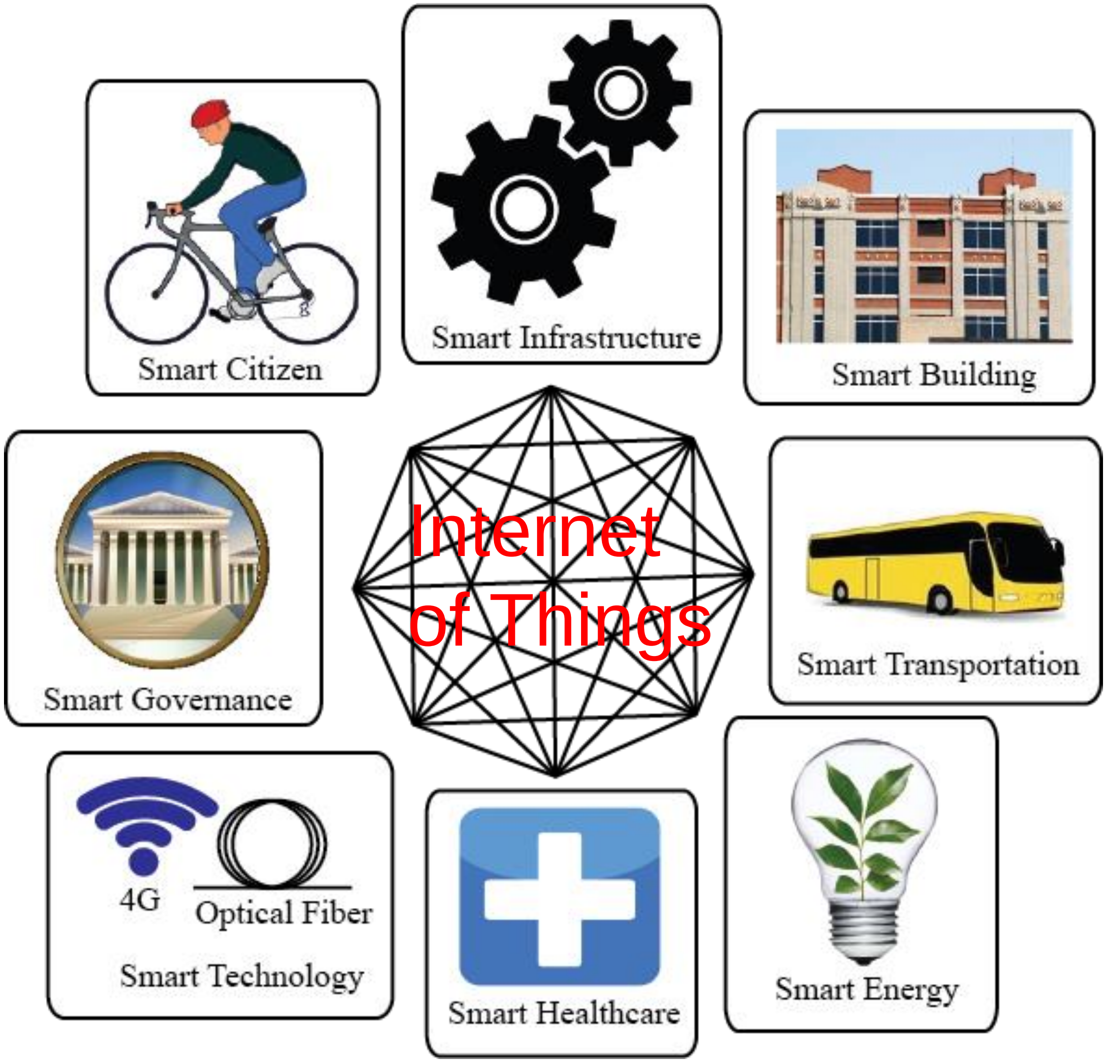
iVAMS: A Paradigm Shift System Simulation Framework for the IoT Era

Saraju P. Mohanty
NanoSystem Design Laboratory (NSDL)
Dept. of Computer Science and Engineering
University of North Texas, Denton, TX 76203, USA.
Email: saraju.mohanty@unt.edu

Smart Cities

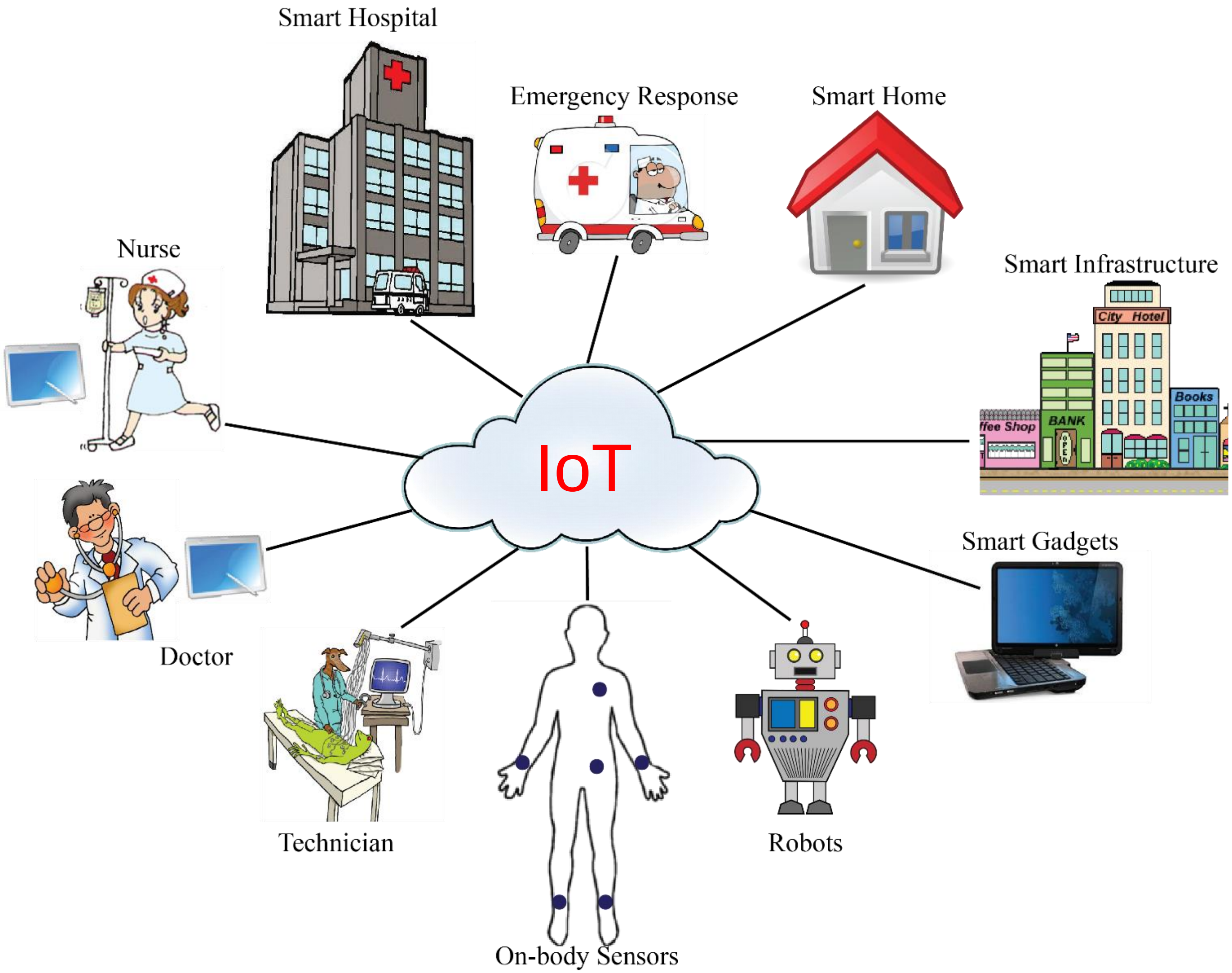


70% of the world population will live in urban areas by 2050.

