Flexible-Radio: a PHY-layer constrained-optimization perspective

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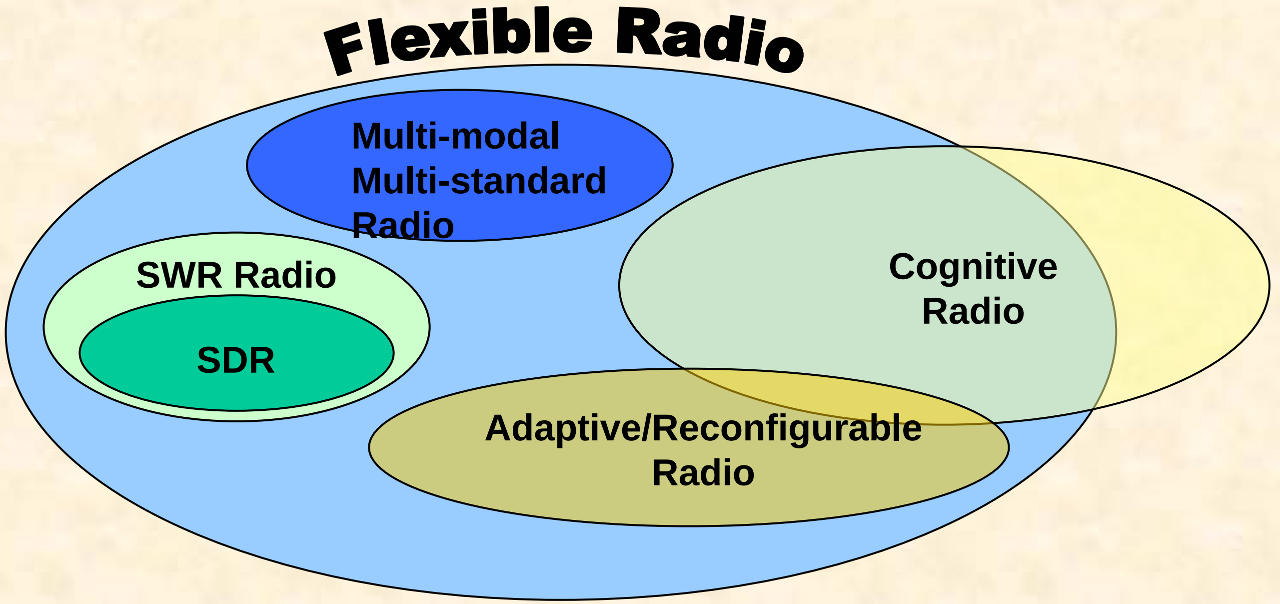
Outline

- **Background**
- **FR Goals and Definitions**
- **Flexibility in an investment viewpoint**
- **Example of a broadly scoped optimizing module**
- **Summary**

Background



- ***Flexible Radios*** (FR) is a fairly recent field of scientific inquiry in the commercial and non-military arena (the subject has existed in the military sector for some time under related names; see Software Defined Radio—SDR, JTRS (http://jtrs.army.mil), etc.)
- Related concepts:
  - Adaptive and/or Reconfigurable radio[1] (reconfiguration via HW, SW, or both)
  - Cognitive (intelligent, smart) radio, opportunistic radio[2]

…………..Notes……………………………………………………………………………………

1. multi-mode (band/standard) radios with parallel chains have existed for some time; "first-generation" flexible radios
2. see COMSOC's new Technical Sub-Committee for Cognitive Networks, plus http://www.ieee-dyspan.com/

Why FR?

Motivators for radio flexibility:

1. Enabling multi-modality and upgrades
   - multi-modal (= multi-band, multi-standard) operation
   - legacy-proofness ("backward compatibility")
   - future-proofness ("easy upgrades"), i.e., to ease introduction of new services and applications without major new-appliance cost, or "pre-standard" releases, etc.
2. Enabling optimization at run time
   - optimized performance as a function of the "operational scenario" =conditions + environment (users' applications/services, infrastructure, channels)
   - potential mixing of multiple available "channels" for the same service
3. Robustness and multi-functionality
   - guaranteed QoS & user satisfaction of various metrics
   - robustness to local channel perturbations & HW malfunctions
   - handling multiple and disparate scenarios with a single architecture ("wide applicability")

