Scheduling and capacity estimation in LTE

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Introduction

LTE is the new, (following up of HSPA) mobile access technology specified by 3GPP:

- Flat all-IP architecture
- Flexible in frequency bands (700 MHz-2.6 GHz)
- Flexible carrier bandwidths (1.4, 3, 5, 10, 15 and 20 MHz)
- Increased spectrum efficiency based on OFDMA for uplink, SC-FDMA for downlink
  - Typical cell capacity (20 MHz bandwidth), 20 – 40 Mbps for downlink link and 5 – 15 Mbps for uplink
- Momentum in the industry, building on current investments in the GSM/UMTS

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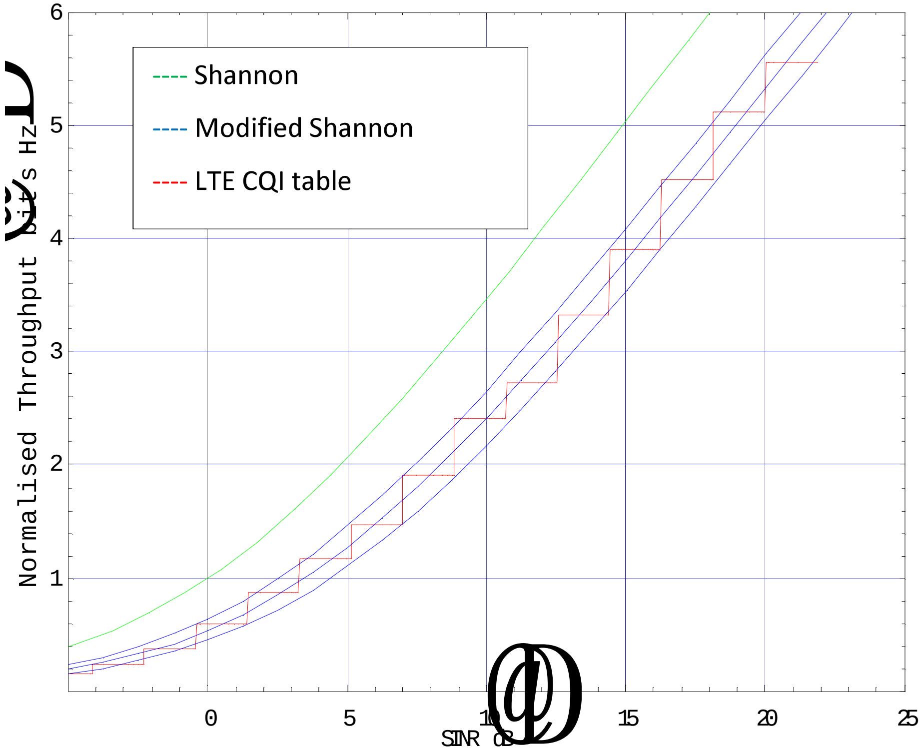
Obtainable bitrate as function of SINR

Bitrate function B=B(SINR)

