# Future mobile communication systems: Implications on digital implementation

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*6.10.2009*

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## Outline

- Introduction
- Cognitive radio
- Basic resources and efficiency measures
- Signal processing energy and transmitted energy
- Example: Power control and power amplifier
- Conclusions
- References

# INTRODUCTION



## Introduction (1)

- Base stations are usually power-limited (finite power, infinite energy) and terminals are energy-limited (finite energy).
- Handheld devices consume 1–3 W during a call and most of it has been used by the power amplifier (modern batteries have a capacity of 3–5.5 Wh)
- Cognitive radios are intelligent radios whose signal processing requirements will increase and thus **energy efficiency** will be crucial.
- Compare: human brain uses 20 % of the body's energy, but its mass is 2 % of the body's mass.

## Introduction (2)

- In future terminals awareness of the environment will be increased. This implies the use of different sensors such as spectrum sensing in cognitive radios.
- Most complicated parts are usually correlator banks, for example Fourier transform (FFT) or the corresponding filter bank, and channel codec.
- In some applications no battery is available (energy scavenging is used), implying that no complicated signal processing can be used and the bit rates are low.



# COGNITIVE RADIO

## Cognitive radio

- A radio system employing technology that allows the system to obtain **knowledge of its operational and geographical environment**, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained (ITU-R WP1B).



## Example: Spectrum sensor

- **Spectrum sensor** (Rockwell): 30 MHz – 2.5 GHz, 18 GHz/s with 100 kHz resolution, 4.8 GHz/s with 25 kHz resolution, resolution bandwidths up to 200 kHz, power consumption is about 2.5 W.
- Cyclostationary spectrum sensor also includes FFT as a key component.

## Integration levels

- Integration is proceeding from bottom up, from transistors to more complicated systems.
- Energy efficiency is improved if application specific processors are used for the most complicated parts.
- Platforms should include different correlators such as FFTs and channel codecs.
- Standardization should be unified (standard of standards needed).

| |
|---|
| Terminals |
| Correlators |
| Registers |
| Gates |
| Transistors |

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9

# BASIC RESOURCES AND EFFICIENCY MEASURES

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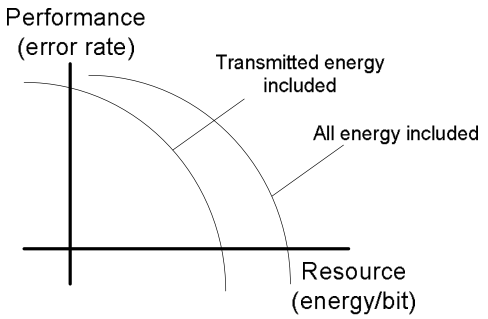
10

## Basic resources

- Basic resources are in general materials and energy, in telecommunications also time (delay) and frequency (bandwidth).
- Energy is usually the most important basic resource and also complexity measure. It can be divided into signal processing energy and transmitted energy.
- Transmitted energy usually dominates at large distances.




11

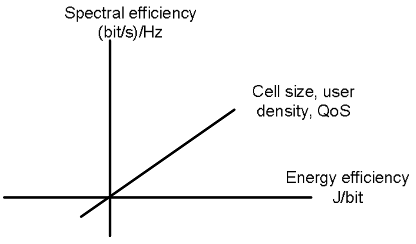
## Efficiency measures

- **Spectral efficiency** is measured in terms of (bit/s)/Hz, averaged over a cell or other given area.
- **Energy efficiency** is measured in terms of J/bit = W/(bit/s), averaged over a cell or other given area and sometimes inverted (bit/J = (bit/s)/W).
- The averages include the bandwidth and energy used for control (pilots, feedback channel). Energy includes all energy used in the system.
- **System level trade-off:** Spectral efficiency is in general decreased when energy efficiency is improved and vice versa (for example M-QAM).

12

## System level trade-offs

- Spectral and energy efficiency are decreased when cell size is increased, user density, e.g., number of users/cell is increased (interference increased), or QoS requirements (error rate, delay) are tightened.