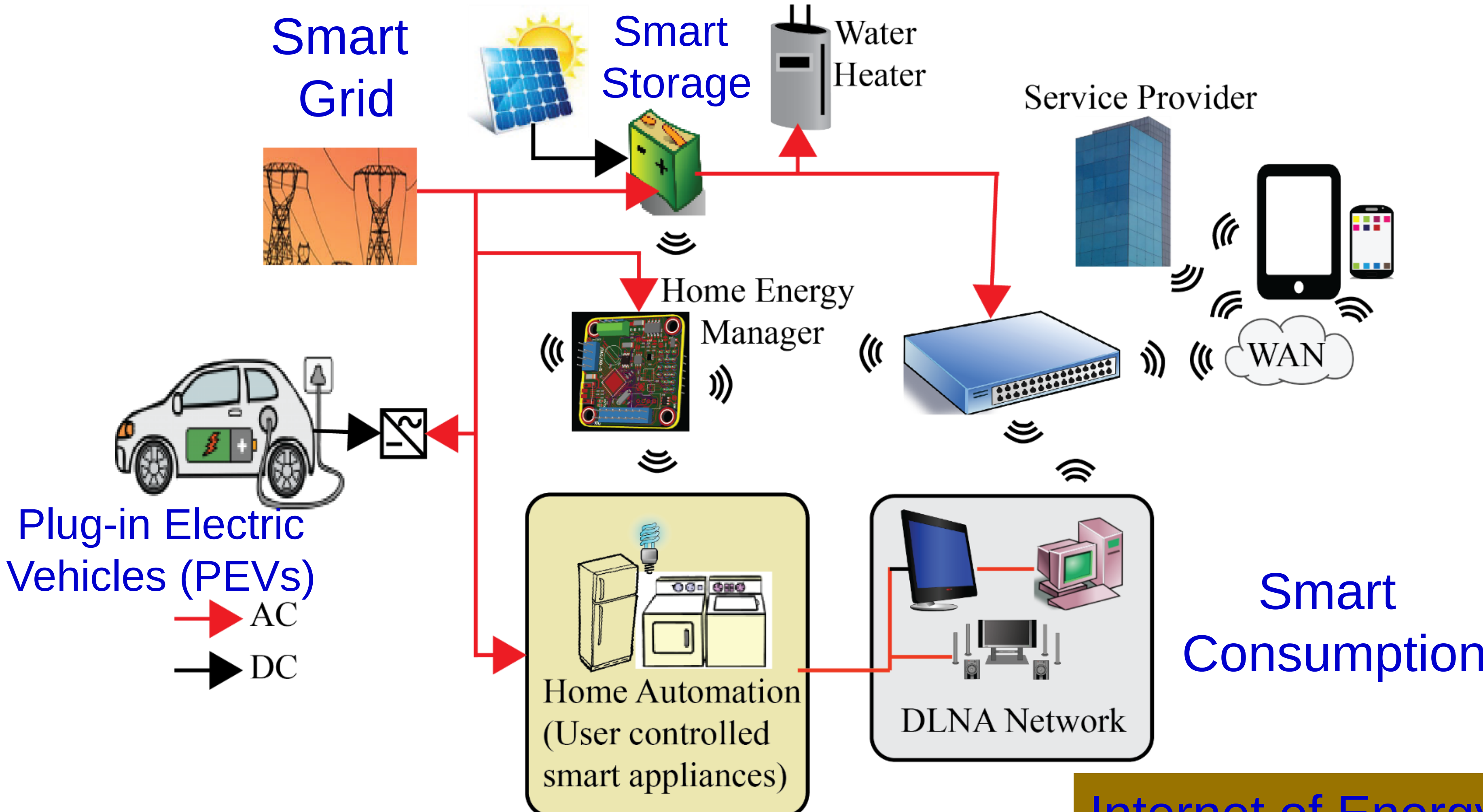
Smart Cities
← Cities
+ ICT
+ Smart Components

Refer: http://smartcities.ieee.org

Smart Health Care

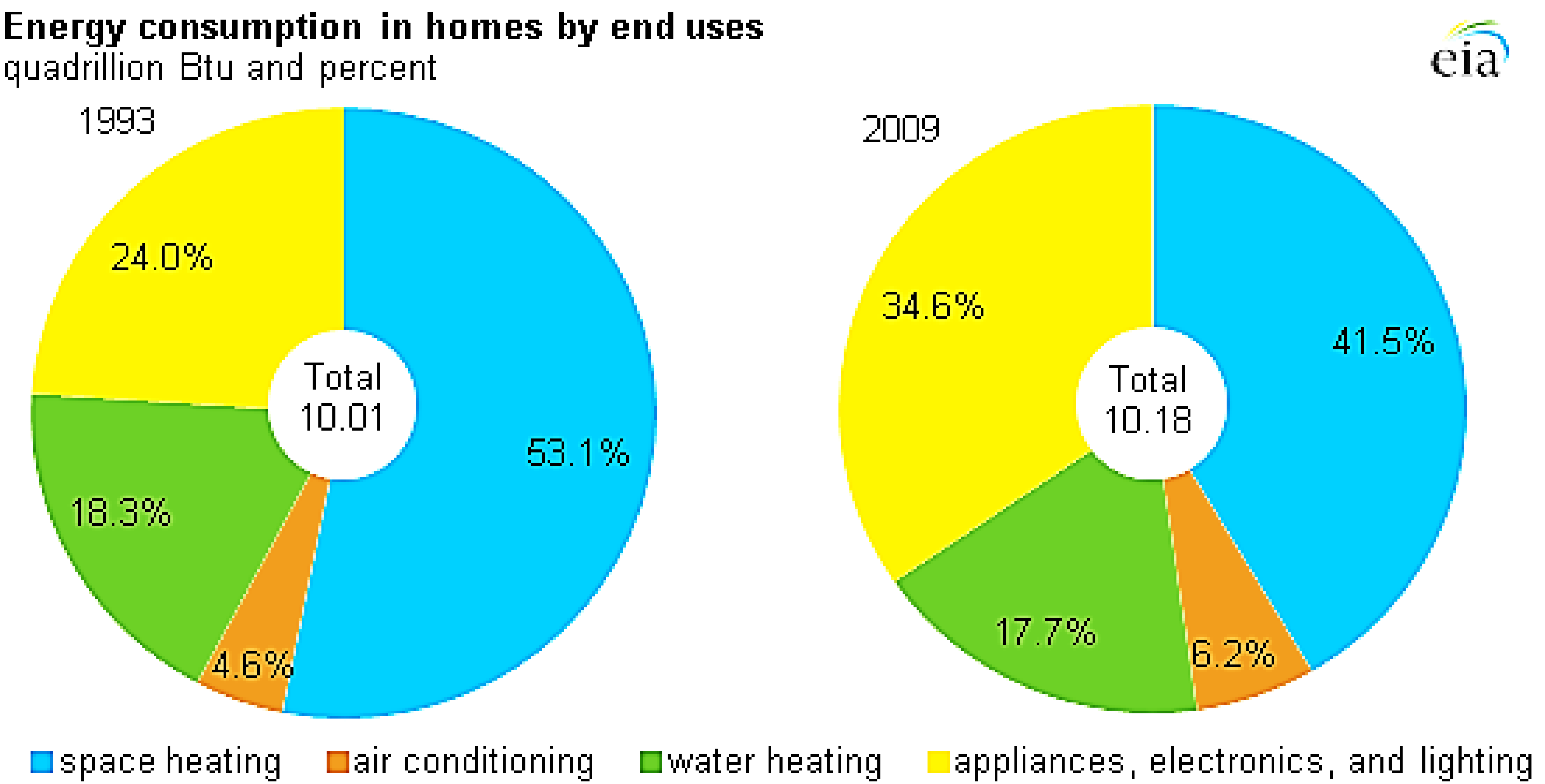


Smart Energy



Internet of Energy

Consumer Electronics Demand More and More Energy



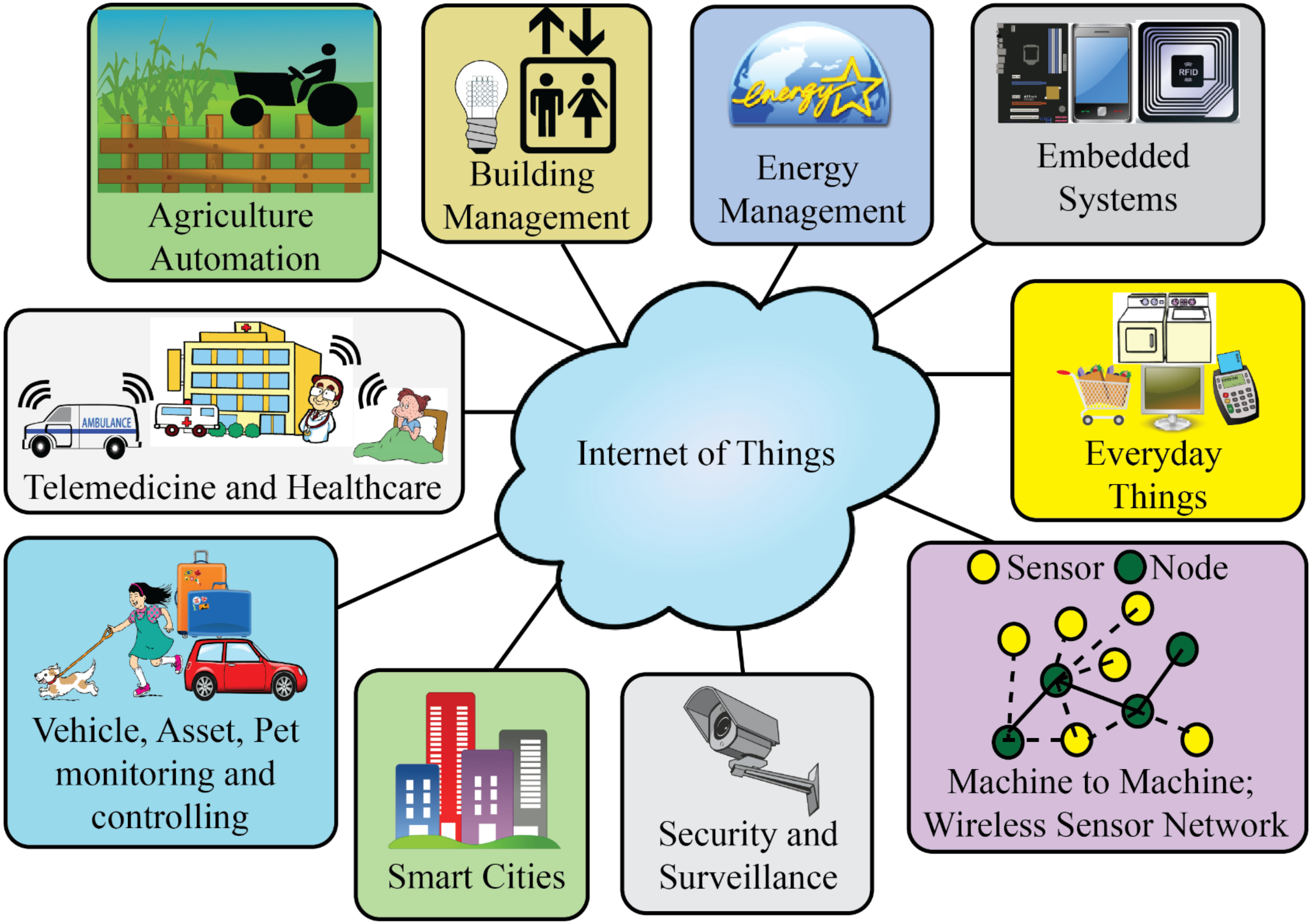
Quadrillion BTU (or quad): 1 quad = 10^{15} BTU = 1.055 Exa Joule (EJ).