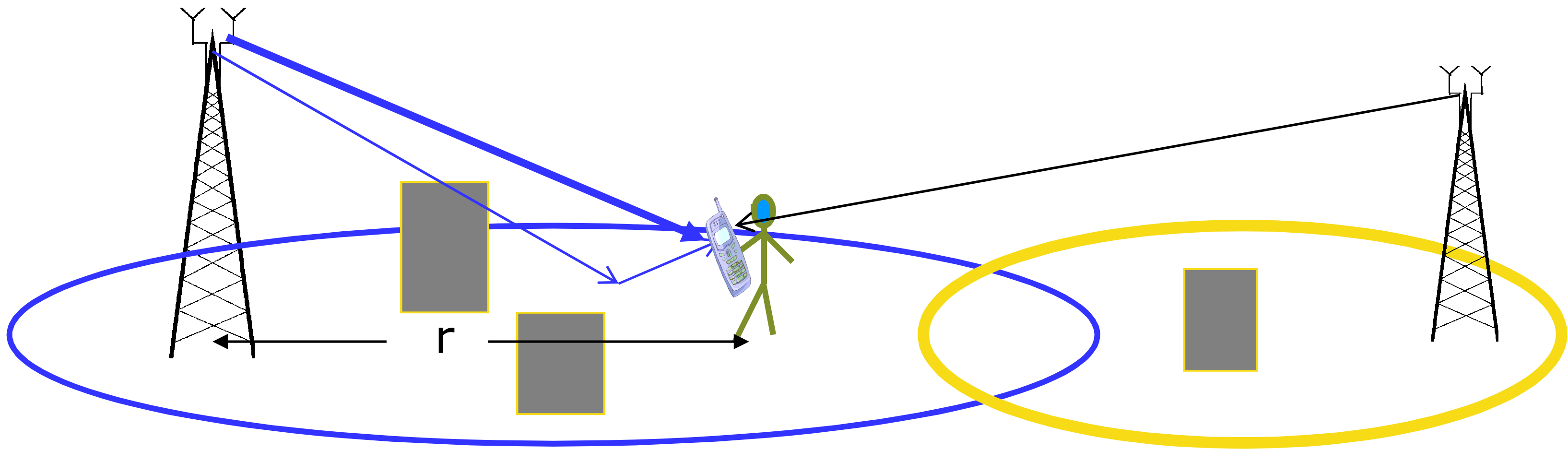
- Upper bound Shannon: $B/f = \mathrm{Log}_2(1+SINR)$
- Discrete; B/f based on CQI-table (3GPP TS 36.213) and Linear relation between SINR[dB] and CQI-index
- Approximate/Truncated modified version of Shannon's formula:

  $B/f = \mathrm{MIN}[T, C\ \mathrm{Log}_2(1+\gamma SINR)]$

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547



Radio channel propagation model



Signal-to-noise ratio: $SINR = \frac{P_w G}{N}$

P_w sending power

Path loss (model): $G = 10^{L/10}$ $L = C - A\log_{10}(r) + X_t$

C and *A* constants, X_t shadowing usually assumed to be normal distributed with zero mean and given standard deviation

Noise $N = N_{\text{int}} + N_{ext}$ sum the internal (or own-cell) noise power and is the external (or other-cell) interference.

Radio signal fading model

SINR on the form: $S_t \,/ r^{\alpha} h(\lambda)$

Stochastic part of SINR: $S_t = X_{\ln} X_e$

Slow fading (shadowing): Lognormal $X_{\ln}$

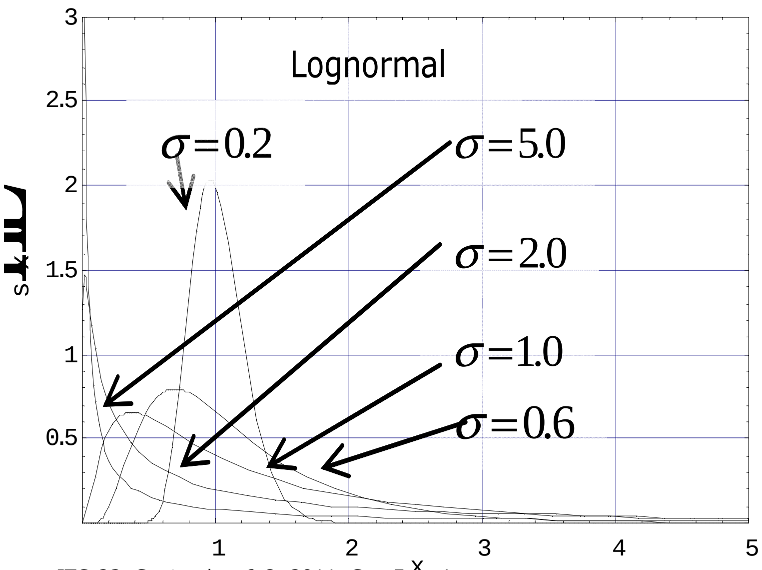
Fast fading: Rayleigh, i.e. neg. exp. distributed X_e

