# Analysing the Effect of Power Control Algorithms on the Receiver's Computing Resource Consumption

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UPC

# Outline

- Motivation
- Computational Costs
- Model
- Measurements
- Power Control
- Conclusions

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- **Motivation**
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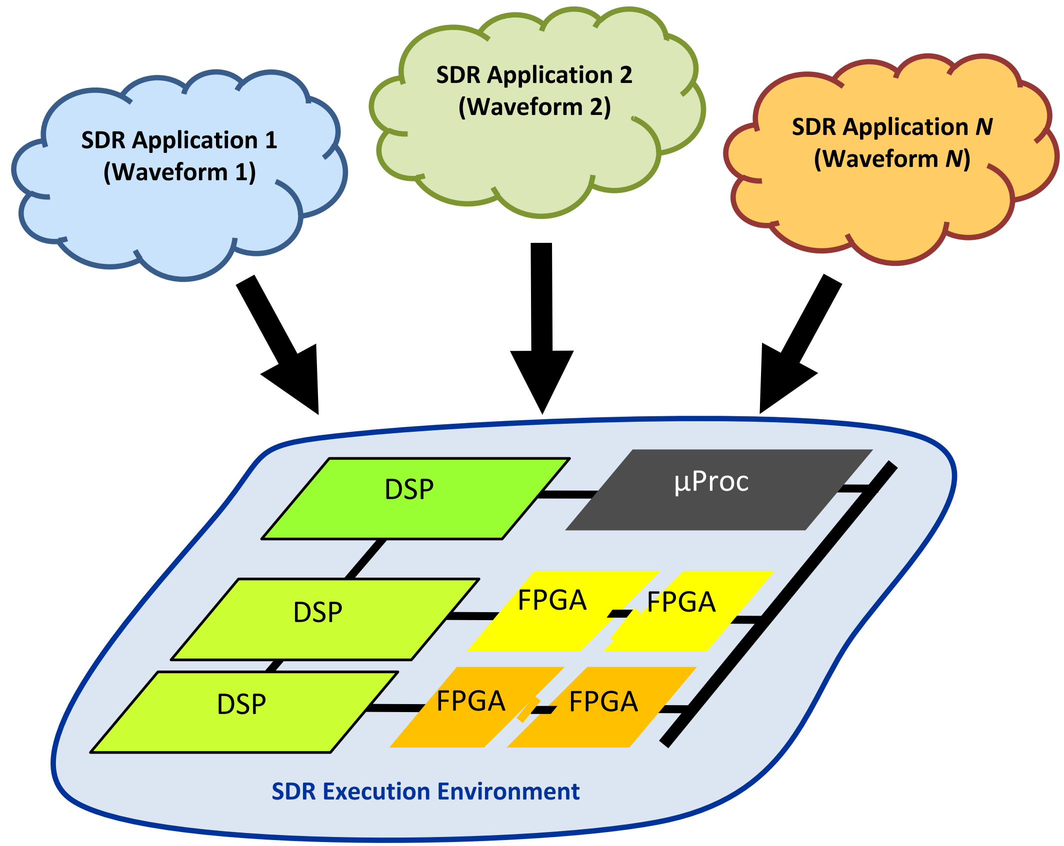
# Motivation 1/4