Source: U.S. Energy Information Administration.

Smart Home

- Source: Cadence

What Makes Smart Cities Feasible?

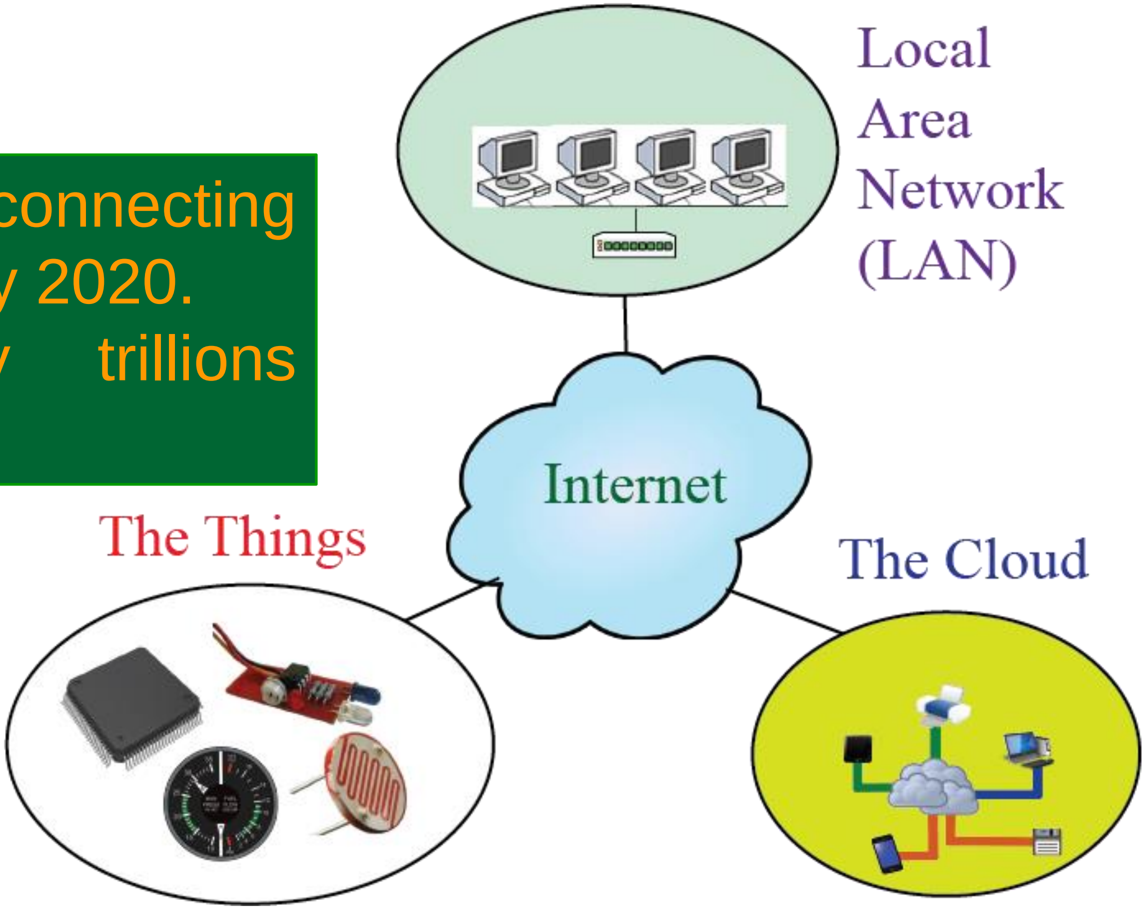


3 key features of Smart Cities come from IoT:

- Intelligence
- Interconnection
- Instrumentation

Internet of Things: Architecture

- ❖ 75 billion connecting devices by 2020.
- ❖ Eventually trillions of things.



❖ Overall architecture:

- ❖ A configurable dynamic global network of networks
- ❖ Systems-of-Systems

Internet of Things: Challenges …

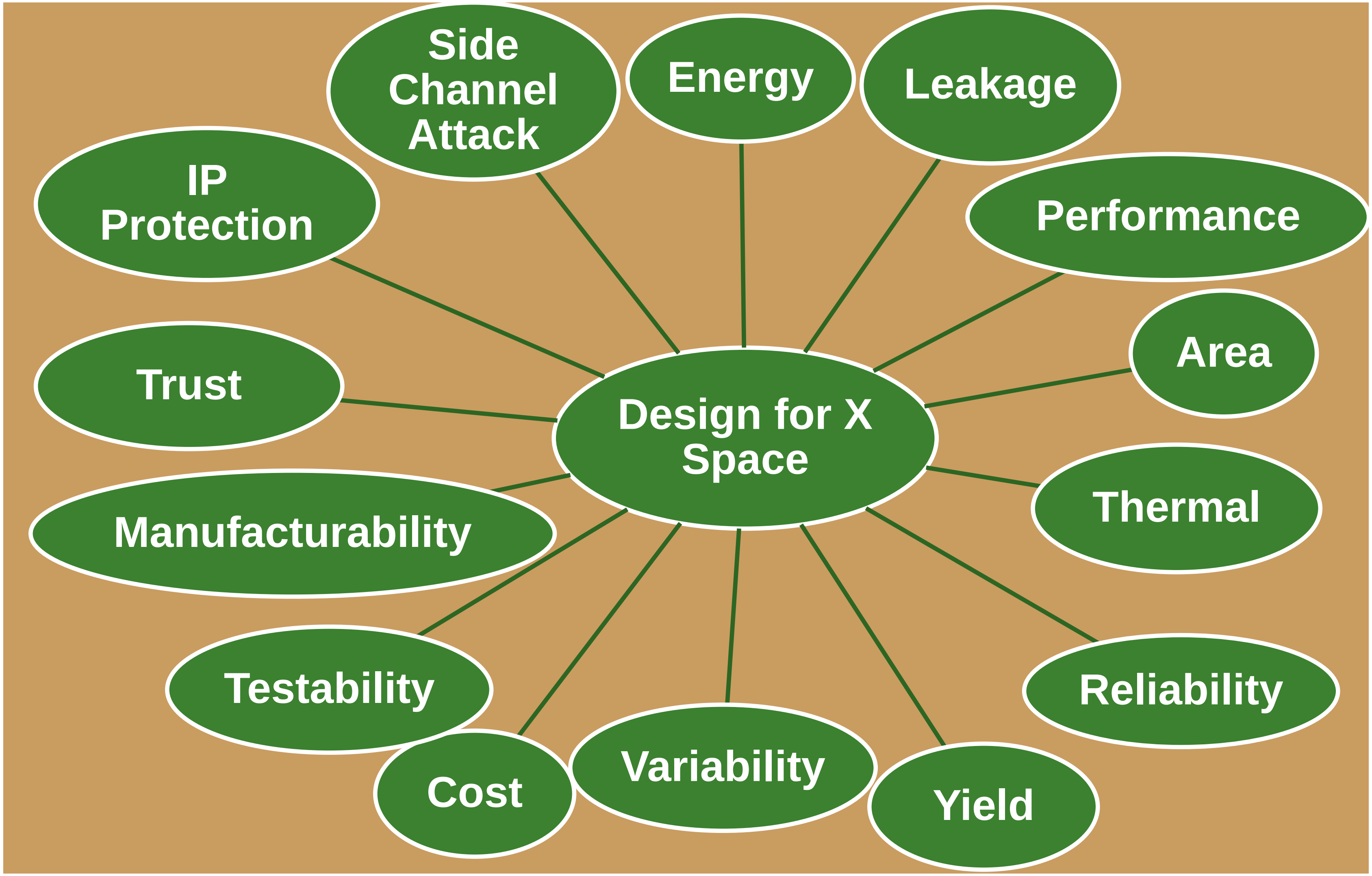
- Massive Scaling
- Architecture and Dependencies
- Creating Knowledge and Big Data
- Robustness
- Security and Privacy
- Energy Consumption
- Design and Operation Cost

❖75 billion connecting devices by 2020.
❖Eventually trillions of things.