Definitions

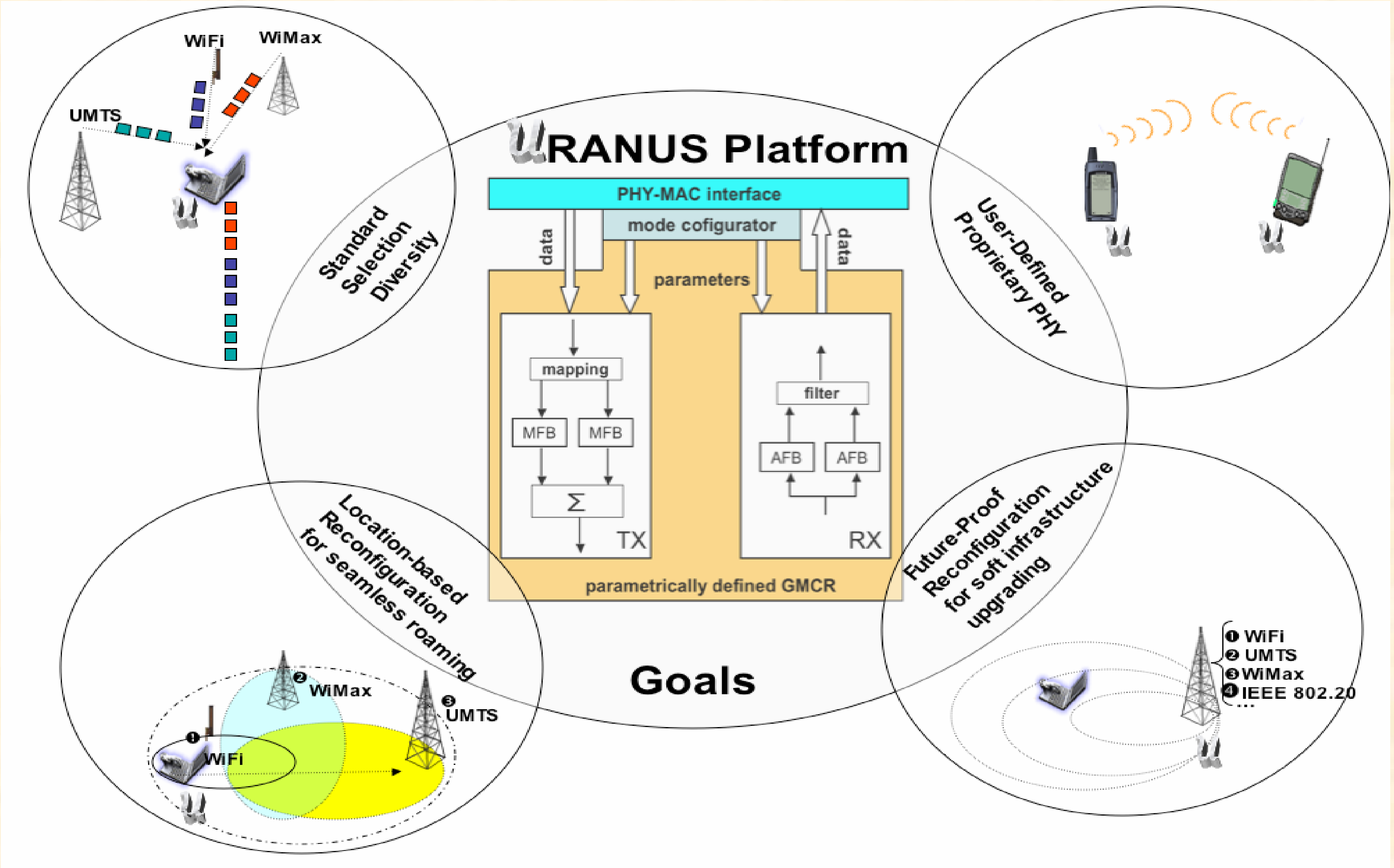
• A system is ***adaptive*** if it can respond to environment changes by properly altering the numerical value of a set of parameters (adjustment to "small" changes)

• It is ***reconfigurable*** if it can be rearranged, at a structural or architectural level, by a non-quantifiable change in its configuration (adjustment to "large" changes)

•It is ***dynamic*** if it is *adaptive* and/or *reconfigurable* in real-time, based on run-time measurements and resulting actions (e.g., cognitive radio is such)

Flexibility may be defined as an "umbrella" concept, encompassing a set of features or attributes, such as ***adaptivity, reconfigurability, dynamism, modularity, scalability***, ***seamlessness, ease of use, ease of re-design, wide applicability***, etc., such that the presence of any subset of those would suffice to attribute the qualifying term flexible to any particular system under consideration.