- **Platform-Independent & Component-Based Design**

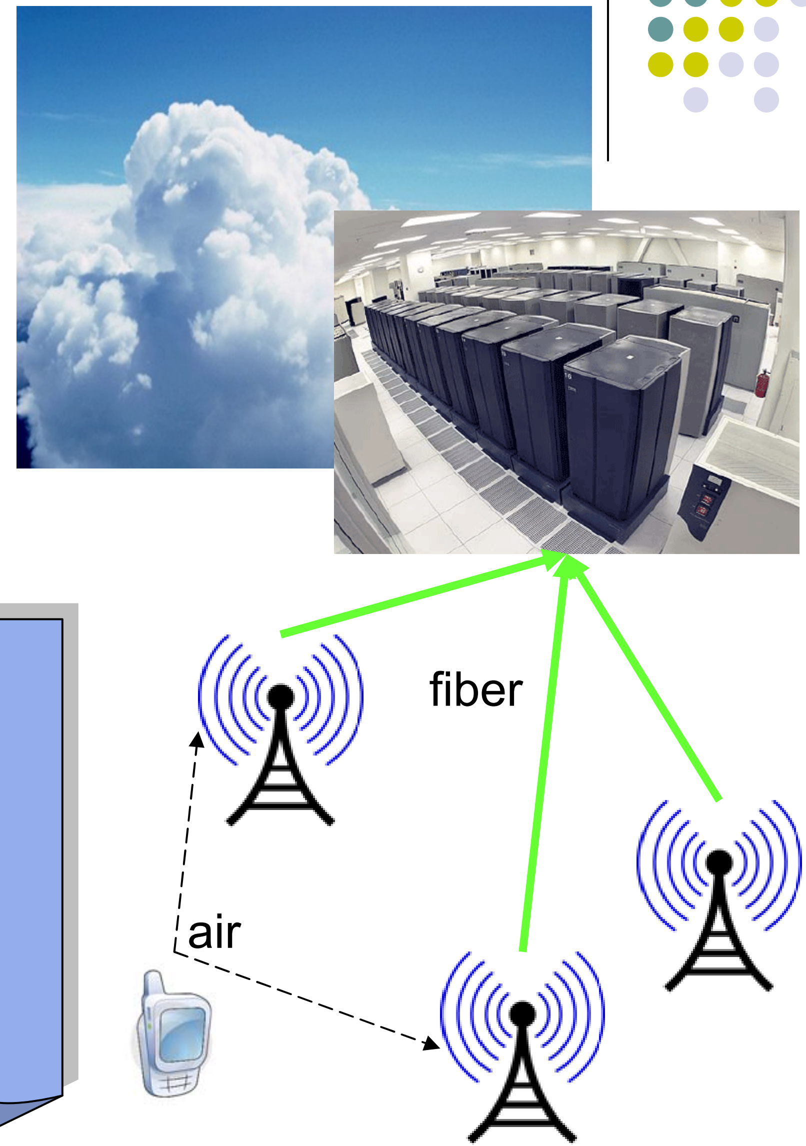
**Well-Known Benefits**

- ✓ Hardware & Software Reuse
- ✓ Low Design Costs
- ✓ Low Time-to-market
- ✓ Risk Shift (Outsourcing)
- ✓ Easy Reconfiguration



# Motivation 2/4

- Wireless Network Cloud
  - Distributed Wireless Processing
- Virtual MIMO




**Future Benefits**

- ✓ Reduces PHY Overhead (BTS cooperation)
- ✓ Enhances MIMO Space Diversity
- ✓ Economy of Scale Benefits (in the Cloud)
- ✓ Increases Processing Energy Efficiency
- ✓ Lower BTS costs, faster upgrades
- ✓ New markets: Infrastructure & Network

# Motivation 3/4

BUT!!

| Obstacles | | Solutions |
|---|---|---|
| Low efficiency of Platform-Independent implementations | ➡ | Design the same component for different instruction sets |
| Management overhead | ➡ | Use simple and specific middleware |
| Real-Time requirements but unknown platform capacity | ➡ | **Need Computing Resource Management for distributed processing** |
| Computational demands difficult to characterize | ➡ | **Need a model!!** |

# Motivation 4/4

- **Recap**: Why do we need Computing Resource Management?