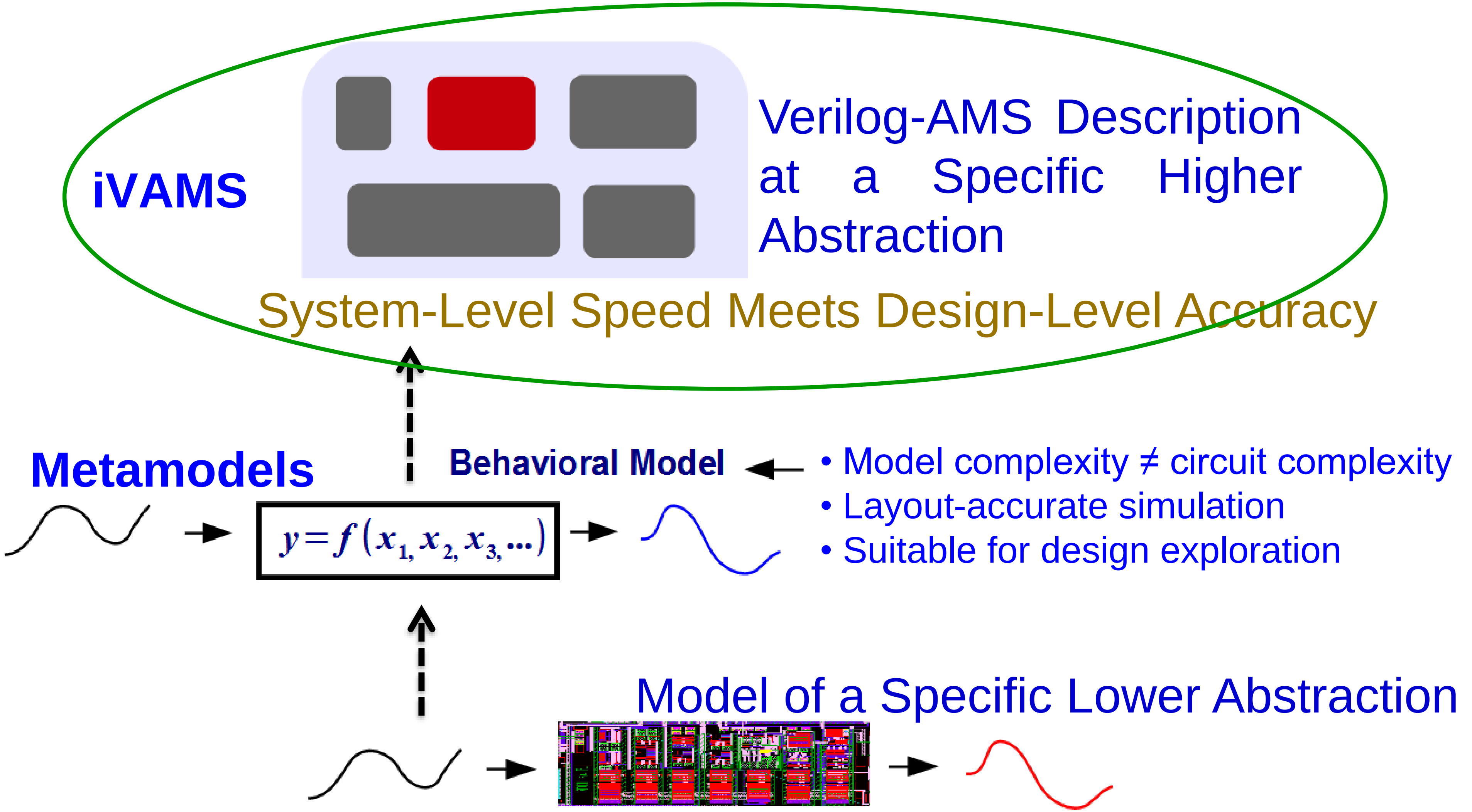
Internet of Things: Challenges

- Traditional controllers and processors do not meet IoT requirements, such as multiple sensor, communication protocol, energy consumption, and security requirements.
- Existing tools are not enough to meet challenges like time-to-market, complexity, design cost of IoT.
- Can a framework be developed for simulation, verification, and optimization:
  - of individual (multidiscipline) "Things"
  - of IoT Components
  - of IoT Architecture

How to Handle DfX in IoT Design?



A Solution - iVAMS



iVAMS code : OP-AMP Example

```
function real NN_metamodel; ... ...
  integer α1, β2, b1, b2, i, j, readfile, ... ...; real w, b, v, u;
  // Read metamodel weights and bias from text files.
  // α1, β2, b1, and b2.
  ... ... v = 0.0;
  for (j = 0; j < nl; j = j + 1)
  begin
     u = 0.0;
     for (i = 0; i < size_x; i = i + 1)
     begin
       readfile = $fscanf(w1, "%e", w);   u = u + w * x[i];
     end
     readfile = $fscanf(w2,"%e",w); readfile = $fscanf(b1,"%e",b);
       v = v + w * tanh(u + b);
  end
  readfile = $fscanf(b2, "%e", b);
  NN_metamodel = v + b; ... ...
end function
```

What are Metamodels?

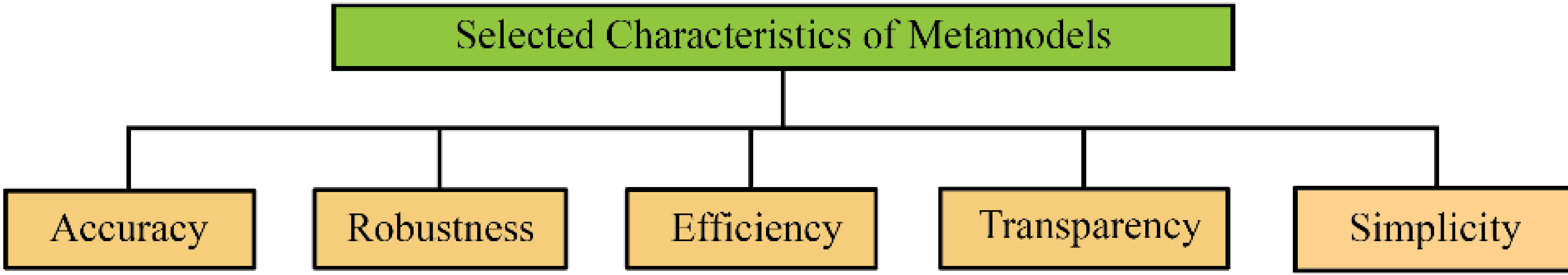
- "Model of a model" -- Metamodels are mathematical function(s) used to represent the computer simulation models – e.g. polynomial functions, DOE predictive functions, neural networks, and Kriging interpolation:

$$\hat{F}(x_n) = F(x_n) + \varepsilon \approx F(x_n)$$

Selected Metamodels

- **Polynomial**
- **Neural-Networks**
- **Kriging Methods**

iVAMS : Key Characteristics



iVAMS: Polynomial Metamodel (POM)

- The OP-AMP characteristics are estimated using POlynomial Metamodel (POM).

Gain

Bandwidth

Phase Margin

Slew Rate

Power

.

.

.

