# Performance of QoS- and channel-aware packet scheduling for LTE downlink

ITG/VDE5.2.4: Workshop on Scheduling and Radio resource management

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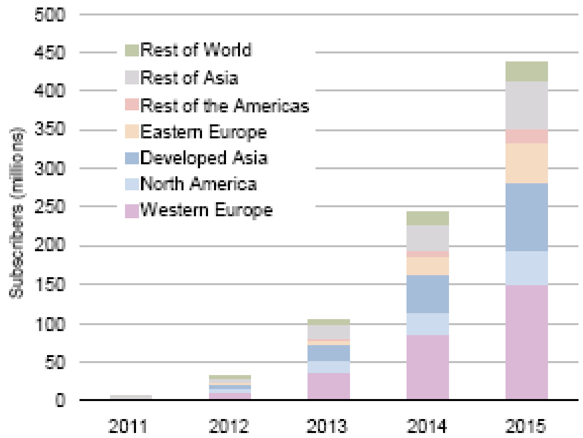
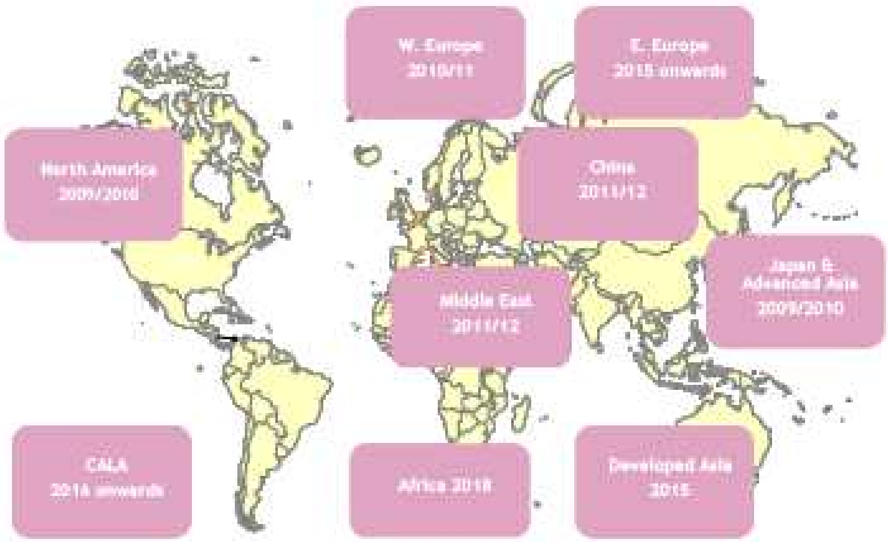
# LTE Market and challenges



*Forecast LTE subscribers [Source: Analysys Research, 2007]*

LTE the common world standard for next generation evolution for 3G WCDMA and CDMA operators

- LTE market is expected to be worth over €2.1Bn by 2012 according to ABI research (3Q 07)
- *Analysys* forecast over 400M LTE subscribers by 2015




Long Term Evolution but short Time To Market

- 3GPP spec functional freeze 2008
- Commercials start in 2010 with major operators in Asia/North America/Europe

**Initial deployments will focus on "Hot Zone" areas to maximise access to high data users**

- Hot zone coverage will be driven by distributed eNB solutions for high density, high Data speed areas



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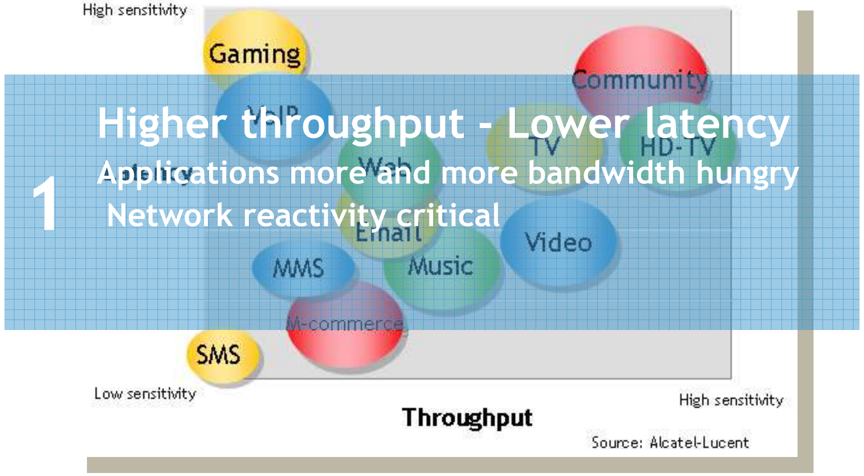
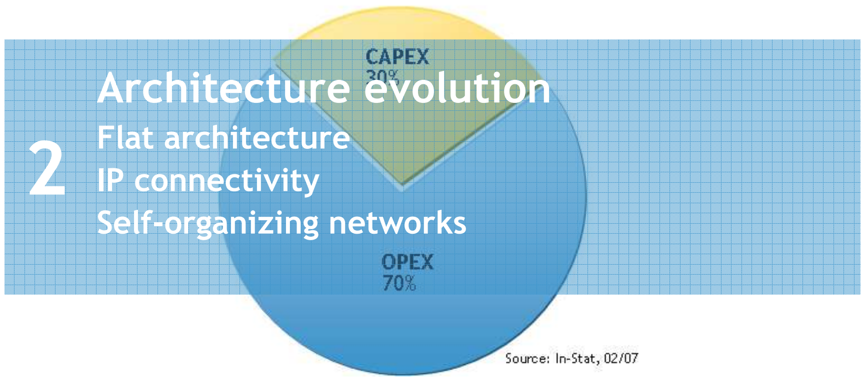
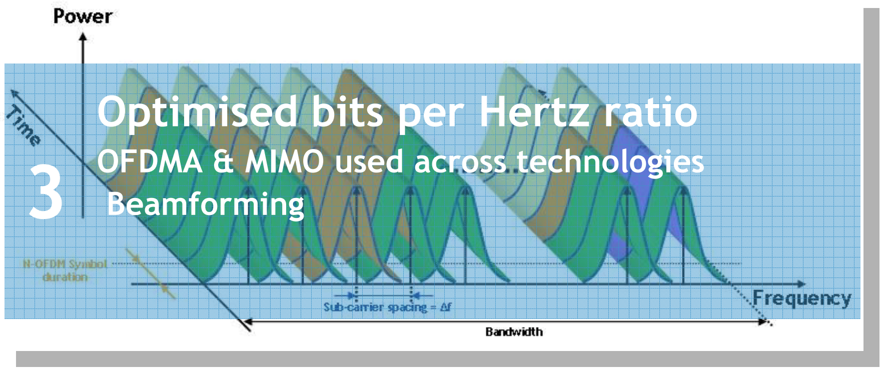
# Wireless Technological Trends … LTE