1. Network operator pays for the utilization of computing resources (Wireless Cloud)

2. Several flows (from different users) share the same resources

3. Platform-independent design

1. Over-the-air upgrades may require more resources than available

2. Decode & Forward relay needs processing capacity

3. Processor power consumption

4. Platform-independent

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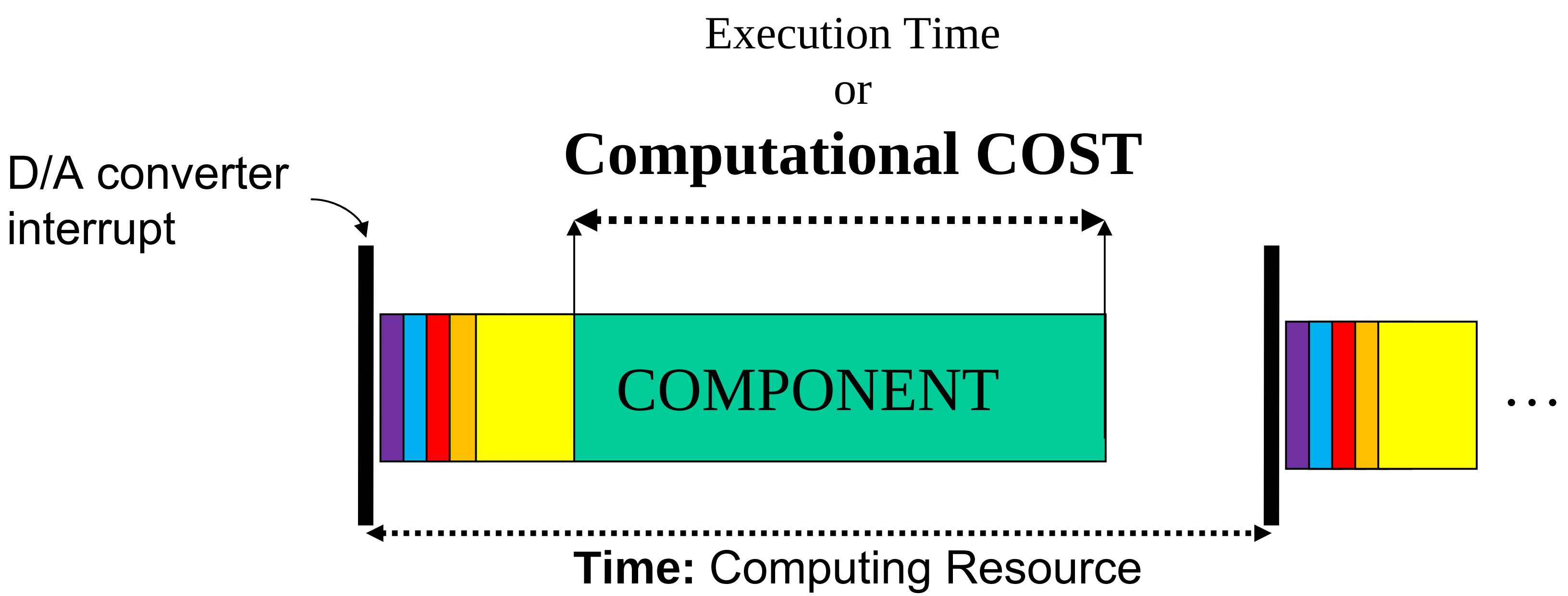
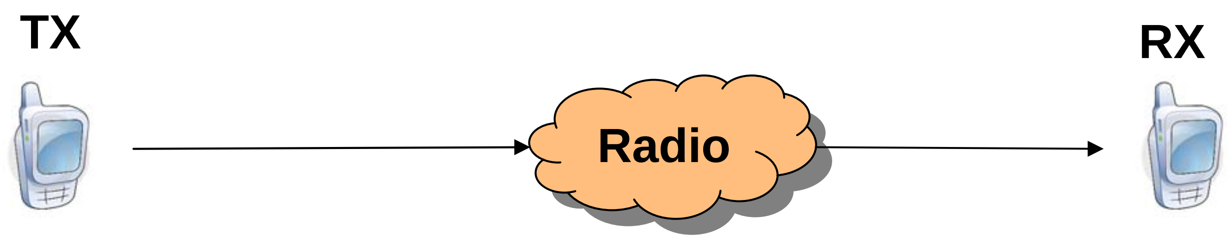
# Computational Costs 1/5

- An essential requirement of CRM is *a priori* knowledge of the execution time



# Computational Costs 2/5

The transmission of a data frame has
**“a cost”** in terms of ***Resources***




**Resources:**
*RF Power* (very high)
*Computing* (low)

**Resources:**
*Power*
*Frequency*
*Space*
*Time*

**Resources:**
*RF Power (low)*
*Computing (very high)*

*“The computing resource depends on modulation and coding complexity and QoS”*

# Computational Costs 3/5

The transmission of a data frame has
**“a cost”** in terms of ***Resources***

- **Optimization problem**:
  - Find the set of signal parameters (bandwidth, transmitter power, modulation, coding, etc.) such that achieves user QoS requirements using minimum **Radio Resources**