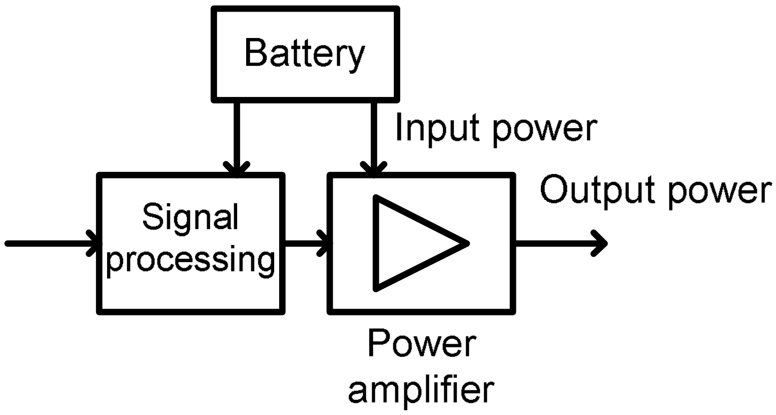





# SIGNAL PROCESSING POWER AND TRANSMITTED POWER

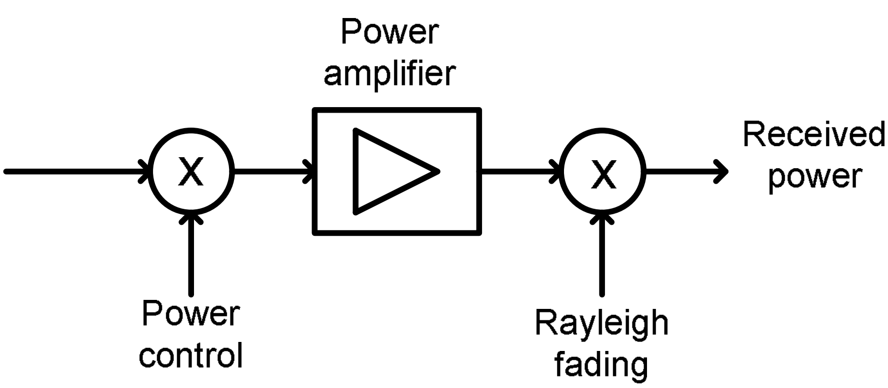
## Signal processing power and transmitted power