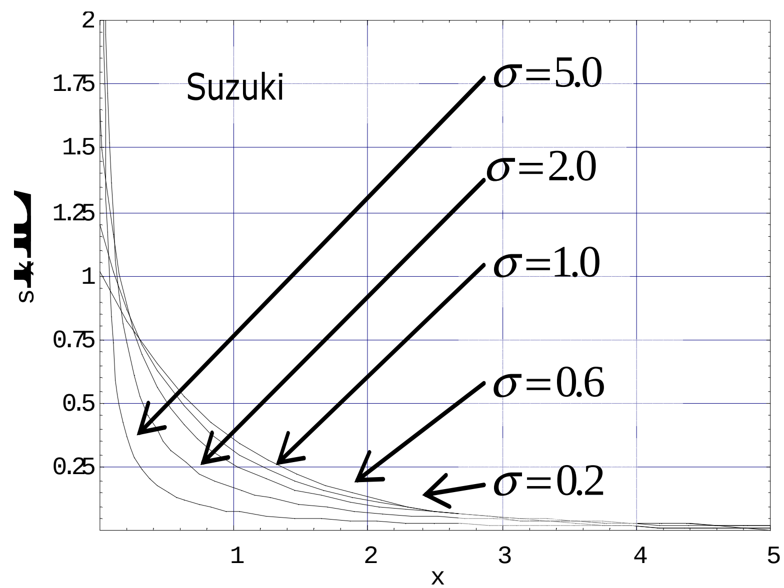
S_t: Suzuki distributed with CDF

$$\tilde{S}_{su}(x) = \int_{t=0}^{\infty} e^{-xt} s_{\ln}(t)dt = \frac{1}{\sqrt{2\pi}\sigma} \int_{t=0}^{\infty} \frac{e^{-t-\frac{(\ln(t/x))^2}{2\sigma^2}}}{t} dt$$

Truncated version:

$$\tilde{S}_{su}(x,T) = \frac{1}{\sqrt{2\pi}\sigma} \int_{t=0}^{T} \frac{e^{-t-\frac{(\ln(t/x))^2}{2\sigma^2}}}{t} dt = \frac{1}{2} \sum_{k=0}^{\infty} \frac{(-1)^k}{k!} x^k e^{\frac{k^2\sigma^2}{2}} erfc\left(\frac{k\sigma}{\sqrt{2}} + \frac{\ln(x/T)}{\sigma\sqrt{2}}\right)$$





Analytical models for LTE radio network performance

- Spectrum efficiency through the bit-rate distribution per Recourse Block (RB) for users that are either randomly or located at a particular distance in a cell.
- Cell throughput/capacity and fairness by taking the scheduling into account.
  - Scheduling based on metrics which depends (only) on own SINR and distance
  - Specific models for the common (basic) scheduling algorithms, Round Robin, Proportional Fair and Max-SINR.
- Estimation of the capacity usage for GBR sources in LTE
  - Non-persistent allocation, i.e. allocation every TTI to obtain GBR rate
- Cell throughput/capacity for a mix of GBR and Non-GBR (greedy) users

Input parameters to numerical examples

Parameters	Numerical values
Bandwidth per Resource Block	180 kHz=12x 15 kHz
Total Numbers of Resource Blocks	100 RBs
Distance-dependent path loss. (Taken from a 3GPP document)	$L=C+37.6\log_{10}(r)$, r in kilometers and C=28.1 dB for 2GHz
Lognormal Shadowing with standard deviation	8 dB (in most of the cases)
Rayleigh fast fading	
Noise power at the receiver	-101 dBm
Total send power	46.0 dBm=(40W)
Radio signaling overhead	3/14