# Computational Costs 4/5

The transmission of a data frame has
**“a cost”** in terms of ***Resources***

- Problems **at the receiver**:
  - In SDR equipment, the computational resources at the receiver can be scarce.
  - The optimization problem does not include **Computational Resources**
- Examples:
  - A terminal with low battery
  - Too much users in the BTS
  - Or even… a service where the users pays as a function of the computational costs at the BTS (Cloud)

# Computational Costs 5/5

- **Recap**: We need to know the computational costs *a priori*.
- It depends on the modulation and coding complexity
- It depends on the user QoS (bandwidth, throughput)
- **It depends on received power!** (iterative receiver)

Then…

"How can we predict the computational costs for **any** received power or SNR?"

…….. we need a **computing usage model!**

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# Model 1/2

Complexity in iterative receivers is a function of the SNR and target BER

$$C_{P_b}(\gamma) = C_0 + C_{iter} NOI_{P_b}(\gamma)$$

$C_0$: Complexity independent of SNR or $P_{b,}$ ,but can be a function of the modulation, bandwidth, etc. (r.v. with non-zero mean)

$C_{iter}$: Complexity per iteration (constant)

NOI: Number of iterations

Units can be seconds or, more generally, "operations"

# Model 2/2

$$NOI_{P_b}(\gamma) = N_{\max} - \left(N_{\max} - N_{\min}\right) f_{P_b}(\gamma) + z$$

$$f_{P_b}(\gamma) = \left(1 + e^{-\alpha(\gamma - \gamma_0)}\right)^{-1}$$

$N_{max}$: Maximum number of iterations

$N_{min}$: Minimum number of iterations

z: zero-mean r.v.

$f_{Pb}(\gamma)$: For a target BER, a complementary sigmoid-like function models the decoder behavior (experimental, but difficult to derive analytically from EXIT charts).