Ex: Scenarios in need of radio flexibility



IST Project URANUS no. IST-027960

http://wireless.phys.uoa.gr/index.html

Flexibility metrics and cost

Metrics

- QoS (bit rate, bit-error rate, latency), relation to applications plane
- transmission-power efficiency (interference, health)
- processing-power efficiency via environment-aware processing
- time-to-market (not for the first round of design!)
- upgradeability
- number of accommodated standards/modes
- breadth of supported scenarios ("wide applicability"), either for the same system (e.g., channel conditions) or different systems

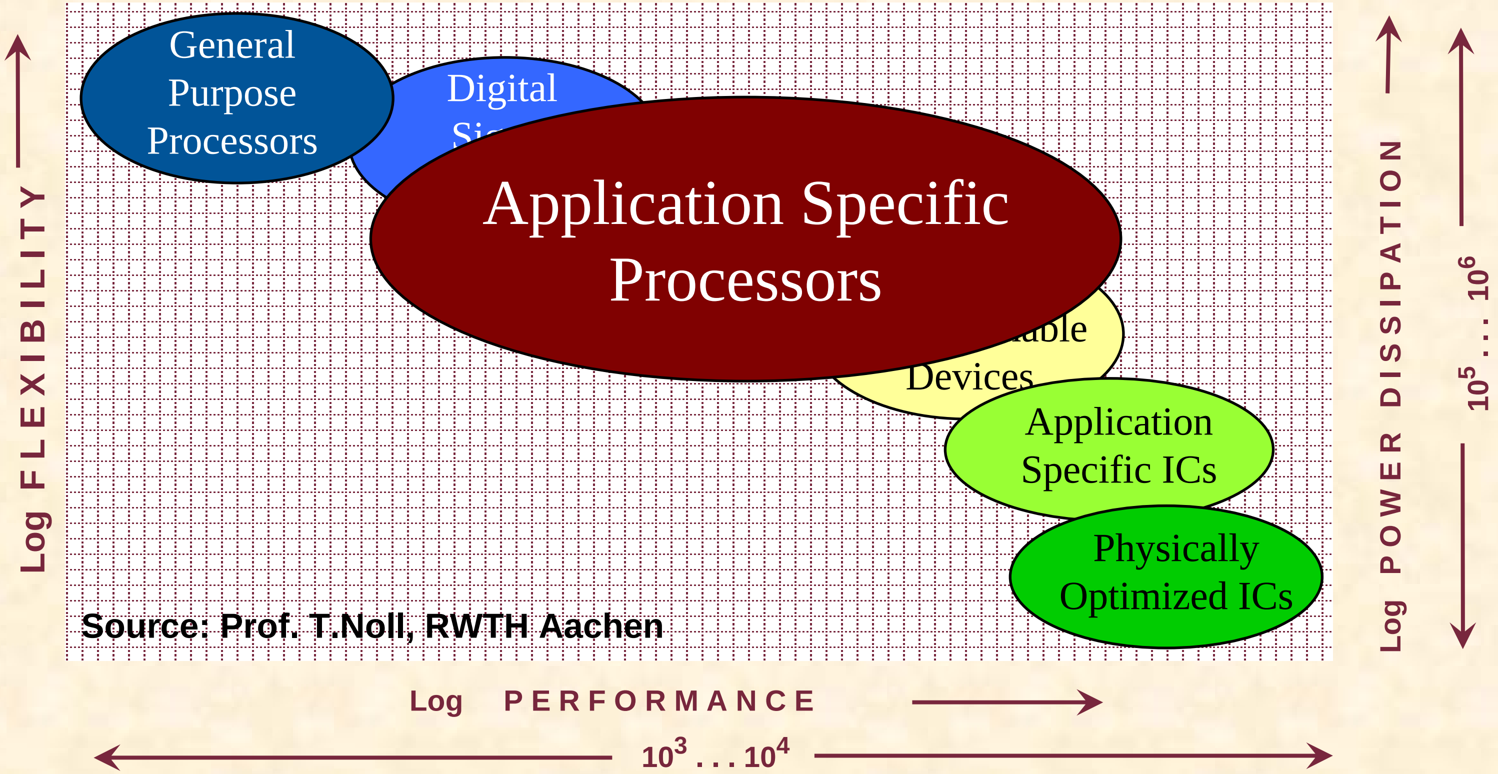
Cost of flexibility

- reduced power efficiency when more power-hungry processors are used
- size & silicon area used, final cost
- reduced performance versus point-optimal solutions to gain applicability breadth