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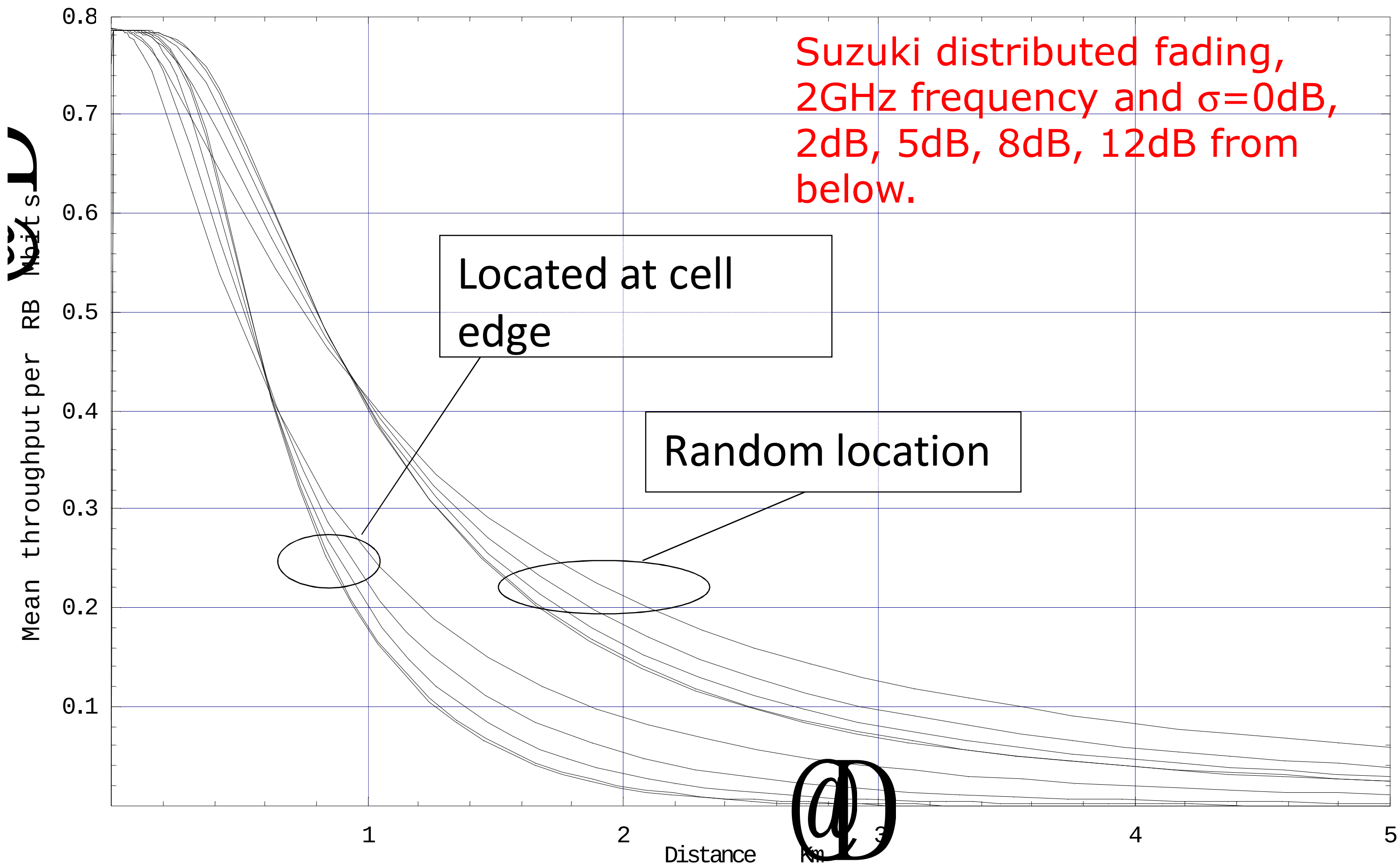
Mean throughput per RB as function of cell radius



Throughput per RB drops for large cells. Approx 0.2 Mbit/s for 2km cell and 0.05 Mbit/s at cell edge with 8dB shadowing.