$\gamma_0$: SNR level where the decoder starts to converge

$\alpha$: Indicates how fast the decoder converges

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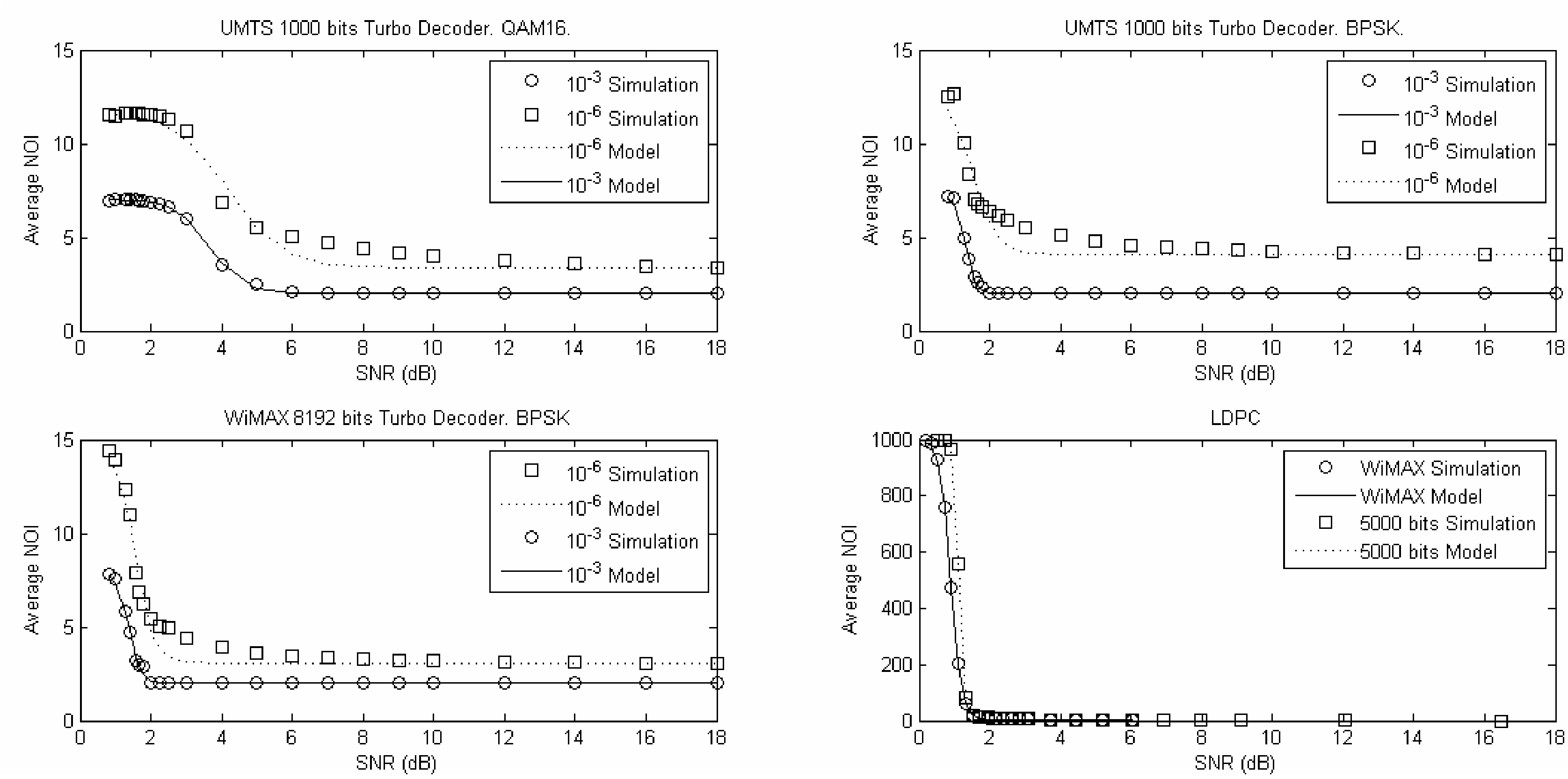
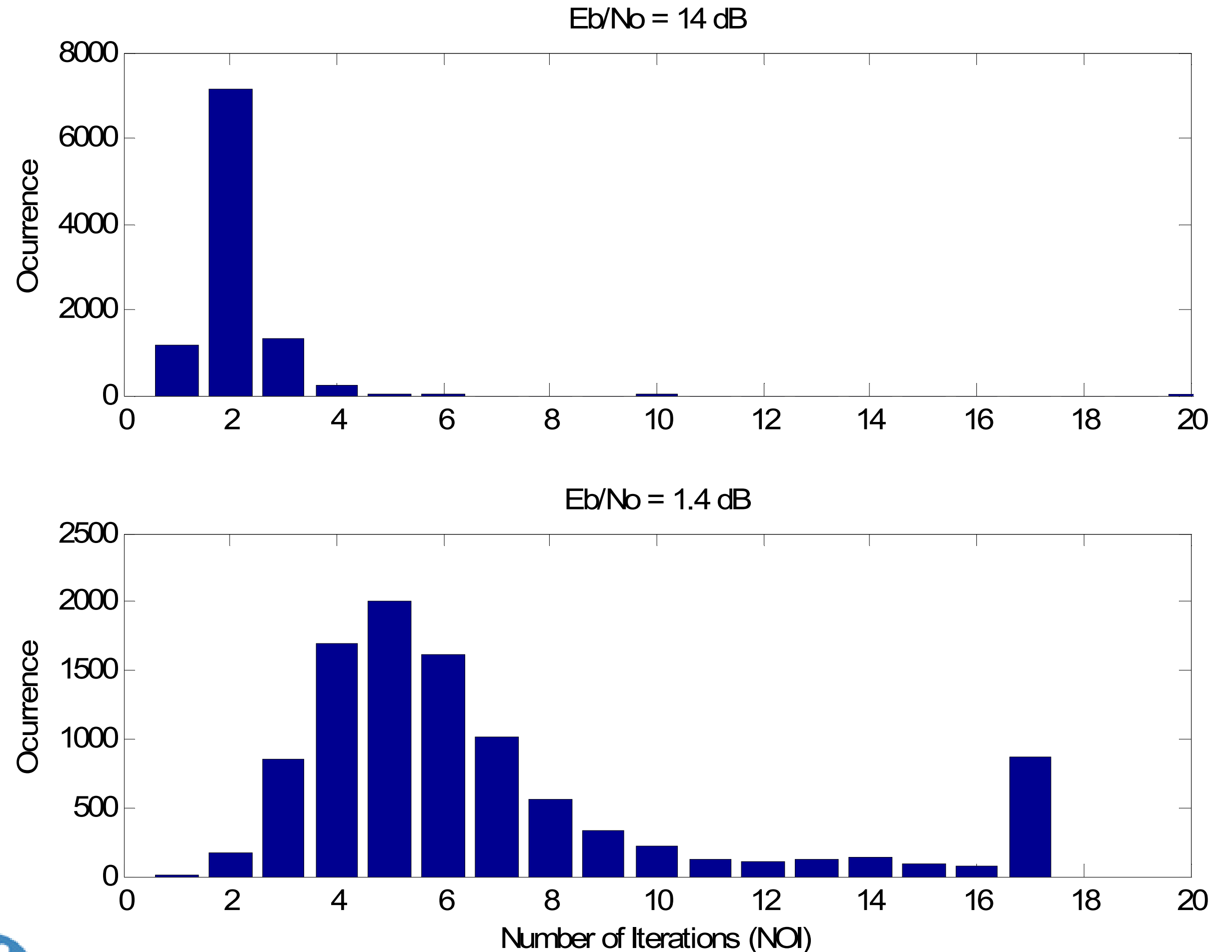
# Measurements 1/3