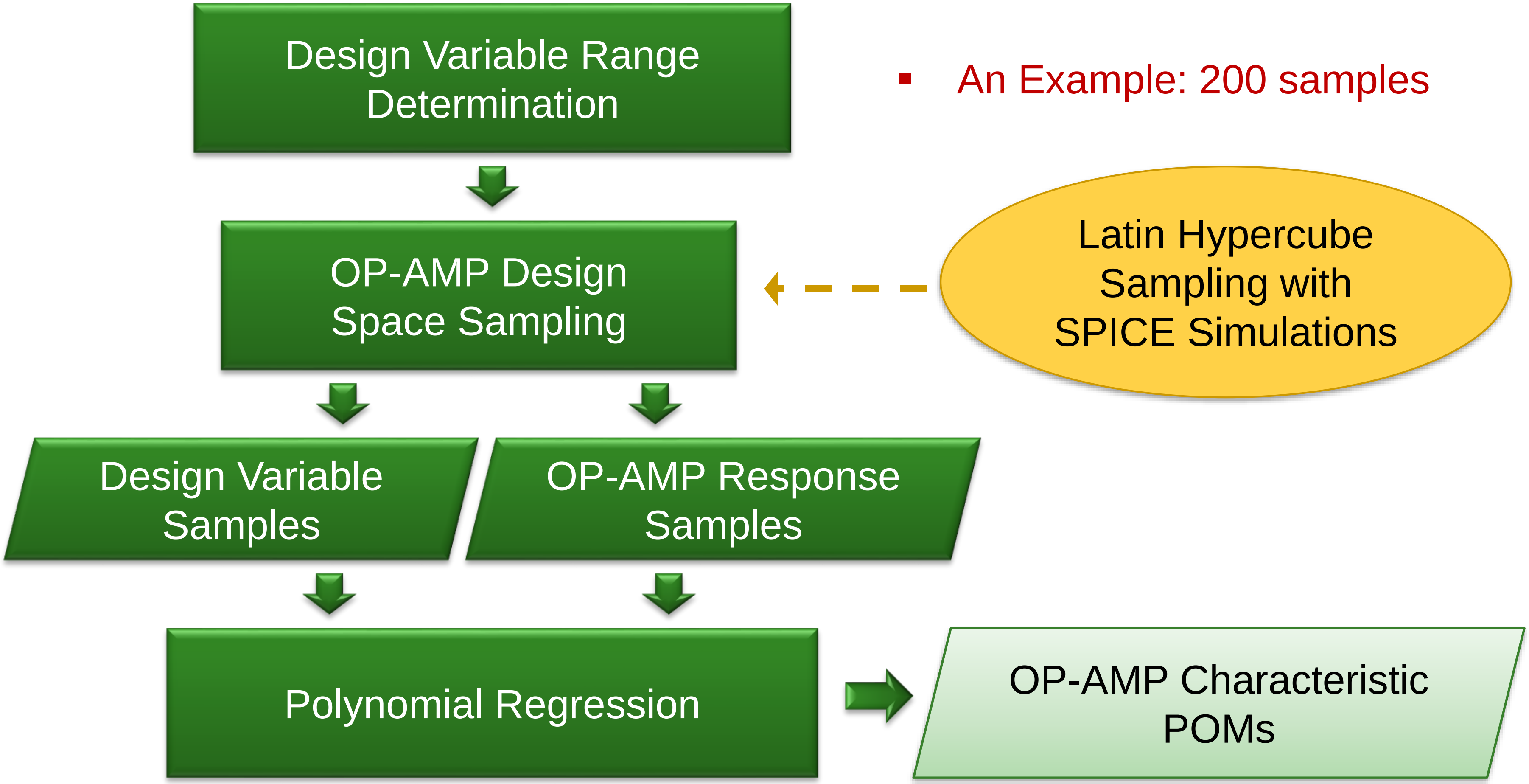
$$f(x) = \sum_{i=0}^{N_B - 1} \beta_i x_1^{p_1} x_2^{p_2} x_3^{p_3} \ldots x_N^{p_N}$$

Transistor widths, lengths, bias current, …

OP-AMP POM Generation

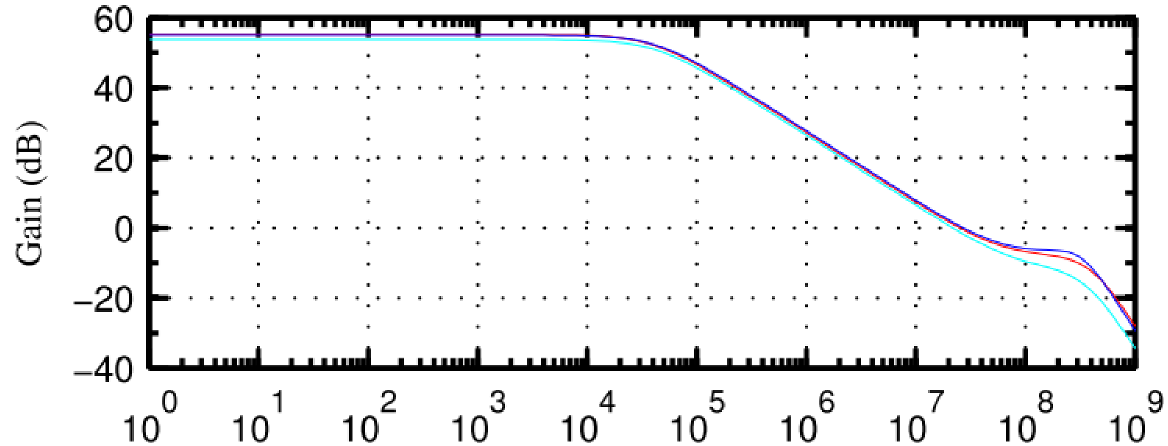
❖ The goal is to find the coefficients for the polynomials.

- An Example: 200 samples



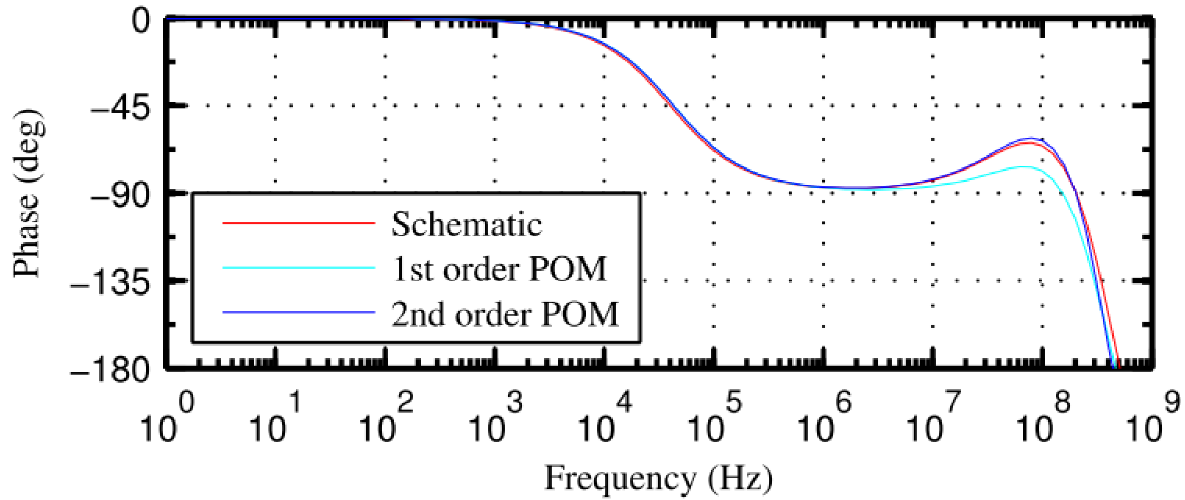
A green light to greatness.