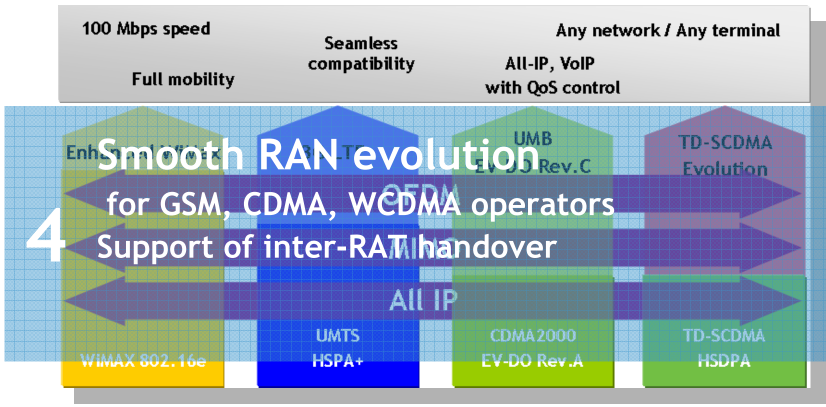

1 **Higher throughput - Lower latency**
Applications more and more bandwidth hungry
Network reactivity critical




2 **Architecture evolution**
Flat architecture
IP connectivity
Self-organizing networks




3 **Optimised bits per Hertz ratio**
OFDMA & MIMO used across technologies
Beamforming




4 **Smooth RAN evolution**
for GSM, CDMA, WCDMA operators
Support of inter-RAT handover

… In line with Total Cost of Ownership reduction



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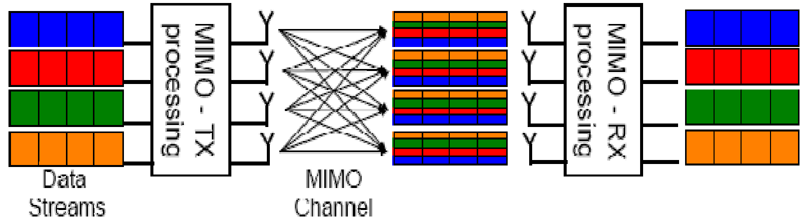
# LTE Characteristics

## Key Principles

**OFDMA** (DL) **/ SC-FDMA** (UL) **: Robust modulation in dense environments**

- Increased spectral efficiency
- Simplified Rx design → cheaper UE
- Scalable BW – 1.4, 3, 5, 10, 15, 20 MHz
- Short TTI: 1 ms (HSPA: 2 ms)

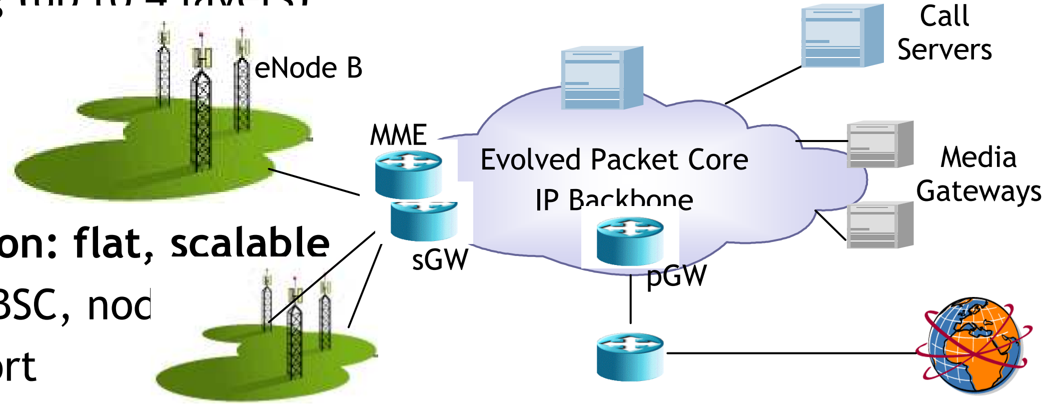



**MIMO: Increased link / cell capacity**

- (DL): Diversity / spatial multiplexing (up to 4 layers)
- (DL): beamforming / SDMA
- (UL): virtual MIMO (UL)

**RAN Architecture / packet core evolution: flat, scalable**

- Single RAN node: eNB (instead BTS/BSC, nod
- Backhaul based on IP / MPLS transport
- Fits with IMS, VoIP, SIP



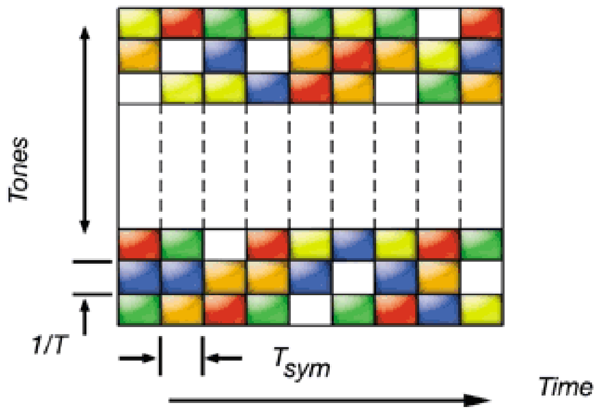

**OFDMA / MIMO - perfect long term partnership**

**Achieve considerable increase in capacity, peak rates & coverage**

# LTE Characteristics

## Key Principles

- Efficient use of OFDMA radio resources
  - packet scheduling in time-/frequency and spatial domain
    - – Multi-user diversity gain
    - – Frequency selective scheduling at low/intermedi mobility
    - – Frequency diverse scheduling at higher mobility
    - – Adaptive modulation & coding
- Balance system capacity vs fairness
- Support of class-based QoS control