Efficiency = Output power/Input power



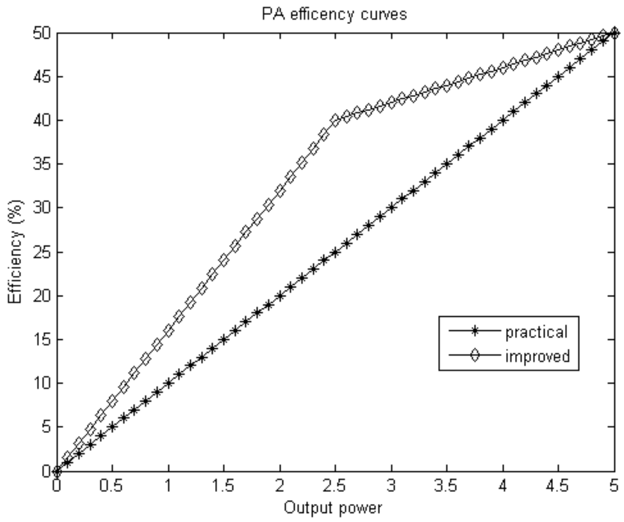

15

## Example: Power control and amplifier (1)



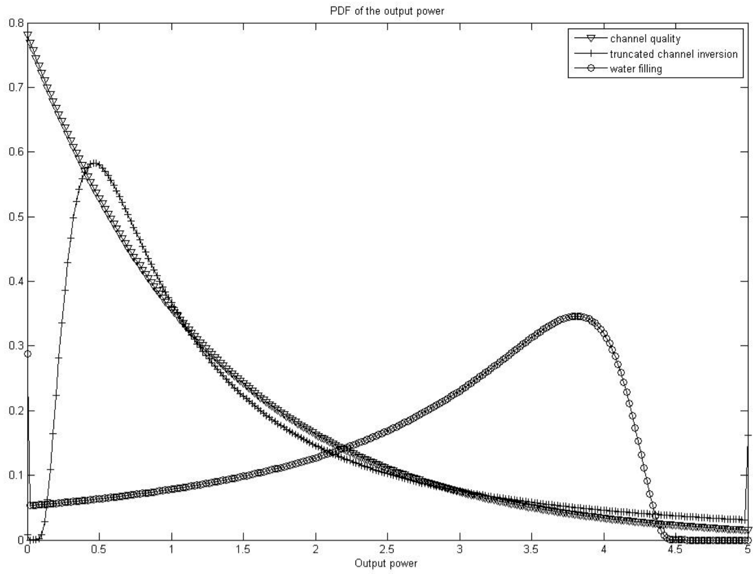

16

## Example: Power control and amplifier (2)

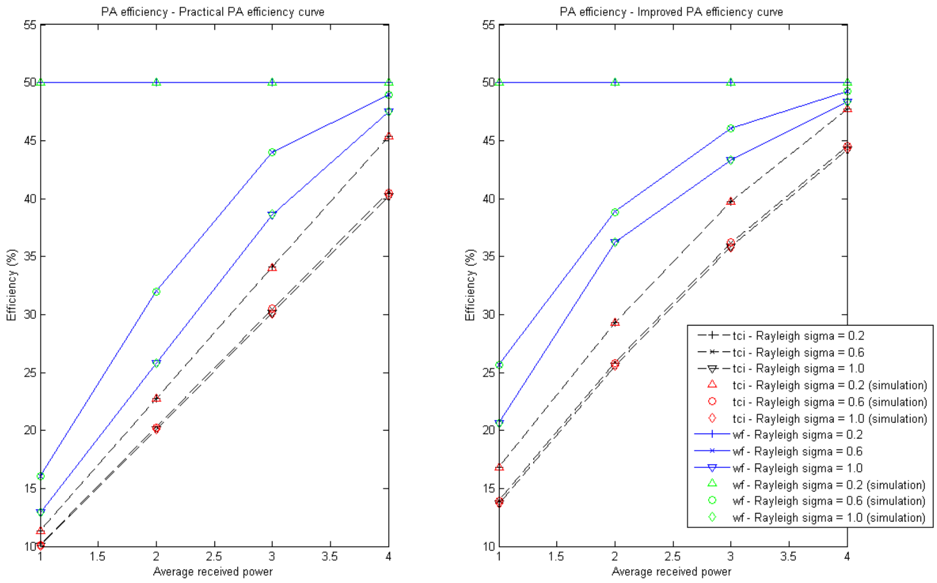



17

## Example: Power control and amplifier (3)



## Example: Power control and amplifier (4)




## Conclusions

- A general trend is that intelligence and awareness about the environment will increase.
- Energy is an essential basic resource, and its consumption tends to increase, but especially in terminals it should be limited to 1-3 W.
- Energy efficiency is crucial, which implies careful selection of algorithms, implementation architecture, and power management.
- A heterogeneous architecture will be needed including special processors for correlators such as FFTs, channel codecs, etc.

20

## References


- C. H. van Berkel, "Multi-core for mobile phones," in *Proc. DATE'09*.
- S. Cui et al., "Energy-constrained modulation optimization," *IEEE Transactions on Wireless Communications*, vol. 4, pp. 2349-2360, September 2005.
- F. Germain et al., "The Cognichip: a flexible, lightweight spectrum monitor," in *Proc. Cognitive Systems with Interactive Sensors 2006, COGIS 2006*, Paris, France, March 15 - 17, 2006.
- A. J. Goldsmith and S. B. Wicker, "Design challenges for energy constrained ad hoc wireless networks," *IEEE Wireless Communications*, vol. 9, pp. 8–27, August 2002.
- S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 25, pp. 201–220, February 2005.
- A. Kotelba, A. Mämmelä, and D. P. Taylor, "Normalization of linear vector channels," in *Proc. GLOBECOM'07*.
- R. Newgard et al., "Broadband spectral sensing for dynamic spectrum allocation", in *Proc. International Symposium on Advanced Radio Technologies*, pp. 137-140, 7-9 March 2006.
- R. V. Prasad et al., "Cognitive functionality in next generation wireless networks: Standardization efforts," *IEEE Communications Magazine*, pp. 72-78, April 2008.


21