Bottom line: Radio Flexibility offers various trade-offs and possesses all the attributes of an investment: short-term cost for long-term benefit

Flexibility trade-offs at the platform level: Application Specific Processors (ASIP)

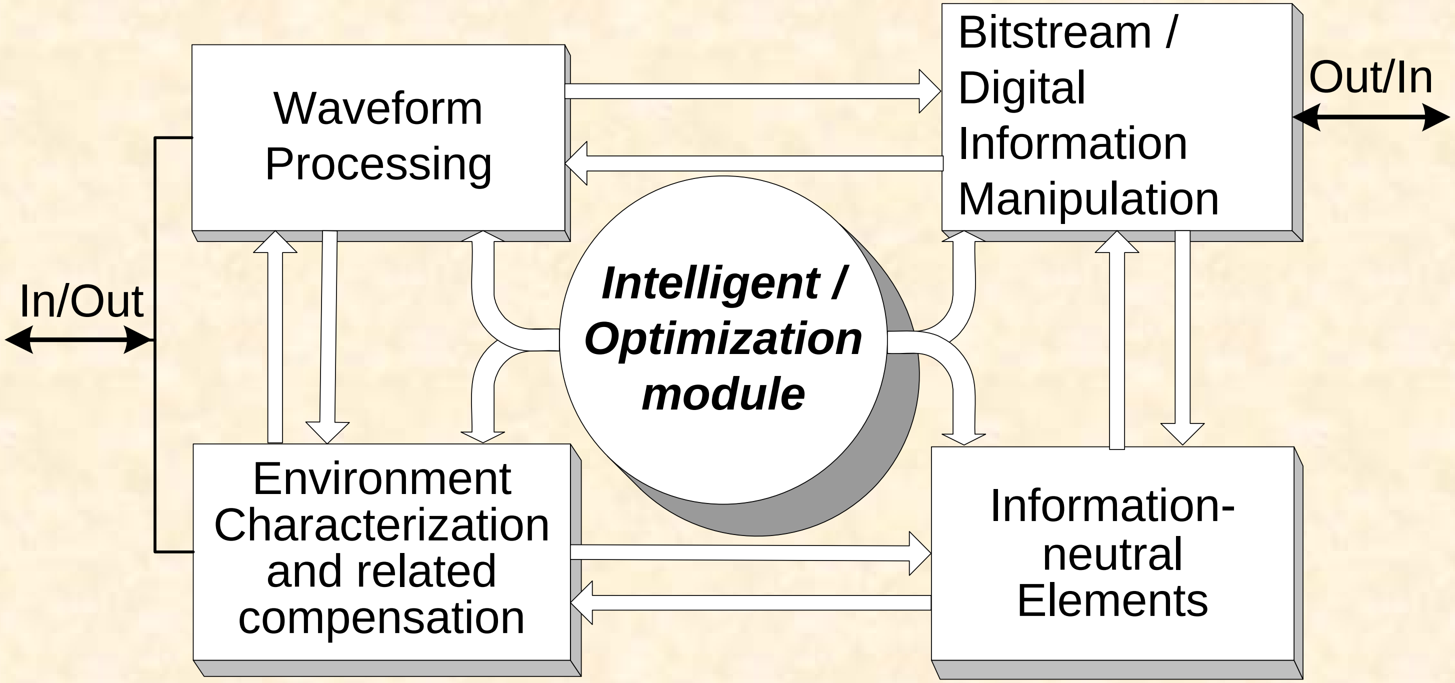
- **Compromise between**
  - ↓ **Flexibility**
  - ↑ **Energy-efficiency and throughput**



Flexibility trade-offs at the baseband portion of the PHY layer

- The "flex" investment trade-offs are fairly clear at the platform/tool level
- Question: are there similar trade-offs that can be quantified at the level of the various functional blocks comprising the PHY layer?
- Fact: There are way too many options and "tunable" parameters in the model of a modern transceiver.
- First step: itemize all the elements ("functional blocks") in the standard makeup of a transceiver's baseband portion, and then proceed to identify further the points amenable to flexible adjustments.
- One potential end goal (among many): a flexible and efficient algorithmic architecture for the optimizing module (the "supervisor").