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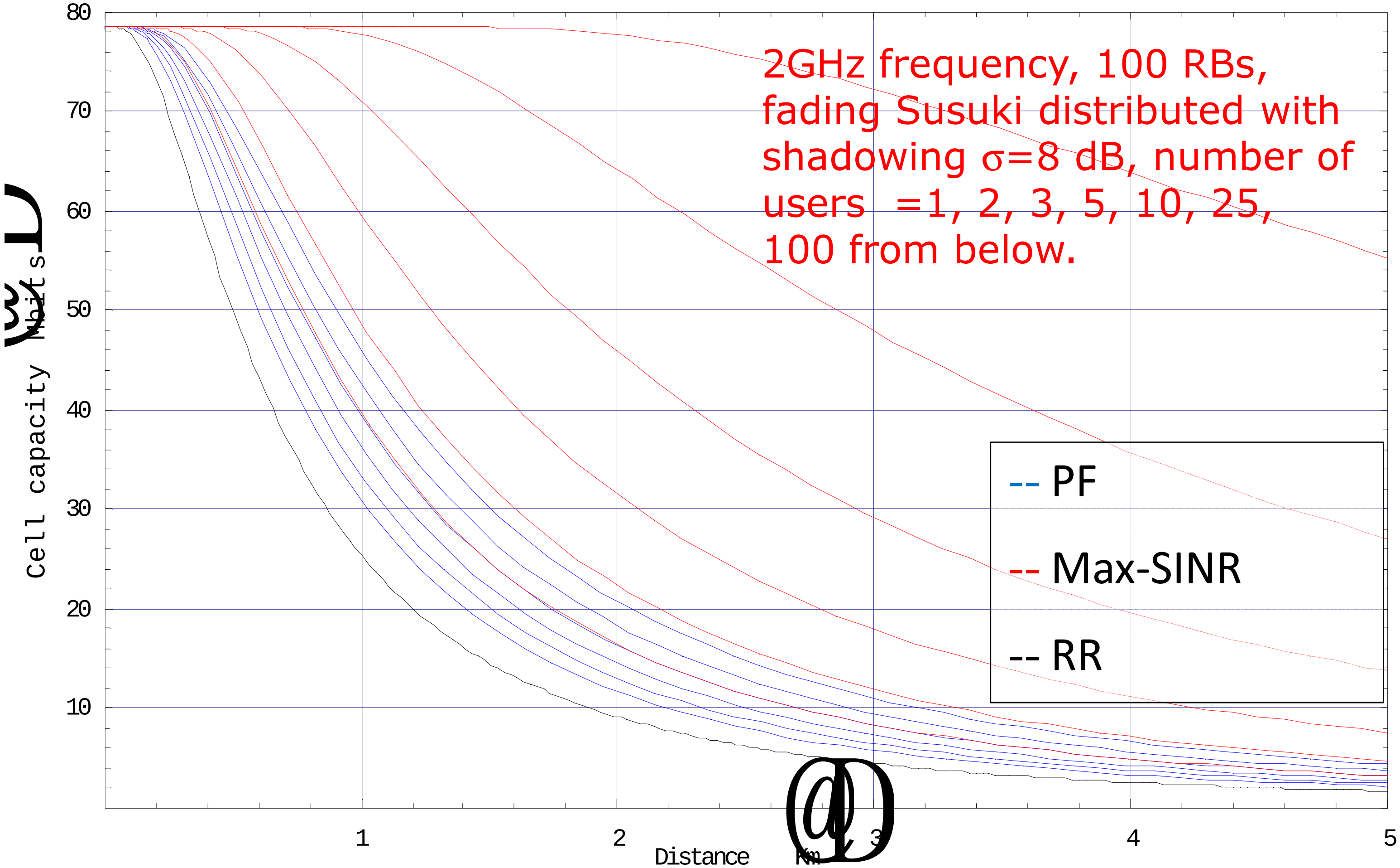