**Real-time services: VoIP**

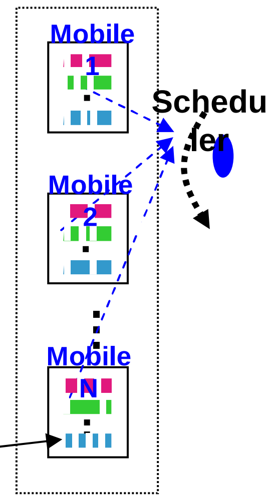
- Hard bounds on packet delay
- Very low tolerance to delay jitter
- High tolerance to packet loss rate

**Streaming services**

- rate constraints GBR/MBR
- Soft bounds on packet delay
- Medium tolerance to packet loss rate

**Best effort / Data**

- In principle no bounds to packet delay statistics (but in practice: TCP /user experience
- High tolerance to packet delay jitter
- Low tolerance to packet loss rate





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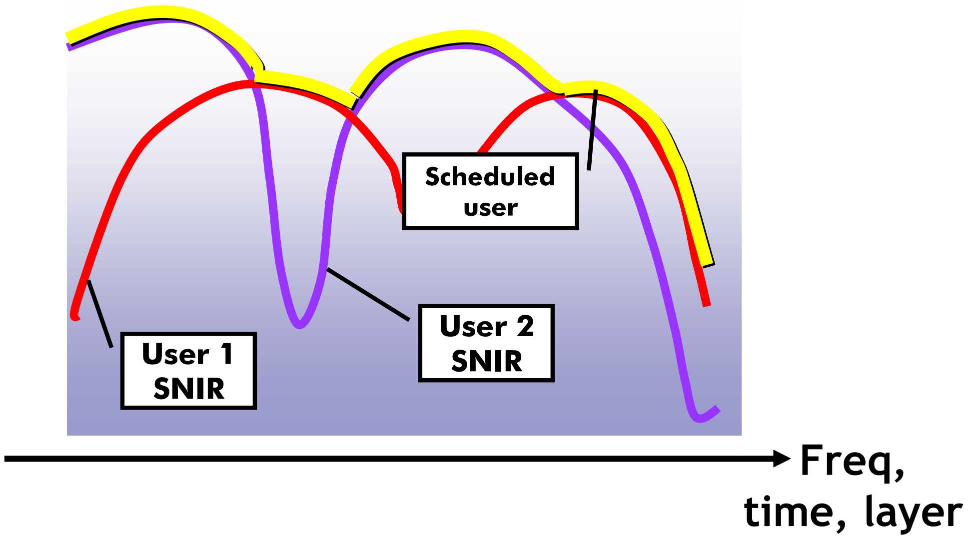
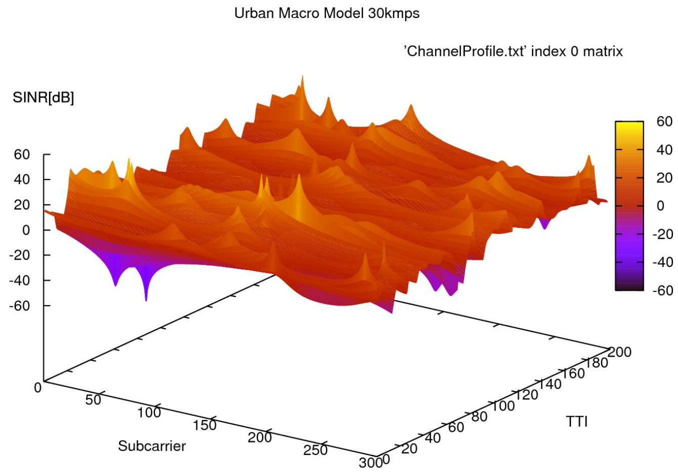
# LTE Characteristics

## Key Principles




Channel-aware dynamic scheduling

- Packet scheduler exploits channel fluctuations in time / frequency / spatial domain
- FDD: feedback of frequency-resolved SINR conditions → Channel quality indicators
- Suitable for best effort / streaming traffic QoS classes



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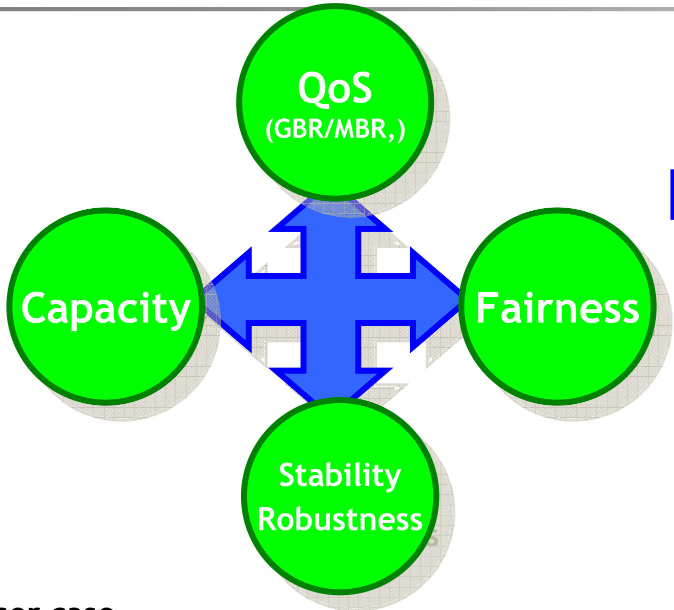
# Gradient-rule for utility based multi-user scheduling