iVAMS: Accuracy Analysis for OP-AMP

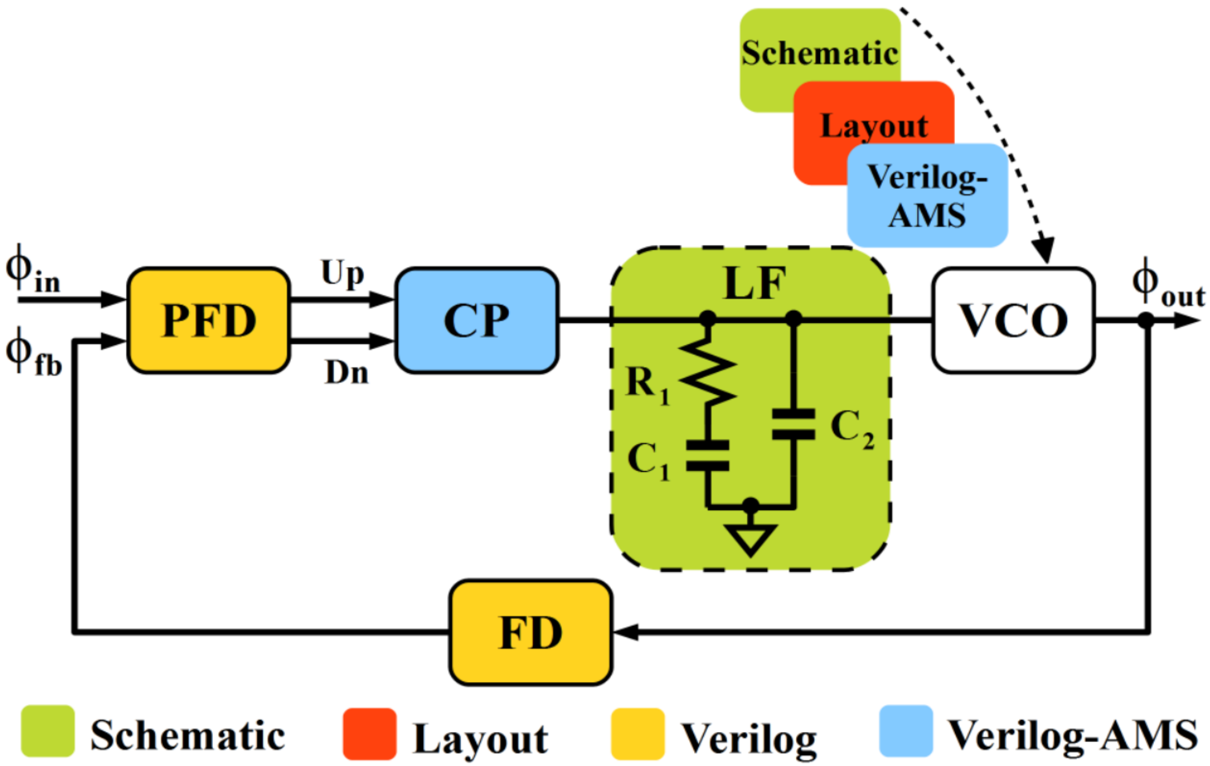


❖ Example: AC analysis

Frequency



Case Study Electronic Design: PLL



Polynomial Metamodel

$$f(X) = \sum_{i=0}^{K-1} \beta_i \, x_1^{p_{1i}} x_2^{p_{2i}} x_3^{p_{3i}}$$

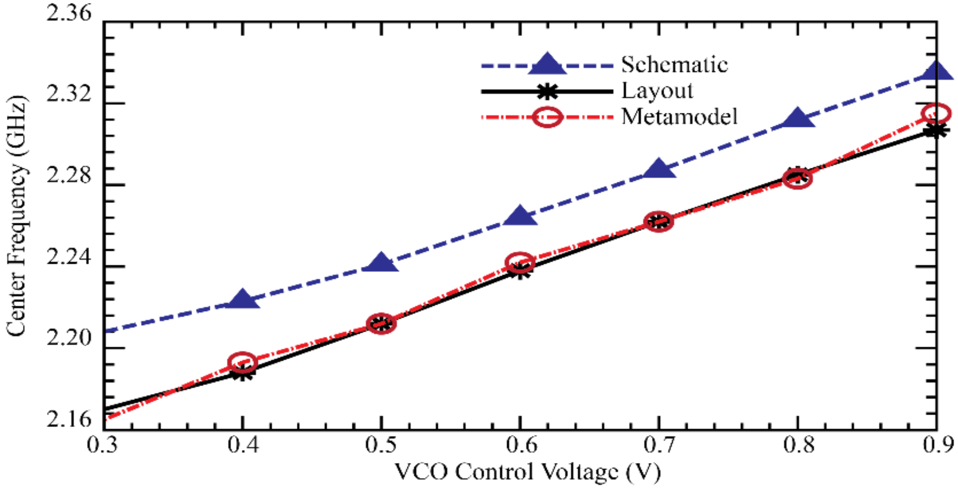
$$x_1 \rightarrow W_P$$

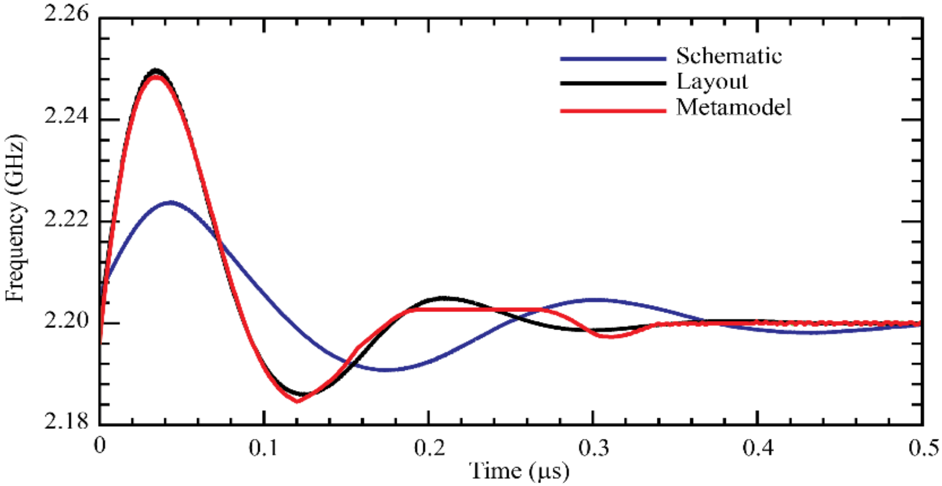
$$x_2 \rightarrow W_N$$

$$x_3 \rightarrow V_{in}$$

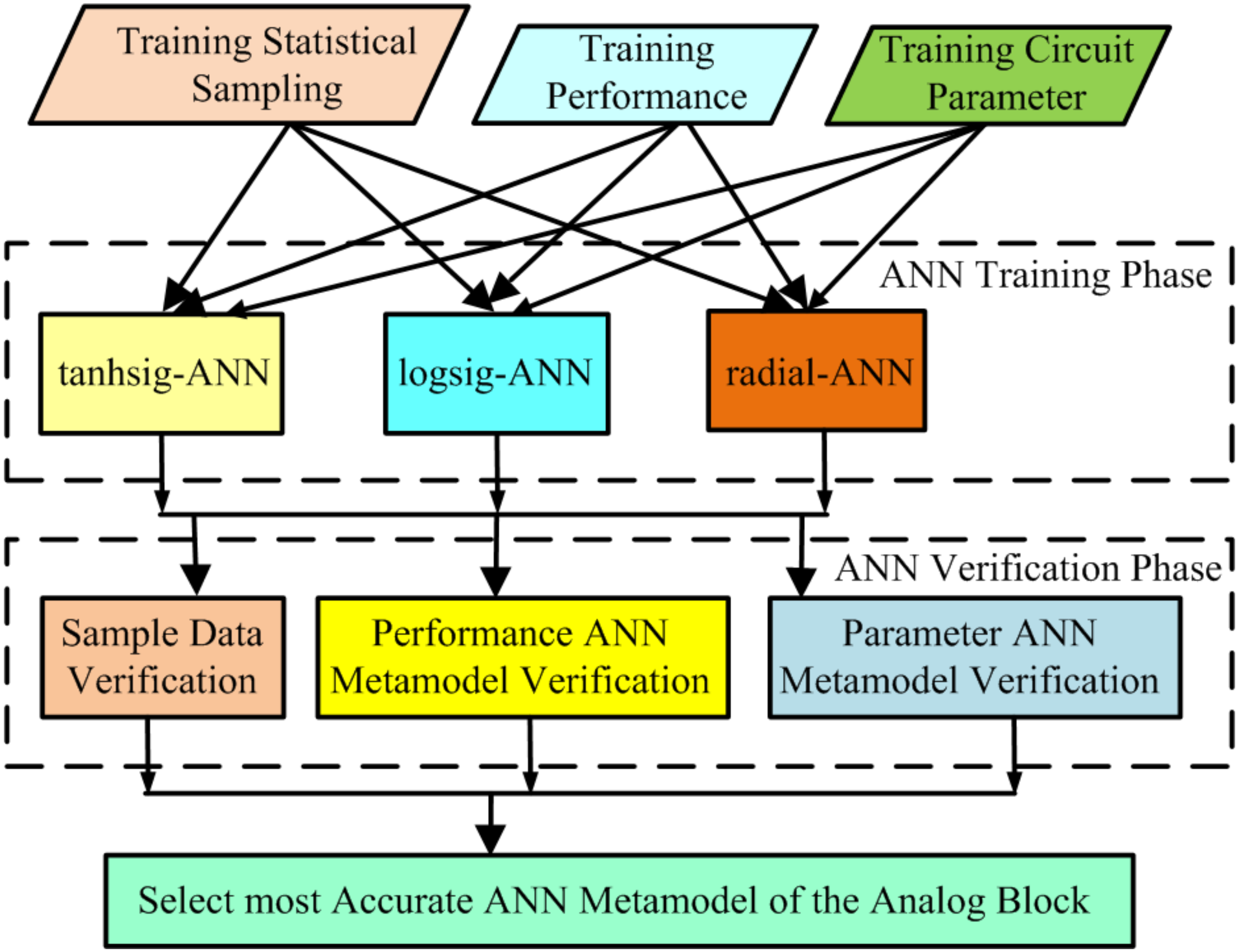
iVAMS: Accuracy Analysis for PLL

- iVAMS is capable of layout-accurate PLL design characteristics such as, center frequency, power dissipation, and jitter.