- NOI model fitting for various decoders...



# Measurements 2/3

- Random effect in the NOI



# Measurements 3/3

- Offset measurements

**UMTS bit level receiver computational costs**

| | 64 kbps | 144 kbps | 384 kbps |
|---|---|---|---|
| $C_0$ (µs/bit) | 0.25 | 0.28 | 0.39 |

**WiMAX bit and symbol level receiver costs**

| | BPSK | QPSK | 16QAM ½ | 16QAM ¾ | 64 QAM ¼ | 64 QAM ¾ |
|---|---|---|---|---|---|---|
| $C_0$ (µs/bit) | 10.3 | 17.6 | 25.8 | 27.6 | 28.0 | 44.2 |

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# Power Control 1/3

- CDMA with perfect power control
  - No fading
    - Constant CIR. Get NOI from the model
  - With fading
    - Take the fading *pdf* and project into the model

- (O)FDMA/TDMA
  - Low-SNR users are more *expensive* for BTS.
  - What if high-SNR users pay less for the service?

# Power Control 2/3

- Cognitive Radio
  - Power control assumes ML decoding and finds optimal CIR for each user, with the constraint of PU QoS.
  - Let us define CIR target for PU & SU slightly higher. This decreases decoders NOI.
  - Now, the SU could pay and extra fee to the PU if it wants to transmit at higher power this means higher NOI for the PU.
  - The model is useful for pricing and to know receiver limitations with just a few parameters

# Power Control 3/3

- Ad-hoc networks
  - Peer-to-peer power negotiation: who is going to *pay the transmission*, the tx or the rx?
  - Relay and power selection: which relay is more capable to work at some SNR? How expensive it is for him? Can he afford it? And I?

- Other scenarios
  - Search & rescue team [1]: A user lost is lost in the mountain. The SAR team tries to communicate with him. They will transmit at the highest power such that NOI at the receiver is low, saving battery.