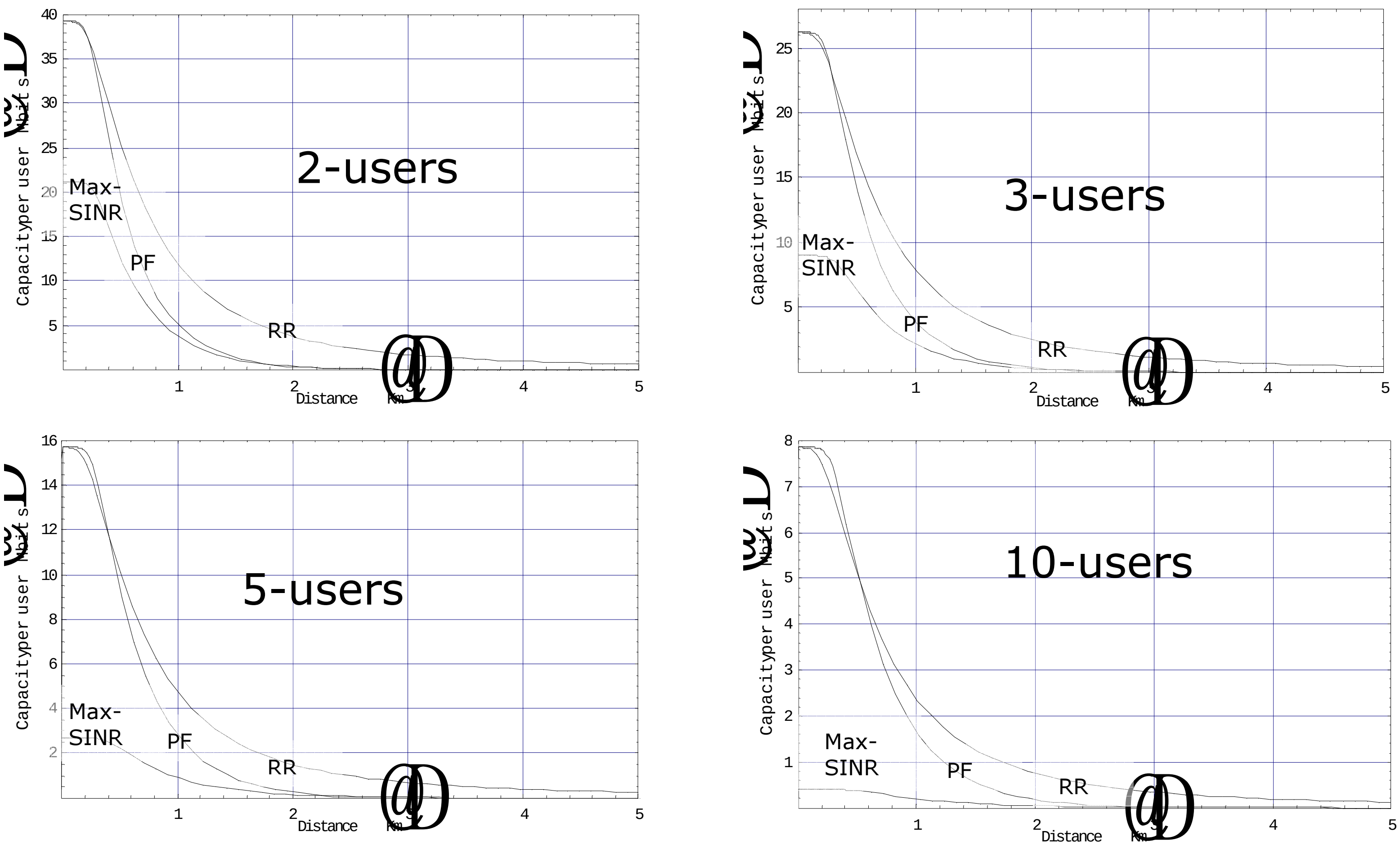
Multiuser gain as function of cell radius



