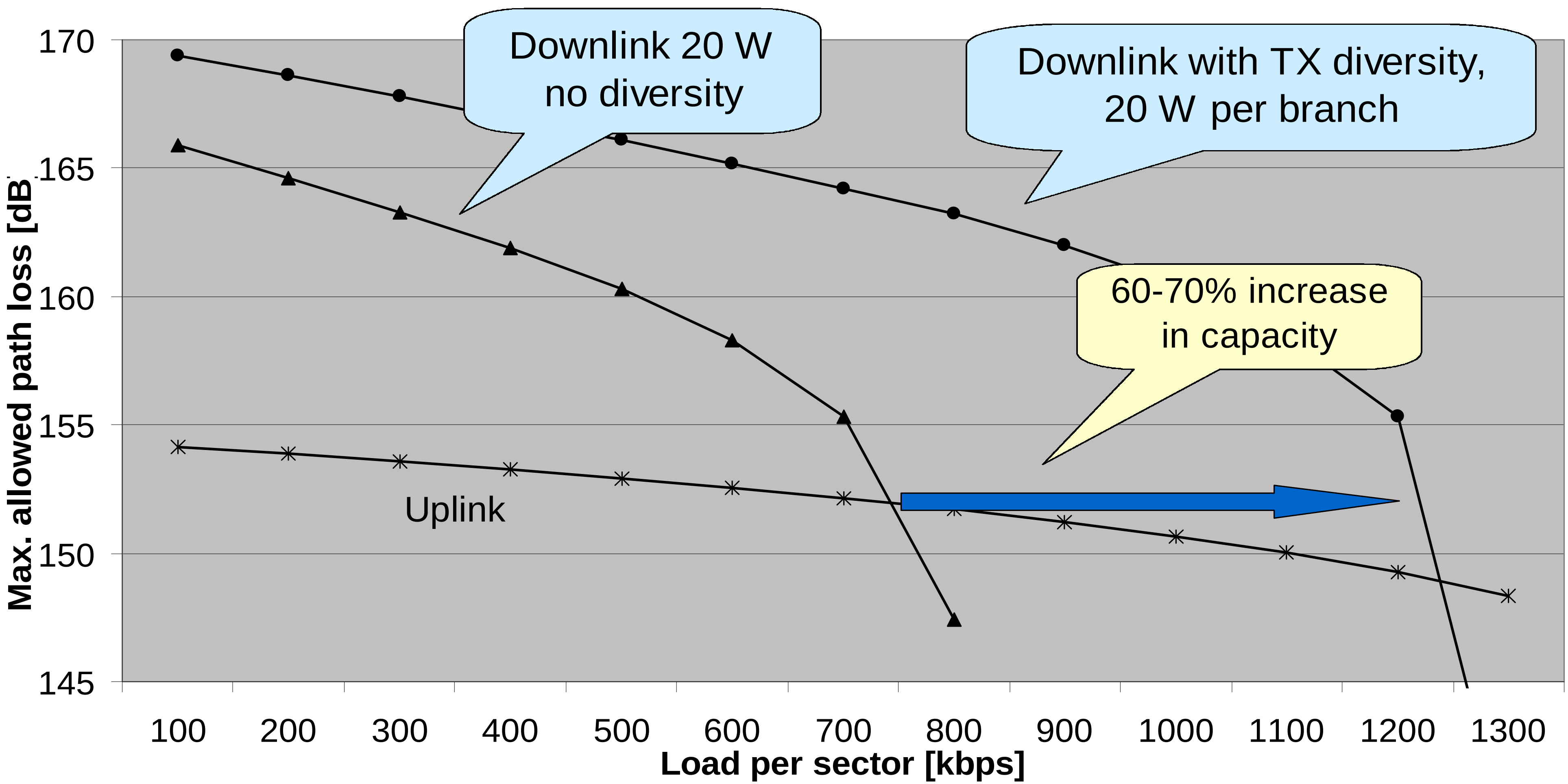
Downlink Transmit Diversity

- More need for downlink capacity than for uplink capacity
  - Asymmetric capacity requirements, with bias in downlink
- Terminal complexity to be minimized
  - Receiver diversity can be used in base station, not feasible in mobile