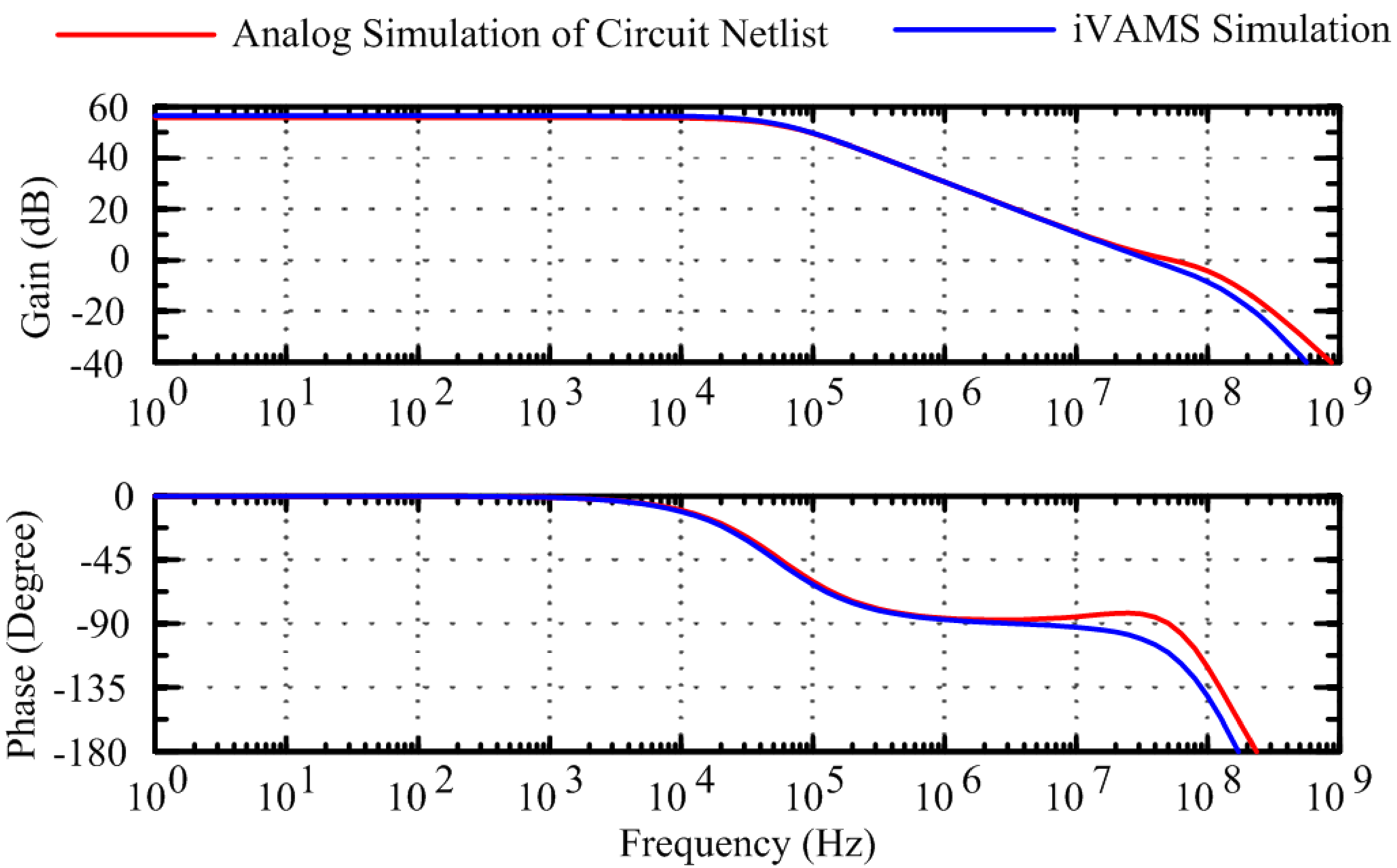




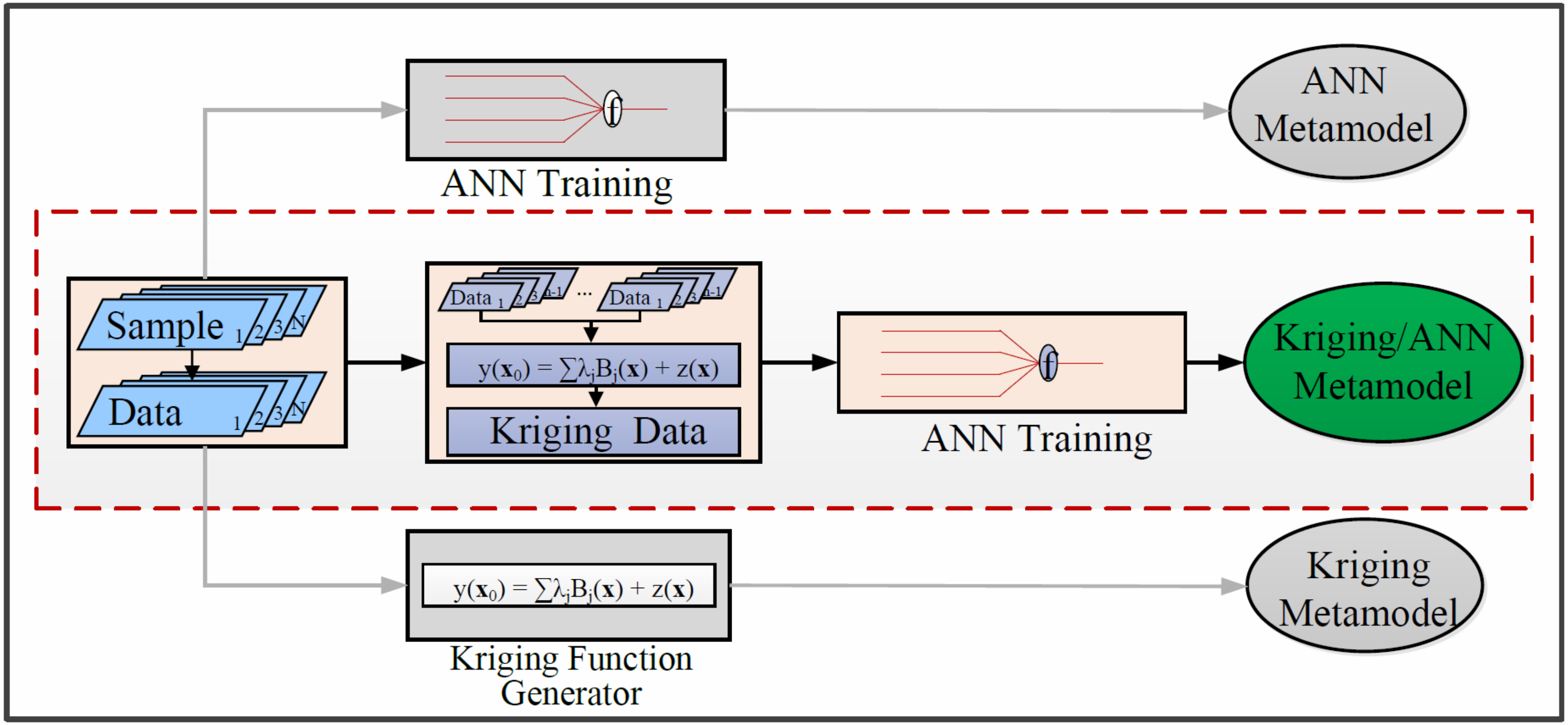
iVAMS : NN Metamodel Architecture Selection