[1] Chia-han Lee, et al., “Energy/Power estimation for LDPC decoders in software radio systems,” *SPSDI 2005,* pp. 48-53, 2005

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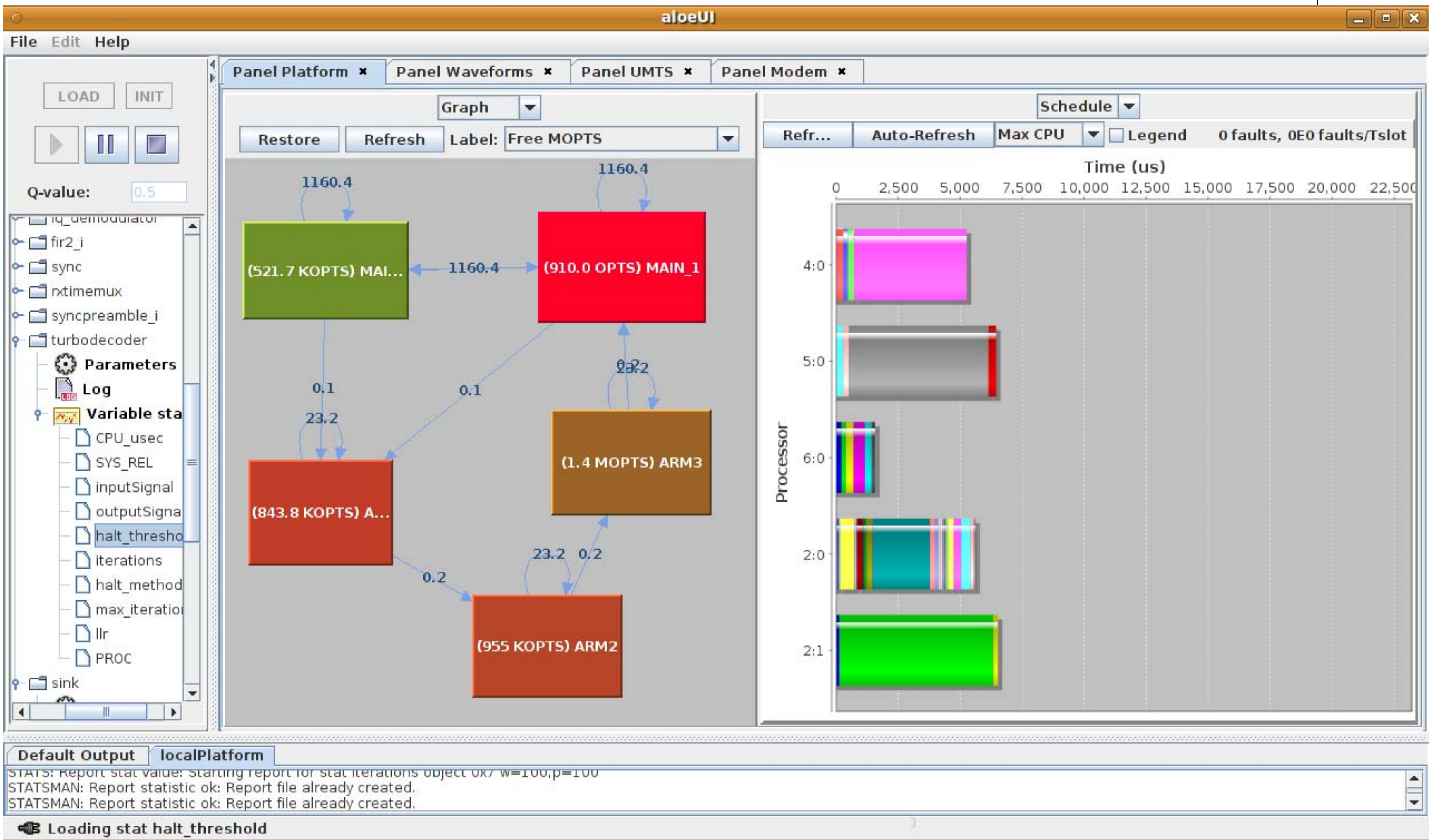
# Conclusions

- Overall system efficiency can be increased by accounting for the receiver's computational complexity
- The model is **simple** and can be integrated in power-control and power selection algorithms
- With only **4 parameters** we characterize the whole SNR range (low control overhead)
- It is essential for Wireless Cloud Network and platform-independent designs

- **Future work**:
  - Analyze RRM strategies with receiver computational cost
  - Analyze decoder iterations *pdf* for different channels
  - Decoder performance degradation when resources are limited
  - Extend the model to other decoders and joint iterative decoding, estimation and detection