➪ Transmit diversity used in WCDMA



Downlink Capacity Enhancement with Transmit Diversity



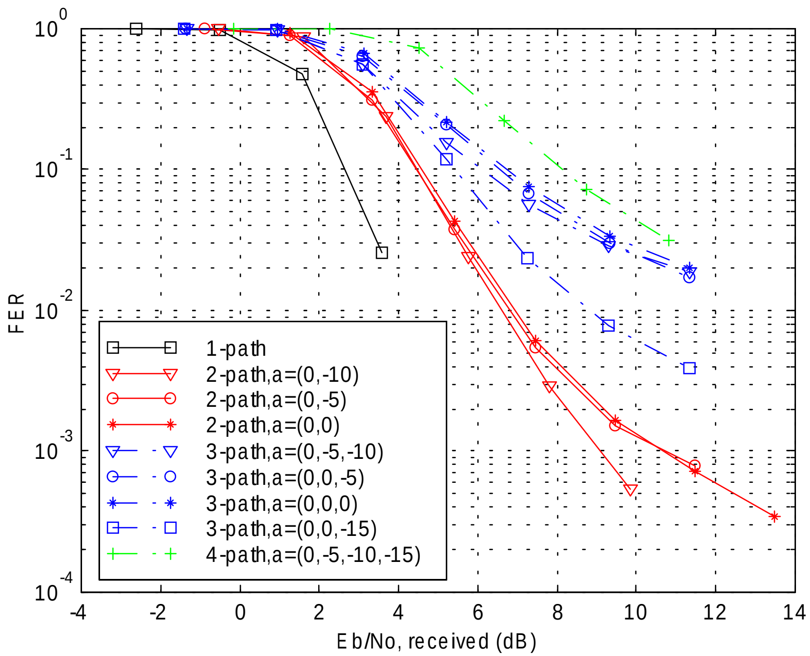
High bit rates (2 Mbps)

Link Level Performance of High Bit Rates (1)

- For low processing gain (high bit rates) inter-symbol interference (ISI) causes degradation in multipath channels
- 2 Mbps / 3.84 Mcps ➪ Processing gain < 3 dB

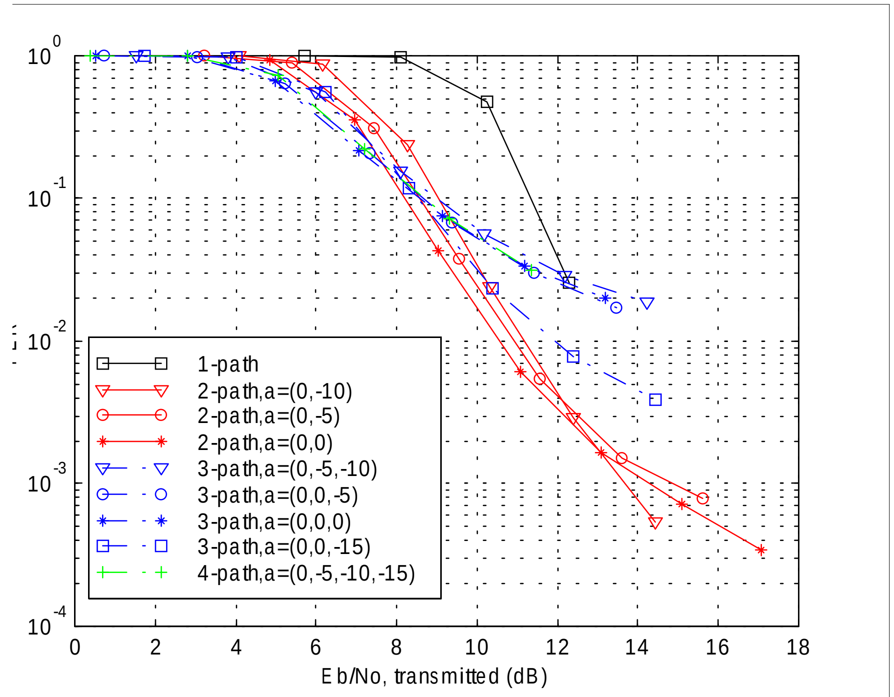
FER vs. received E_b/N_0

- degradation due to ISI



FER vs. average transmitted power

- multipath diversity gain



Link Level Performance of High Bit Rates (2)