**Formulate multi-criterion objective**

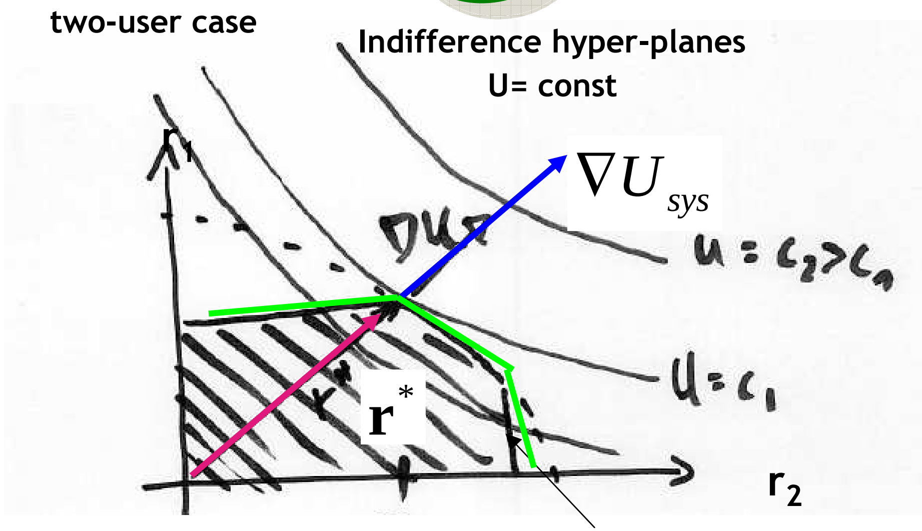
$$\mathbf{U} = \begin{pmatrix} U_1 \\ \vdots \\ U_N \end{pmatrix} \qquad \boldsymbol{\lambda} = \begin{pmatrix} \lambda_1 \\ \vdots \\ \lambda_N \end{pmatrix}$$

**Maximize scalar system utility**

$$U_{sys} = \boldsymbol{\lambda}^{\mathrm{T}} \cdot \mathbf{U}$$

**Gradient-based scheduling policy**

$$\mathbf{r}^* = \arg\max_{\mathbf{r} \in R} \nabla U_{sys} \cdot \mathbf{r}$$



# Gradient-rule for utility based multi-user scheduling

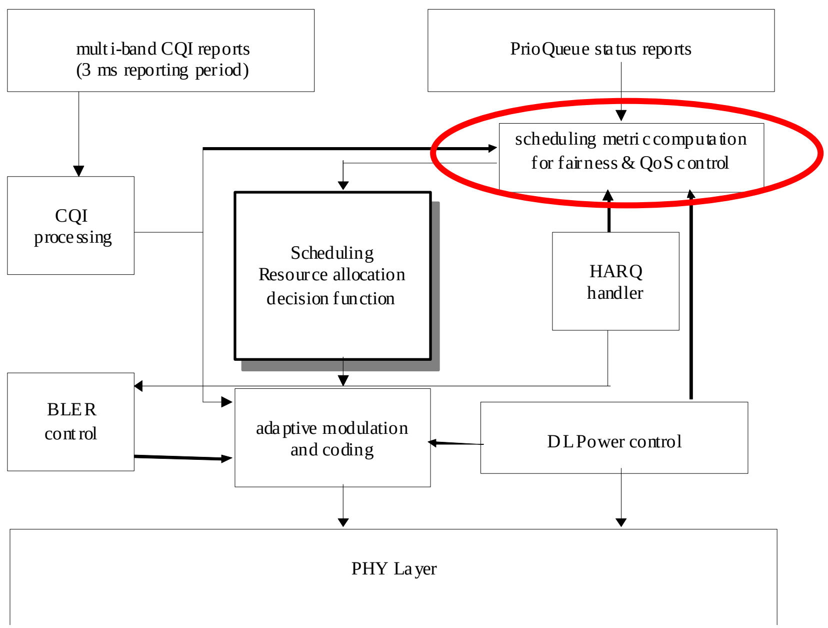
## Extension of 3G (eg.HSPA, EVDO) in definition of utility metrics for fairness and QoS control and extension to OFDMA

- propFair: *maximize* $\Sigma w_i \log(<R_i>)$

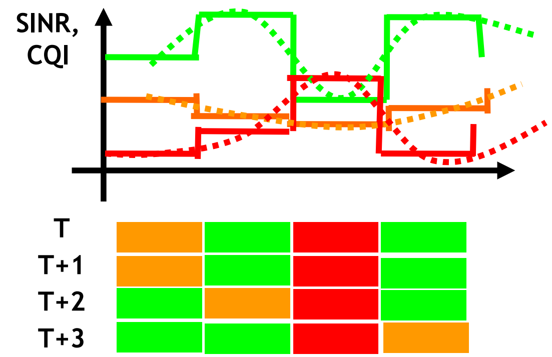
$$\max \sum_{\text{user } i, \text{RU } j} w_i \frac{r_{i,j}(n)}{< R_i > (n)}$$

- propFair with min/max constraints for GBR/MBR BELL LABS INNOVATION (M. Andrews et al., INFOCOM'05)

$$\max \sum_{\text{user } i, \text{RU } j} w_i \frac{r_{ij}(n)}{< R_i (n) >} > e^{a_i T_i (n)}$$