Generic FR framework: TRx functional blocks



Note: all these functional blocks are amenable to a flexible adjustment:

-- adjustable waveforms (e.g., MC-CDMA, "GMCR")

-- flexible FEC (e.g., "F-LDPC") in rate and block size

-- variable pilots, new channel estimators, synch units, etc.

-- adjustable MIMO (no. of antennas, changeable STC)

-- …

Focus: a flexible PHY optimization module

Basic Property:

Optimize performance through proper ***parameter selection*** (adaptivity), plus ***directives*** (reconfigurability).

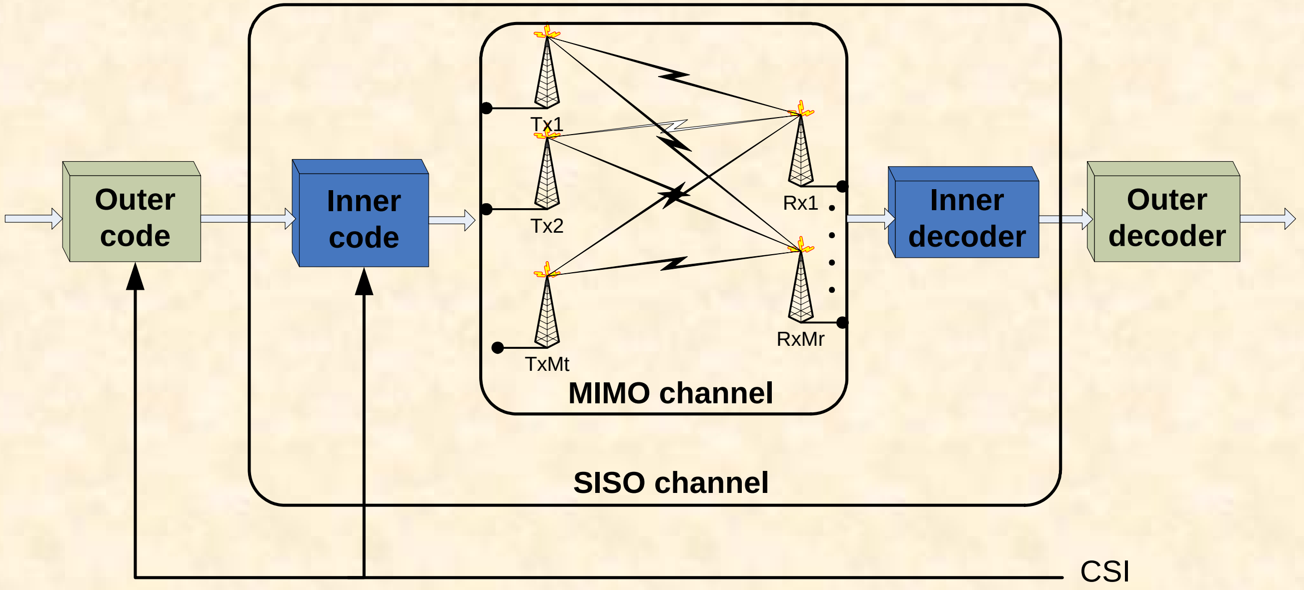
Basic Steps:

- Create a “simple” model for total-system description, amenable to run-time optimization.
- Proper simplification steps (“pruning”) are the key to attaining such a model
- These entail a compromise between wide applicability (hence, flexibility) and inevitable performance loss (since we move away from point-optimal solutions).
- To achieve that, we must identify and functionally quantify the effect on system performance of various parameters or algorithms (modules) under this model.

Ex: MIMO-OFDM, step 1

- **Pruning Step #1:**

  Choose only Space-Time codes (STC) or general combining modules that transform the MIMO channel to an equivalent SISO channel.



Note: All low-rate block STC's and the high-rate V-BLAST fall in this category; a sphere decoder does not.