- 2 Mbps packet data works with WCDMA even with a simple Rake receiver
- Some degradation due to inter-symbol interference
  - required received power in 2-path channel was about 1.8 dB higher than in 1-path channel
- Multipath diversity gain is still higher than inter-symbol interference
  - transmitted power in 2-path channel was about 2.3 dB better than in 1-path channel
- Performance improvements possible with ISI cancellation in the receiver (~equalizer)

Downlink Coverage of 2 Mbps

- How large is 2 Mbps packet data coverage compared to 144 kbps speech coverage in downlink?
- Assumptions
  - Power allocation assumption: 1 W power is allocated for 144 kbps users, more power can be allocated for 2 Mbps, let's assume 10W
- Results
  - Difference from bit rates 10*log10(144/2000) = -11.4 dB
  - Difference from power allocation 10*log10(10/1.0) = 10.0 dB
  - Total = -1.4 dB

➪ Good coverage of high bit rates is possible in downlink with GSM1800 sites

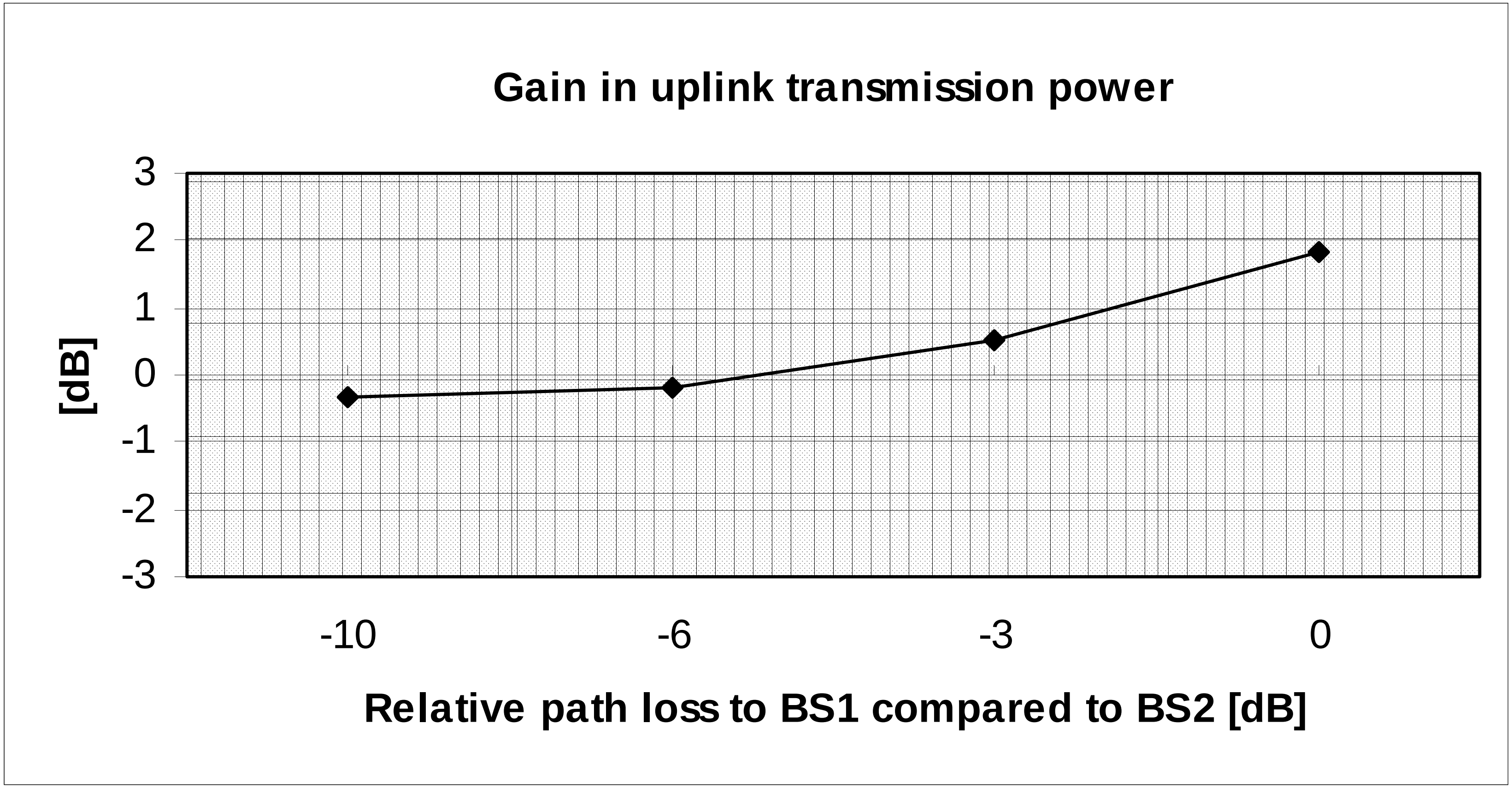
- But, 2 Mbps in every cell (also cell edge) at the same time requires high capacity