## Extended framework for a new core to implement scheduling policy in OFDMA




MULTIBAND CQI

Adaptive transmission bandwidth + frequency-selective RU allocation





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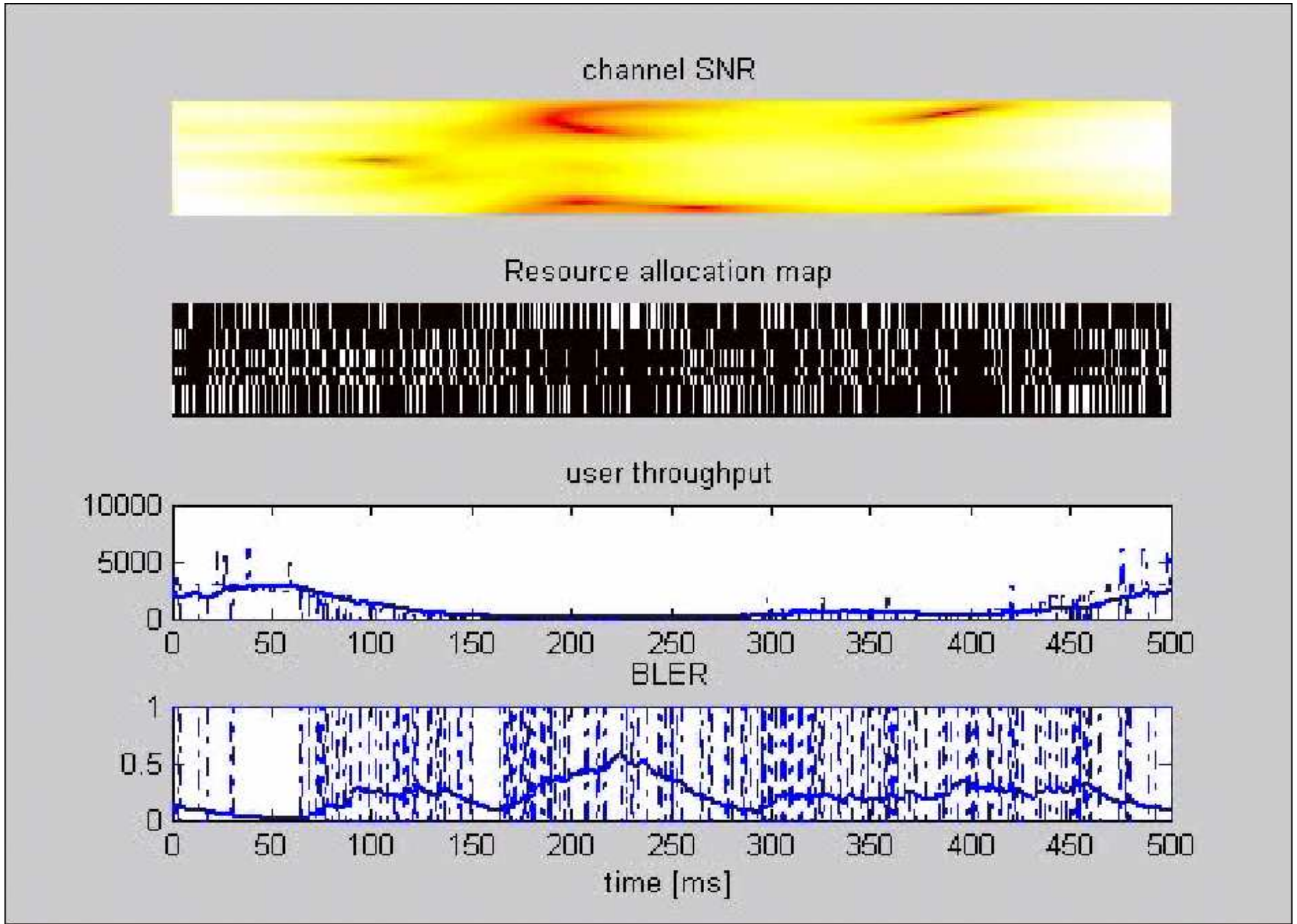
# Impact of different scheduling policies - RoRo




D22_DL_MAC_RoRo_4Ue.avi





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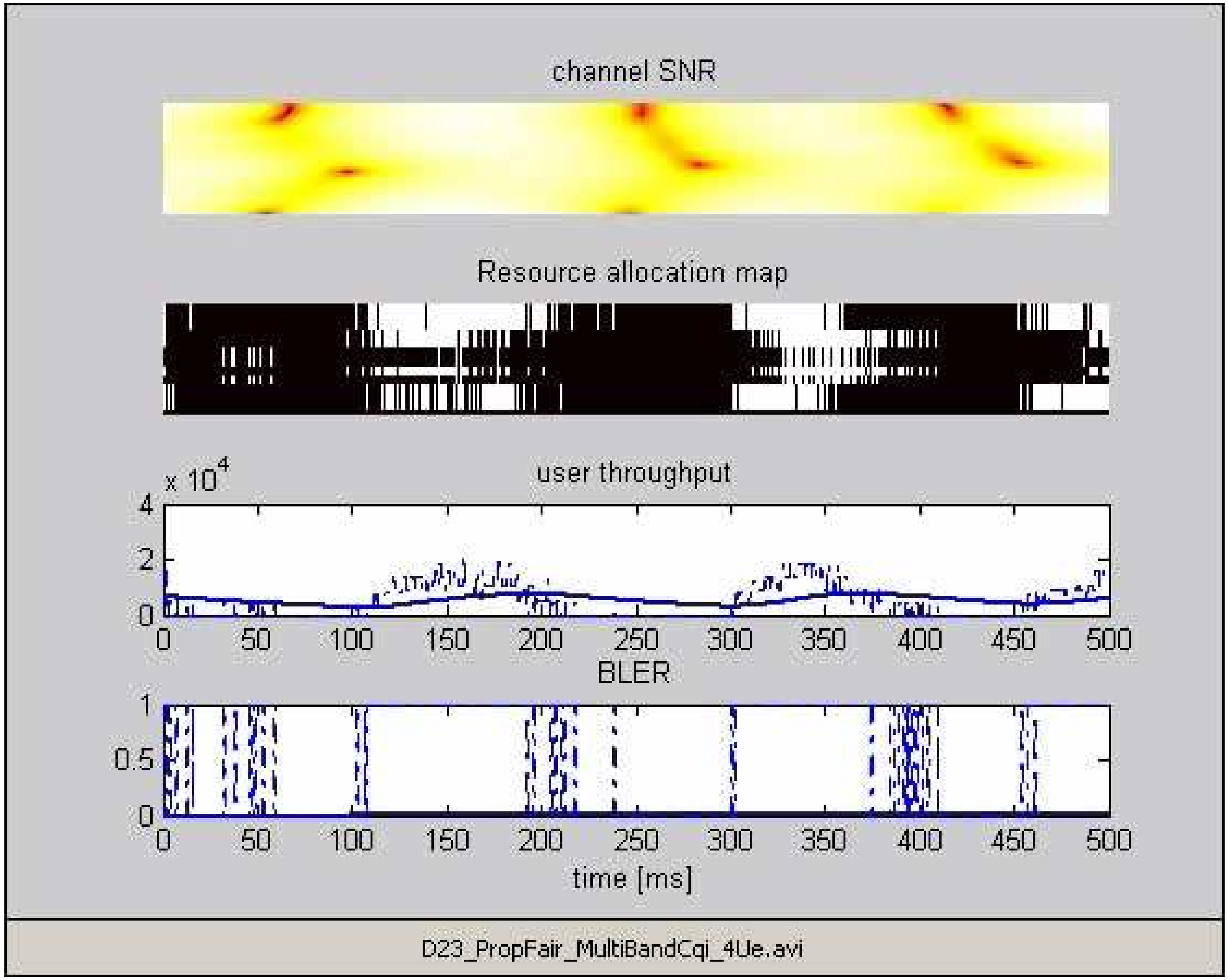
# Impact of different scheduling policies - propFair