Ex: MIMO-OFDM, step 2

Pruning Step #2: ***Use the uncoded performance of the effective SISO channel as the basic metric needed for choosing the Tx mode, given a target coded BER as the QoS "system" constraint .***

– Need a LUT, for each possible outer FEC, which contains the required uncoded BER (UBER) of the effective SISO channel for a given target coded BER for each mode *l*.

- Let:

$f_M(\bullet)$ = *BER* of M-QAM; $a_k = |H|_k^2 / N_0$ = channel SNR at the *k*th sub-carrier

$\gamma_k = a_k p_k$ = corresponding SNR at the demodulator after power loading via p_k

- The supervisor employs bit & power loading algorithms to find the solutions (*p*,*M*) for each mode (*l*), based on an optimization criterion and system constraints, to solve

$$\frac{1}{N_l} \sum_{k=1}^{N_l} f_{M_l}(a_k p_k) = UBER_l$$

$UBER_l$ = required *UBER* for mode *l*

M_l = constellation size for mode *l* N_l = number of used sub-carriers for mode *l*

Ex: MIMO-OFDM, step 3

Pruning Step #3: ***Model as AWGN and quantify functionally the effect to the effective channel of all basic impairments in OFDM.***

All suitable functions that model various impairments of a typical OFDM system such as:

- phase noise
- frequency offset
- channel estimation errors
- Inter-Carrier Interference (ICI)

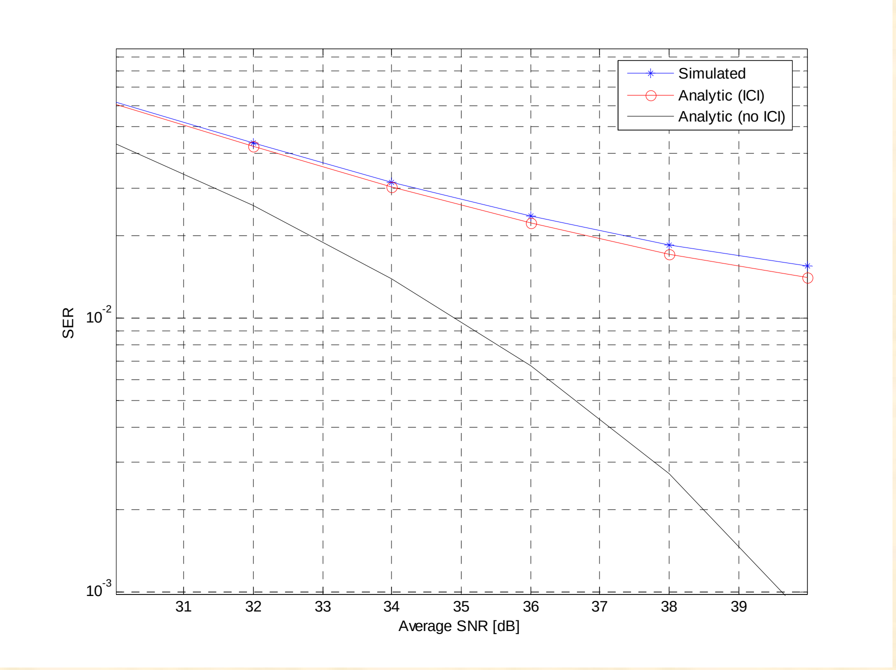
can be identified and properly simplified for representation within the module.

Step 3:MIMO-OFDM ICI in static channels

$$\mathrm{ICI}(k) = \sum_{l=0, l\neq k}^{N-1} I(l-k) H_l s_l$$

The basic term to compute for the ICI above is

$$E\left[\left|I(p)\right|^2\right] = \frac{1}{N^2}\left\{2\Re\left(\frac{d_p^{N+1} - (N+1)d_p + N}{\left(d_p - 1\right)^2}\right) - N\right\} \qquad d_p = e^{j(2\pi(p-\Delta\phi)-(\sigma_\varphi^2/2))}$$



System simulation parameters:

64-QAM modulation

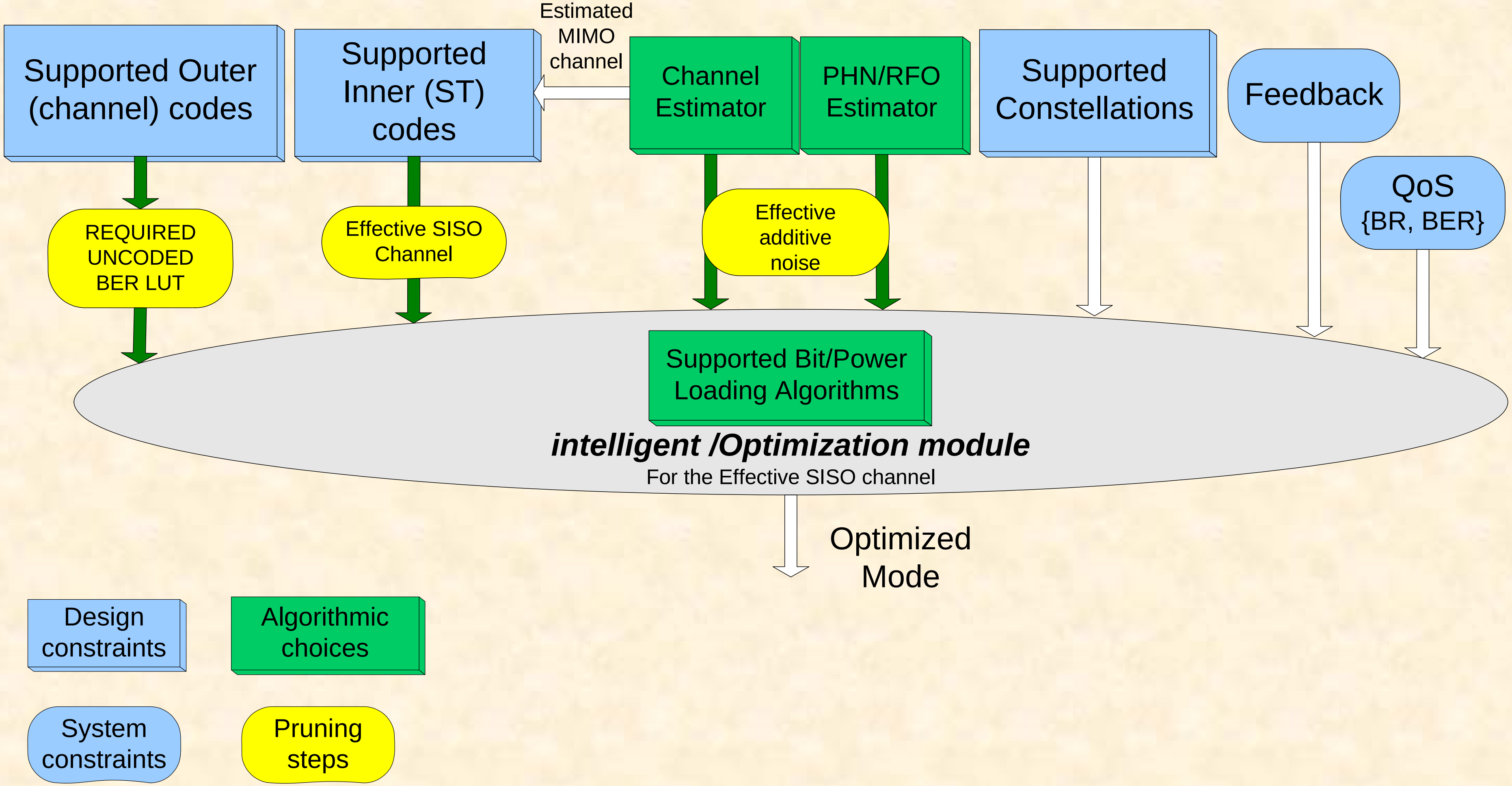
FFT length N = 256

$\Delta\phi = 2\%$

$\sigma_\varphi = 0.003$

A non-line-of-sight channel for a fixed wireless access system in a small urban scenario at 5.8 GHz

Conclusion: A flexible MIMO-OFDM optimizing module in quasi-static channels



Final Summary

- The science of FR architecture and design is evolving
- The art of FR already advanced in some topics
- It is a very inter-disciplinary field in need of “intellectual” discipline.
- Limited perspective presented here (PHY/device); extensions to other layers important (“reconfigurable” networks).
- The subject harmonizes well with the R&D trends suggested by the EC: multi-modality & reconfigurability to enable service creation and interoperability.