NOKIA

Handovers

Macro Diversity Gain in Uplink

- Mobile tx power can be reduced during macro diversity since there are 2 or more base stations receiving the signal
- Gain in mobile tx power against fast fading shown below

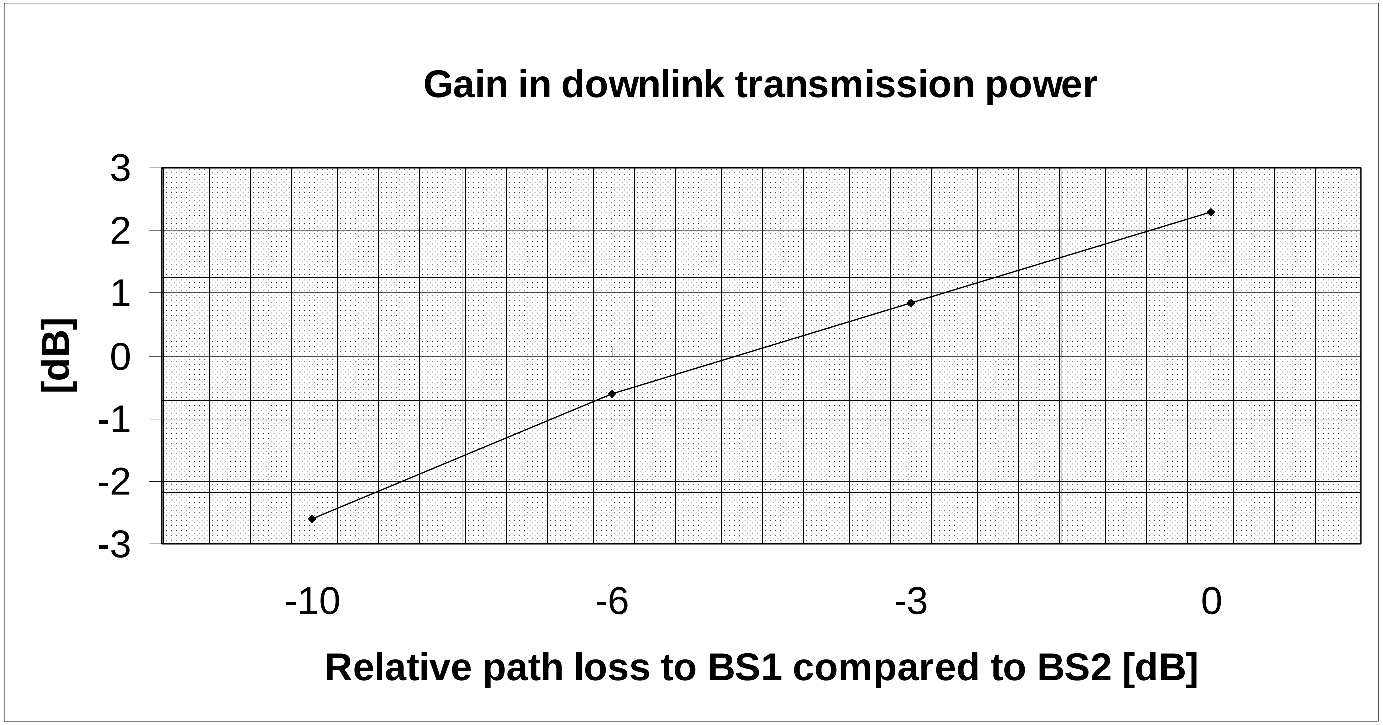


NOKIA

Macro Diversity Gain in Downlink

- Macro diversity in downlink
  - provides more diversity
  - requires two transmission links
- If the path loss to both base stations is the same, macro diversity reduces the total required transmission power in downlink