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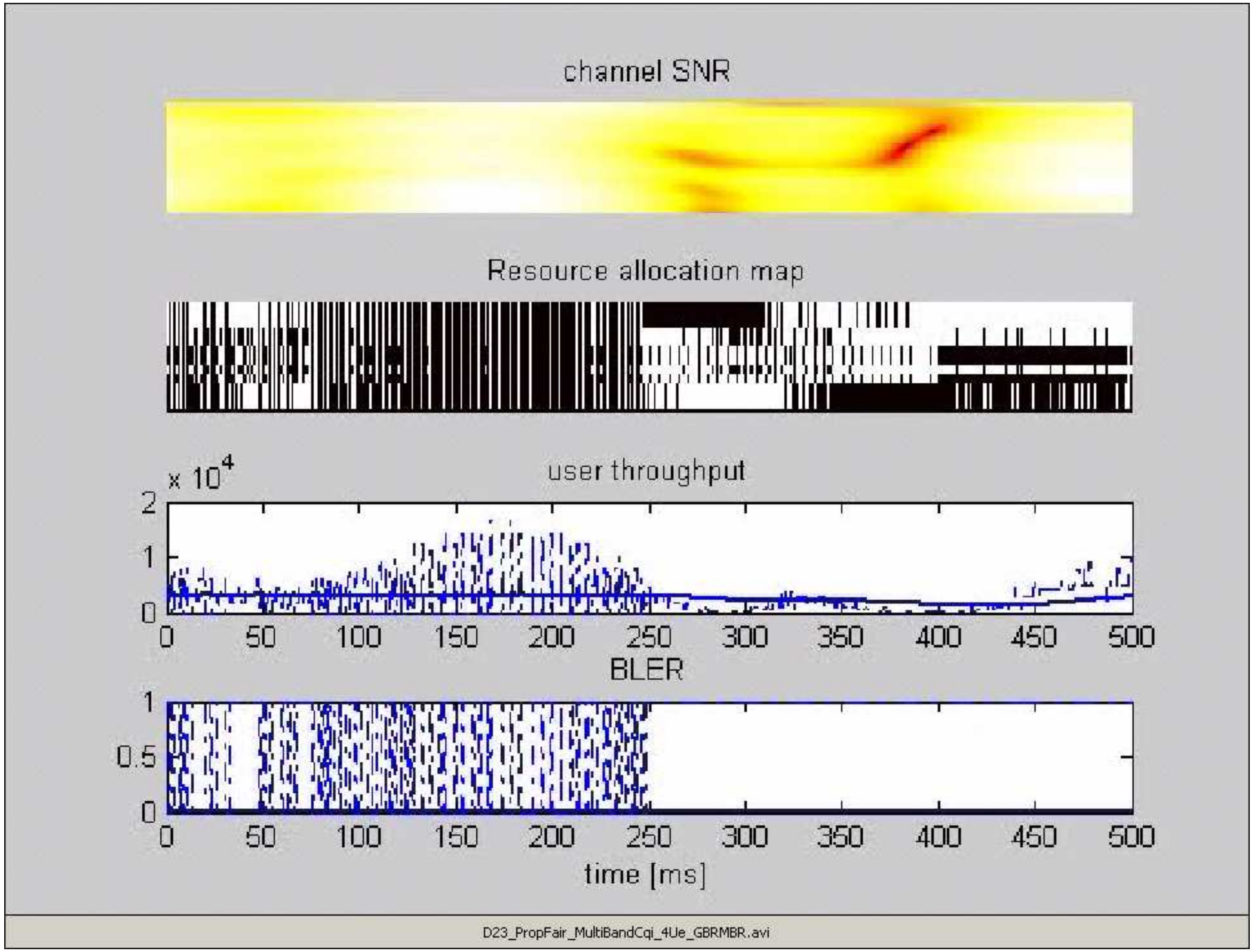
# Impact of different scheduling policies – propFair with GBR/MBR





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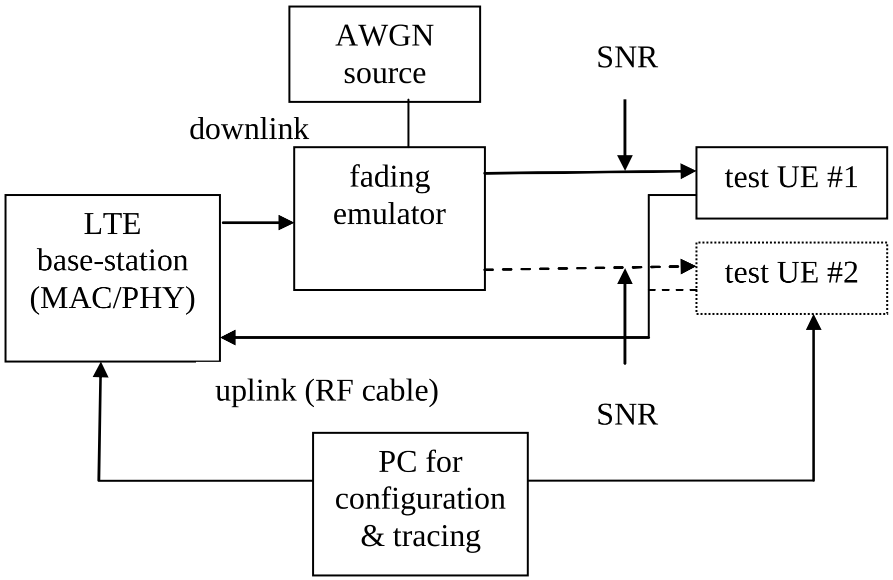
# Experimental setup




| Parameter | Setting |
|---|---|
| System bandwidth / carrier frequency | 10 MHz / 2.1 GHz |
| Antenna configuration | SISO |
| Physical channels | PBCH, SCH, PDCCH, PDSCH, PUCCH |
| Transport channel | DL-SCH |
| Transport formats of PDSCH | QPSK, 16QAM, 64QAM<br>Various Code rates<br>12,24,36,48 physical resource blocks |
| Freq.-selective CQI | 10 samples with 4 bit / 1 MHz resolution<br>3 ms reporting period on PUCCH<br>2 ms FIR averaging filter |
| Hybrid ARQ | Incremental redundancy<br>max number of transmissions 4 |
| Link adaptation | Enabled |
| Traffic source | Full buffer |
| Radio channel profile | Extended pedestrian A |
| UE speed | 3, 7, 10, 15, 20, 30 km/h |
| Scheduling metric | PF and PFMR<br>200 ms averaging time of IIR filter |
| CQI reporting latency | 9 ms |