# Demo – This Evening



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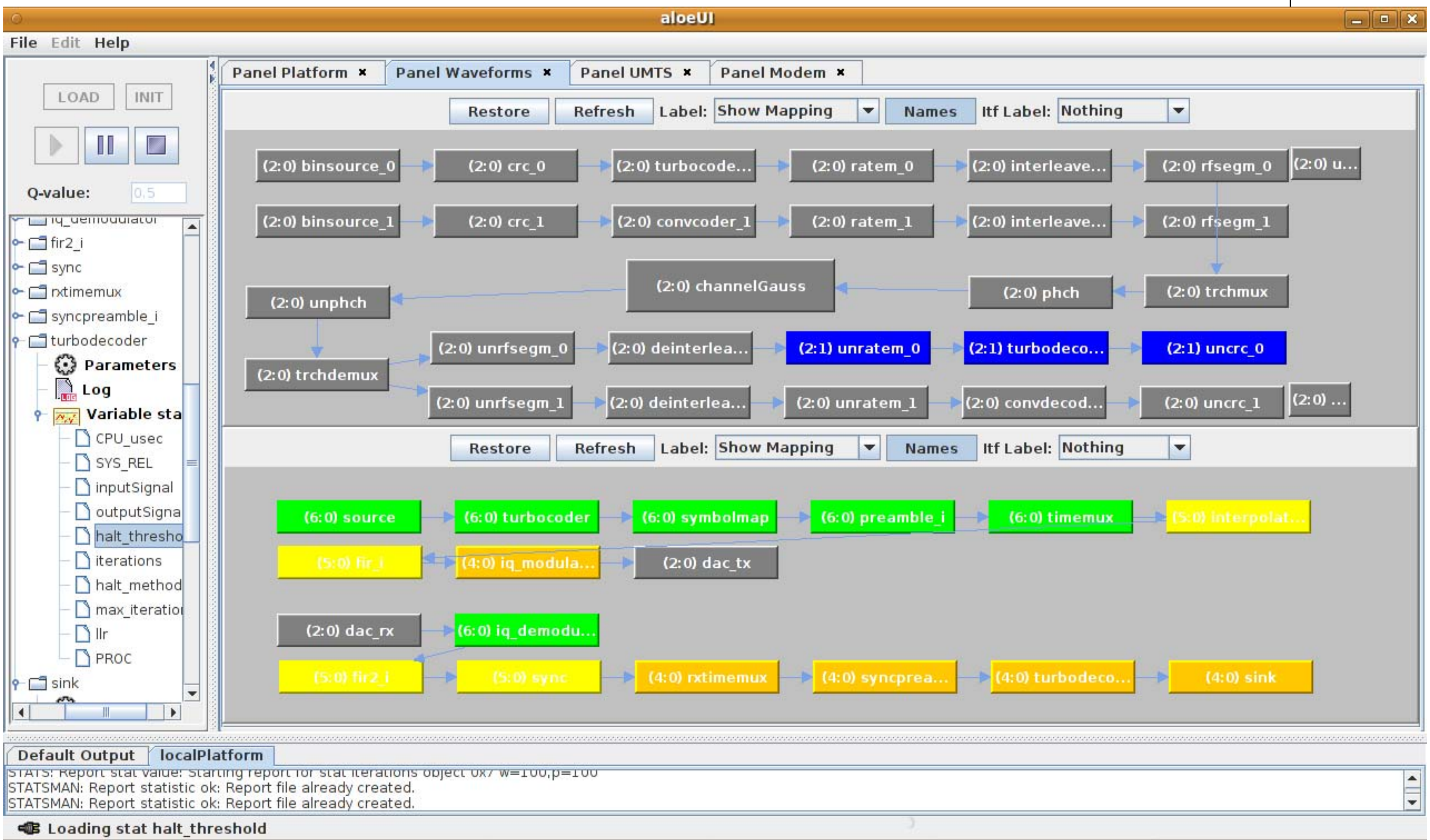

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# Thank You!

# Questions?

Visit us @ http://flexnets.upc.edu

(ALOE open source middleware downloads, doc, papers, etc.)

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