Both transmission links are taken into account



Packet Data

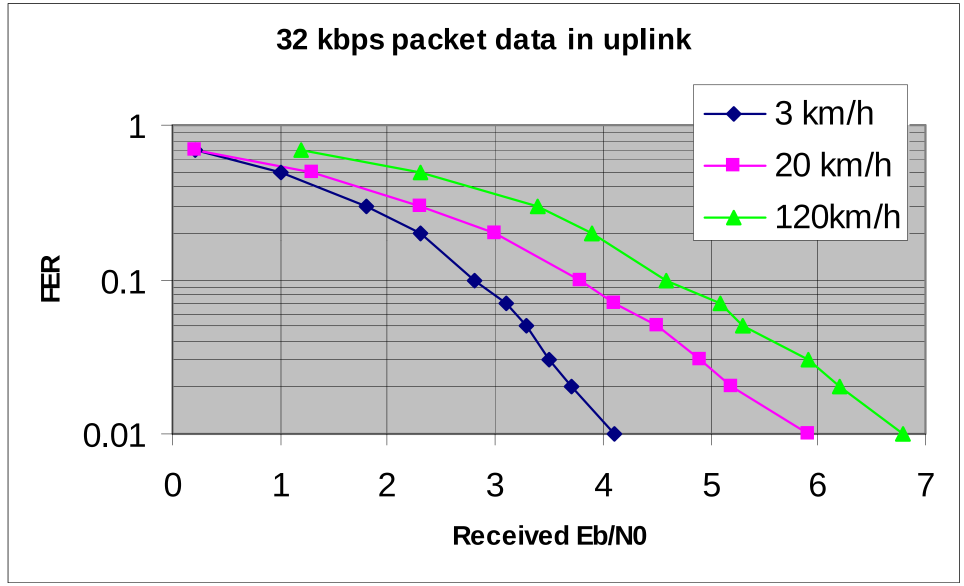
Packet Data, Link Level Performance

- Link level performance: FER vs. Eb/N0

$$Throughput_{cell} = \frac{W}{k}\frac{1-FER}{E_b/N_0}$$

$$f_{capacity} = \frac{E_b/N_0}{1-FER}$$

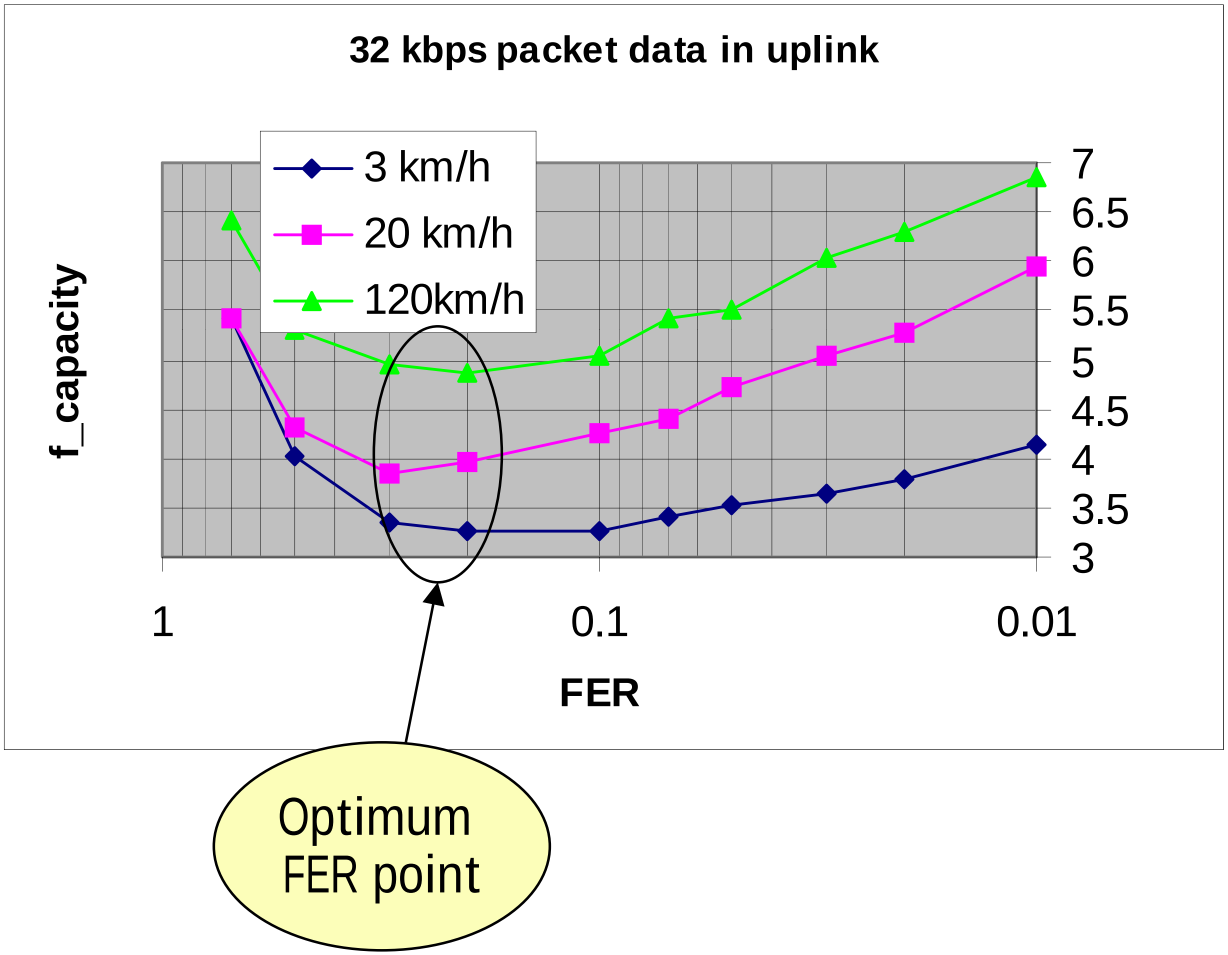