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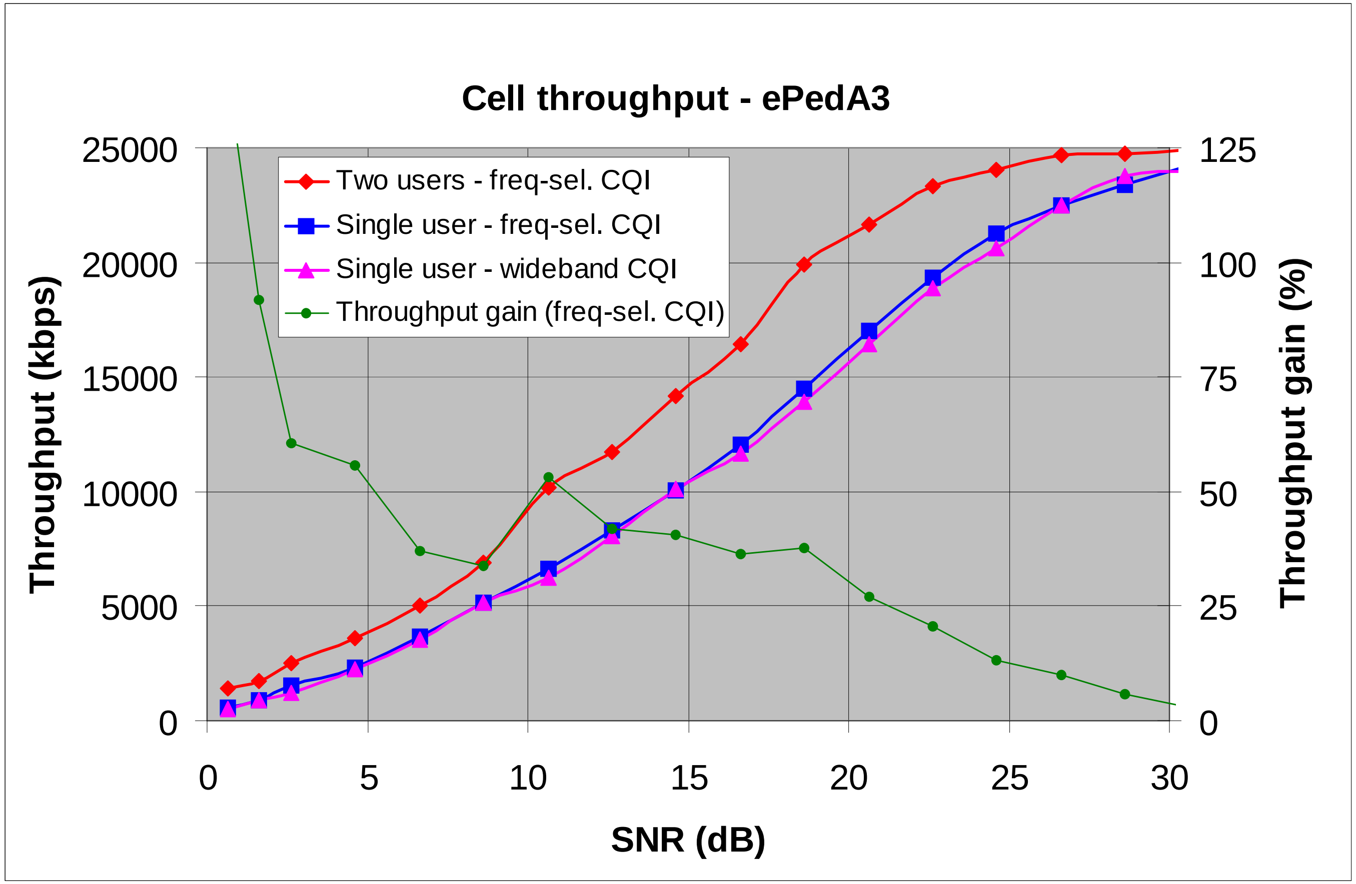
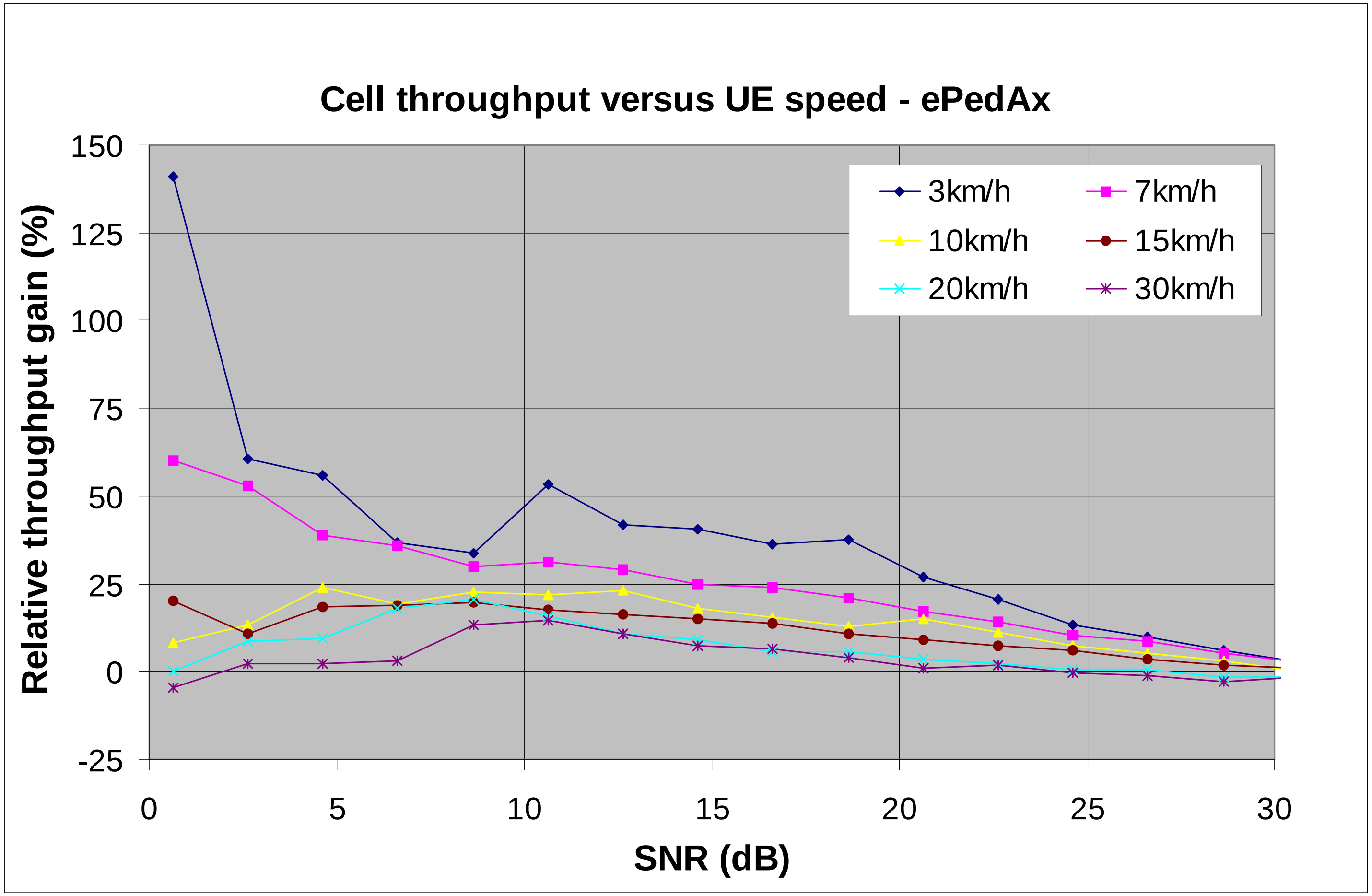
# Scheduling Gain at Low UE Speed