Multiuser gain very large for Max-SINR. PF doubles cell throughput compare to RR for cell of 2 km and 25 users.

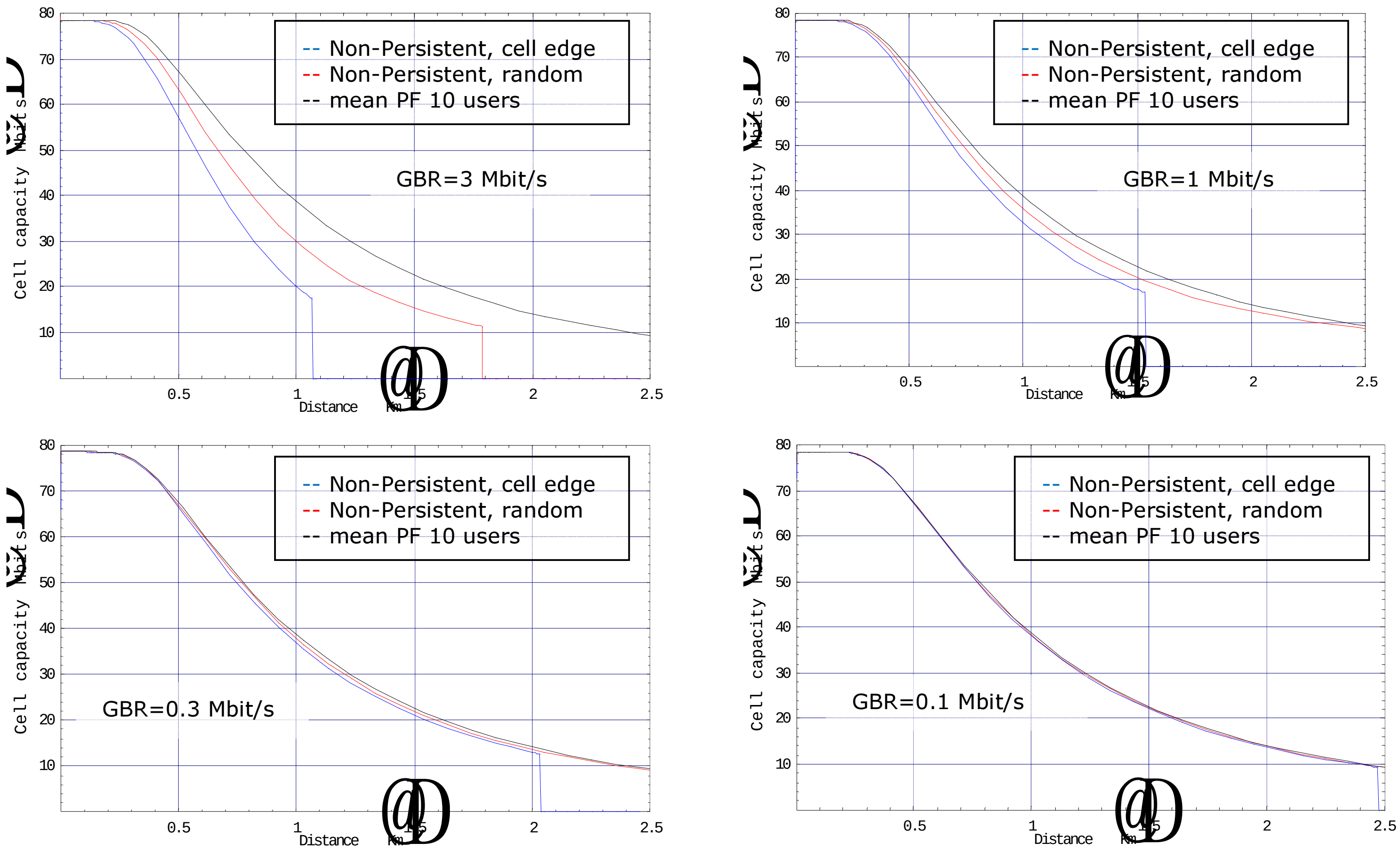
Mean Bitrate for a user located at cell edge as function of cell radius.



Max-SINR shows very poor cell edge performance

Scheduling: RR, PF and Max-SINR scheduling algorithm , 2GHz frequency and 100 RBs

Mean cell throughput for 10 users scheduled according to PF and a GBR user



GBR rates of less than 1 Mbit/s does not reduce the overall throughput very much. GBR rates larger than 1 Mbit/s is not recommended.

GBR of 3.0, 1.0, 0.3, 0.1 Mbit/s using non-persistent scheduling, for 2 GHz and 100 RB and Suzuki distributed fading with std. σ=8dB.

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Conclusions

- The two most important factors for the radio performance in LTE are fading and attenuation due to distance.
- Numerical examples for LTE downlink shows results which are reasonable;
  - In the range 25-50 Mbit/s for 1 km cell radius at 2GHz with 100 RBs .
  - Multiuser gain is large for the Max-SINR algorithm but also the PF algorithm gives relative large gain relative to plain RR.
  - The Max-SINR has the weakness that it is highly unfair in its behaviour. (Not recommended to use in real operation.)
- The usage of GBR with high rates may cause problems in LTE due to the high demand for radio resources if users have low SINR i.e. at cell edge.
  - GBR rate limited to at most 1 Mbit/s per user?

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