E_b/N_0 including retransmissions



- What is the optimum FER operation point for packet data when we take into account retransmissions?
- The smaller $f_{capacity}$, the larger the capacity

Packet Data, Link Level Performance

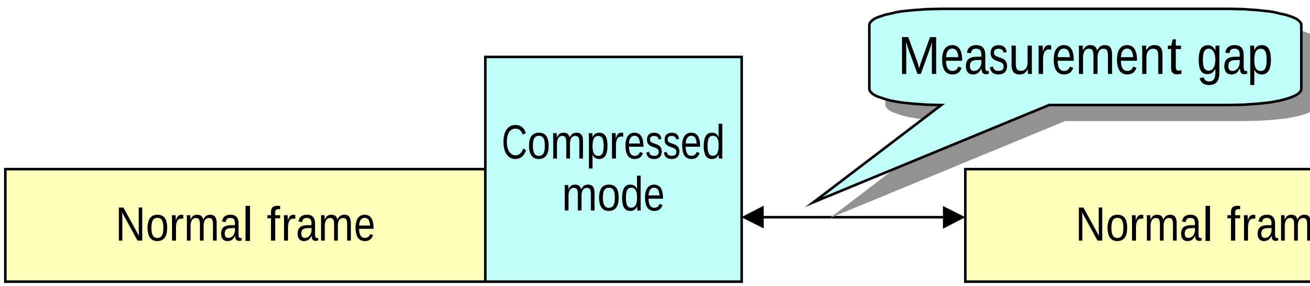
- Optimal FER operation point 10-30 % to maximize the capacity