Cell throughput with two users increases over single-user throughput due to frequency-selective scheduling, relative throughput gain increases with decreasing SNR.

# Scheduling Gain versus UE Speed




Gain in cell throughput due to frequency-selective scheduling decreases with increasing UE speed, due to CQI feedback delay.





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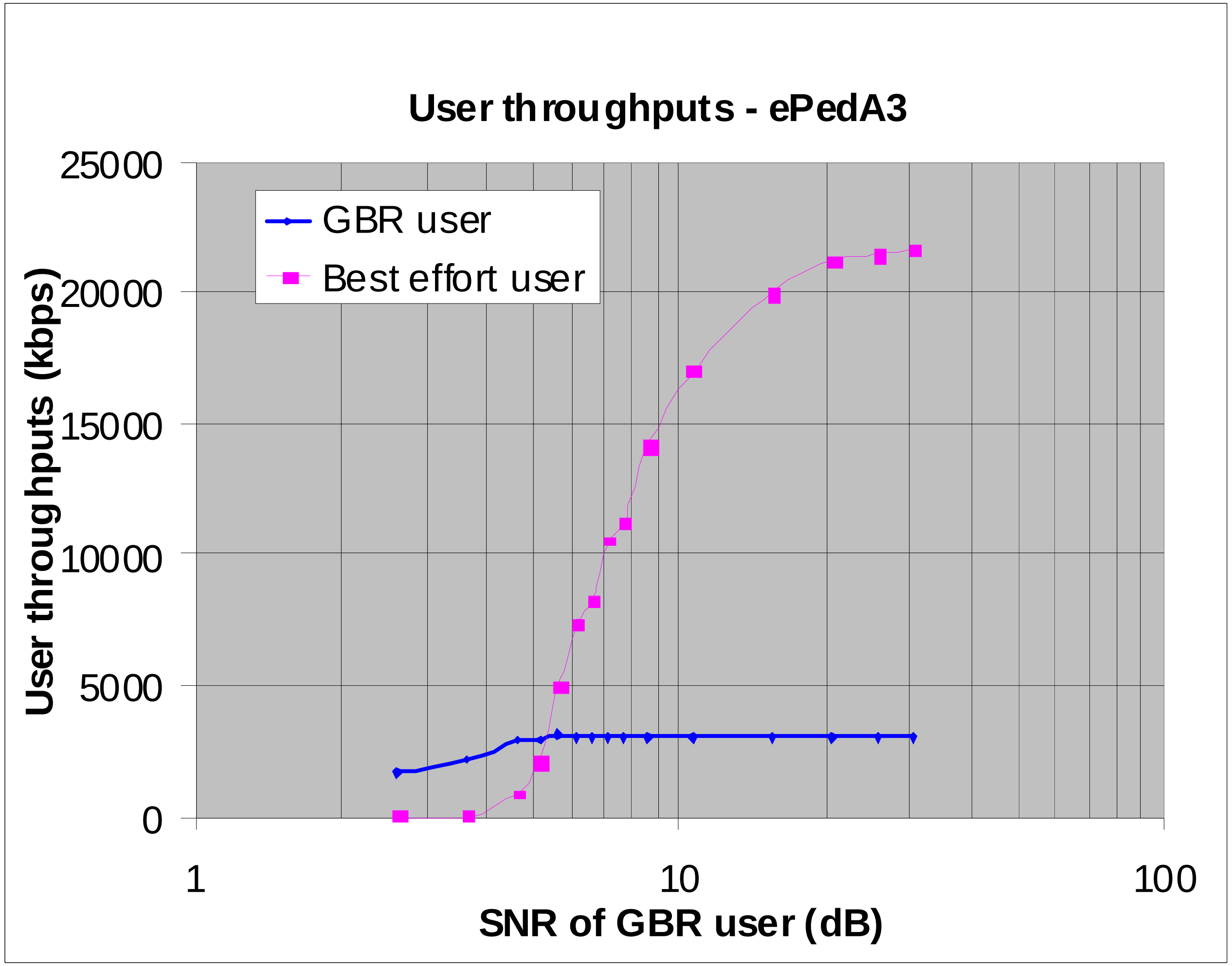
# QoS control: impact of GBR / MBR



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# Key take-aways

- Packet scheduler & dynamic radio resource management is differentiator for optimized LTE DL system performance
- Lab trials show performance gains > 50% of time/frequency selective scheduling with proportional fairness (PF)
- Most efficient for UE at low speed and low / medium SINR
- Demonstration of soft QoS (GBR/MBR) with PF and minimum / maximum rate constraints per user

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