WCDMA Compressed Mode

WCDMA Compressed Mode

	WCDMA	IS-95A	GSM
Why inter-frequency measurements?	For inter-frequency & inter-system handovers	No IF-measurements => utilization of multiple frequencies difficult	For all handovers
How to make IF-measurements	**Compressed mode**		Simple since discontinuous tx & rx



- More power is needed during compressed mode
  => affects WCDMA coverage
- Power control cannot work during compressed frame => higher Eb/N0
  => affects WCDMA capacity

NOKIA

Performance of Compressed Mode : Capacity

Assumption	Effect to the capacity
Required Eb/N0 is 1.5 dB higher during compressed frames	1.5 dB = 41% more interference
Every 3rd frame is compressed	41% /3 = 14% more interference
10% of the users are measuring at the same time	14% /10 = 1.4% more interference

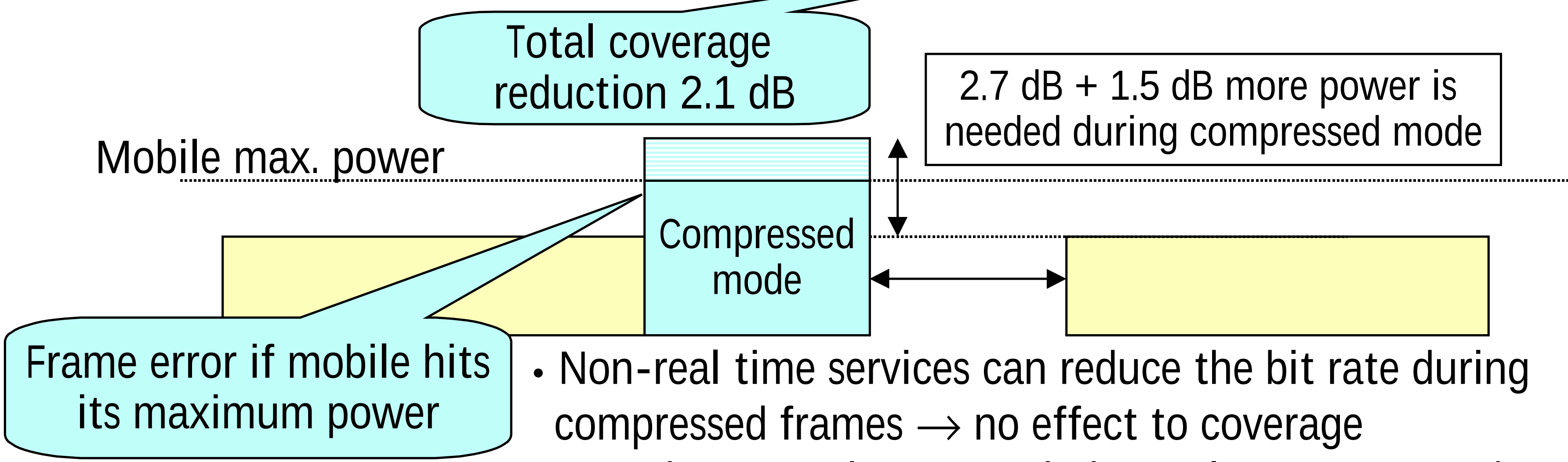
Capacity degradation <2%

Exact increase in Eb/N0 depends on service, multipath diversity, antenna diversity, mobile speed, uplink or downlink, measurement gap length, compressed mode method (spreading factor or puncturing), and 1.5 dB represents a typical value.

NOKIA

Performance of Compressed Mode : Coverage

Assumption	Effect to the capacity of real time services
Required Eb/N0 is 1.5 dB higher during compressed frames	1.5 dB reduced coverage
7-slot gap is used	10*log10(15/8) = 2.7 dB reduced coverage
Every 2nd frame is compressed with 20 ms interleaving (speech)	4.2 dB / 2 = 2.1 dB reduced coverage



- Non-real time services can reduce the bit rate during compressed frames → no effect to coverage
- Speech connection can switch to a lower AMR mode