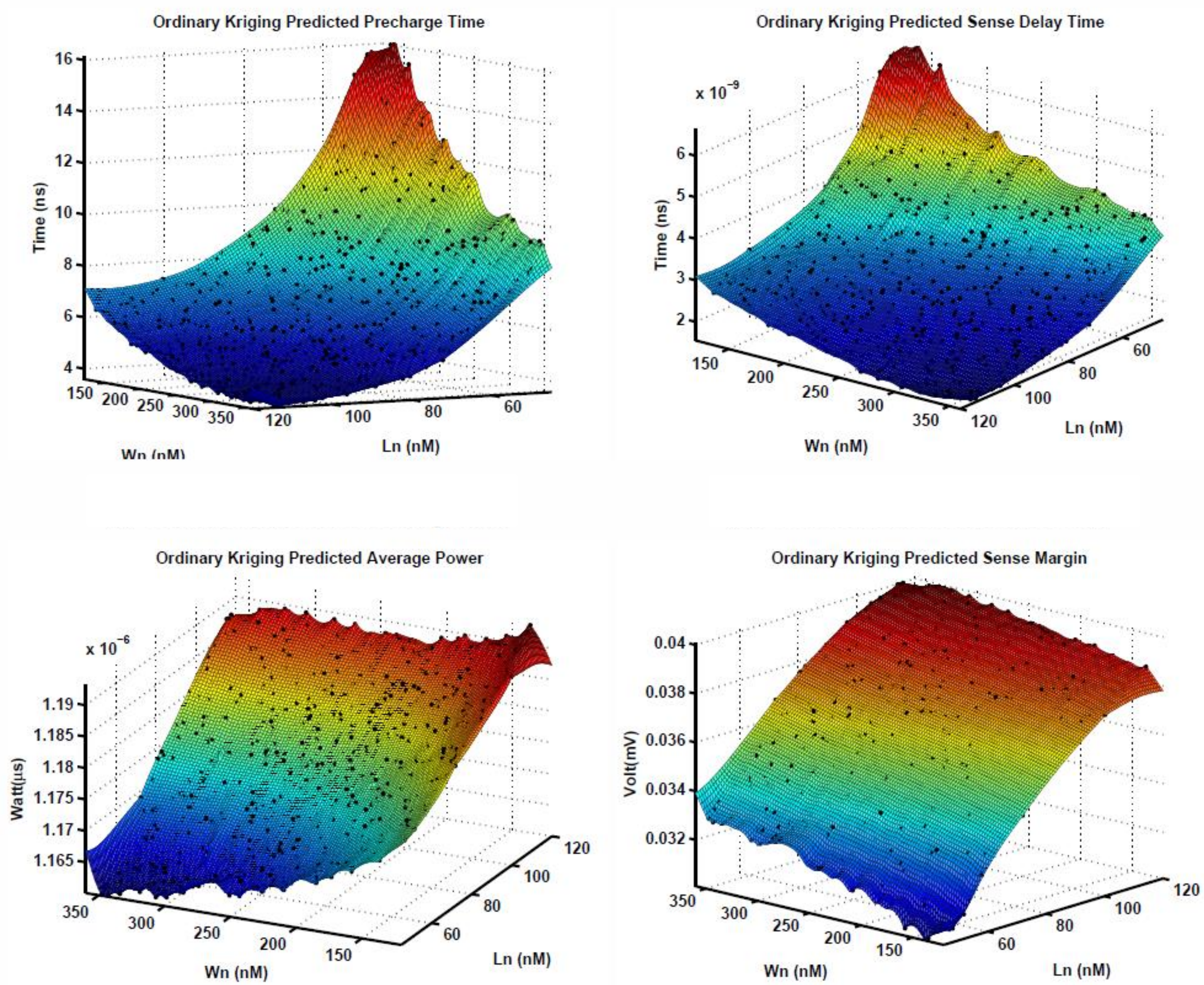
iVAMS : AC Analysis for Comparison



Kriging Bootstrapping NN Metamodel



Ordinary Kriging Metamodels



For a Sense Amplifier Design

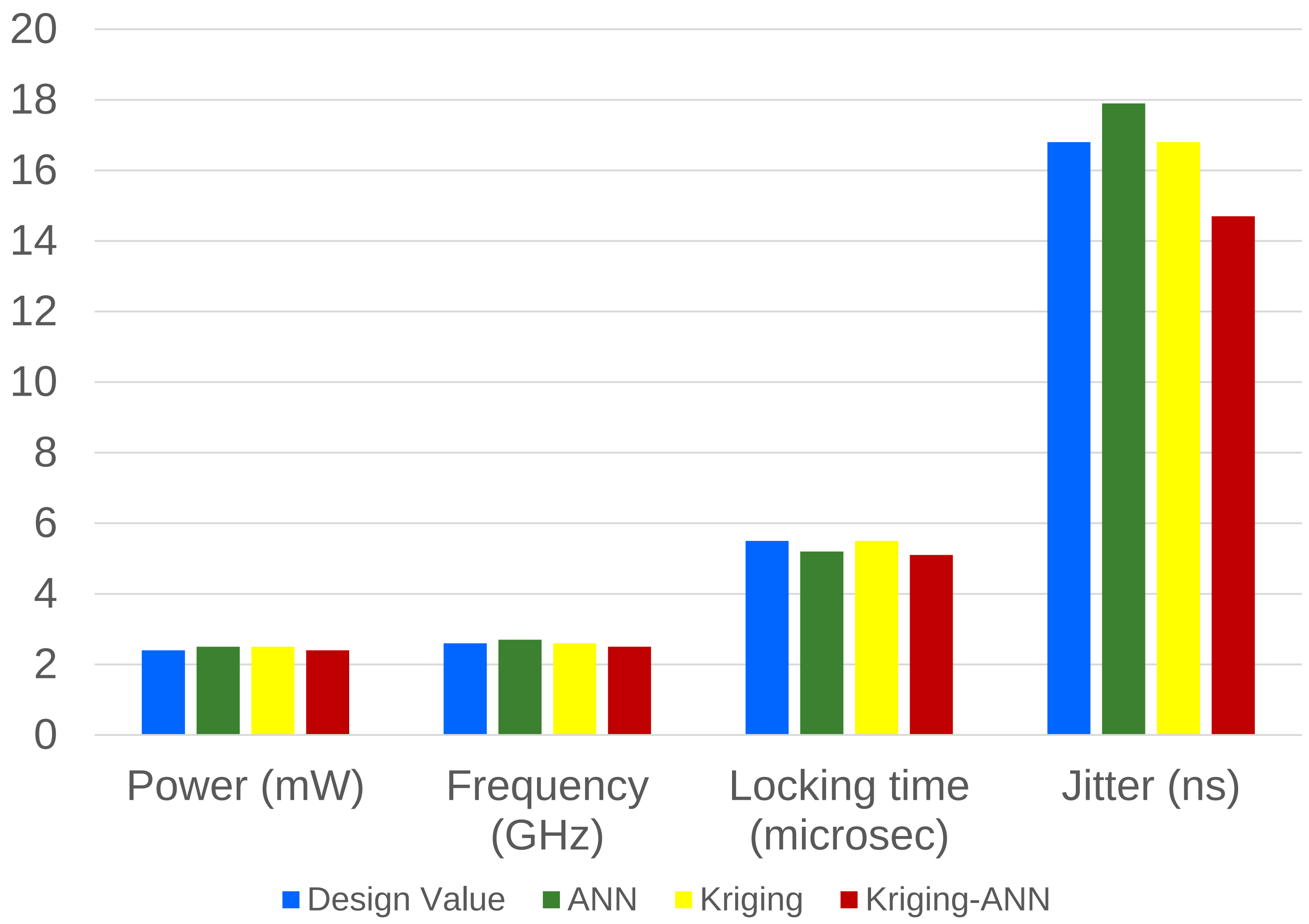
Metamodel Comparison: Polynomial Vs Nonpolynomial

180nm CMOS PLL with Target Specs: f = 2.7GHz, P = 3.9mW, 8.5μs.

Figures-of-Merits (FoM)	Polynomial		Nonpolynomial (Neural Network)
	# of Coefficients	RMSE	
Frequency	48	77.9 MHz	48 MHz
Power	50	2.6 mW	0.29 mW
Locking Time	56	1.9 μs	1.2 μs

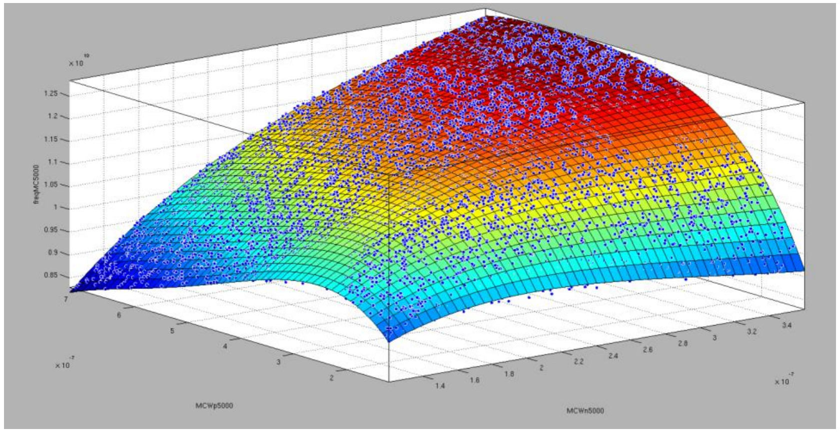
- 56% increase in accuracy over polynomial metamodels.
- On average 3.2% error over golden design surface for NN metamodels.
- Nonpolynomial is more suitable for large design.

Nonpolynomial Metamodel Accuracy

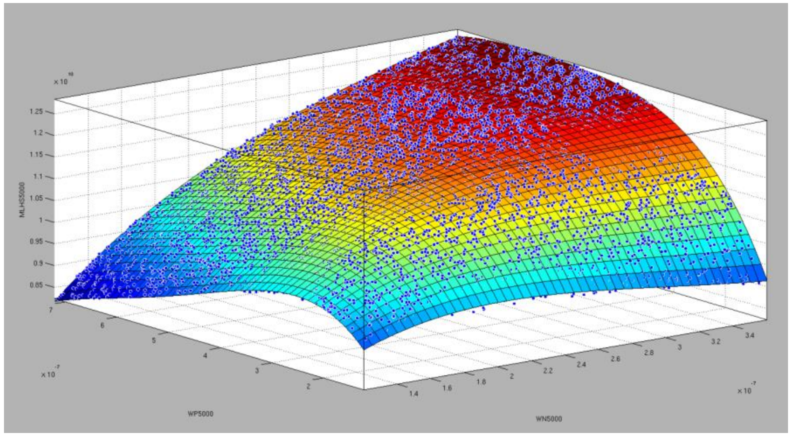


Sampling Techniques: 45nm Ring Oscillator Circuit (5000 points)

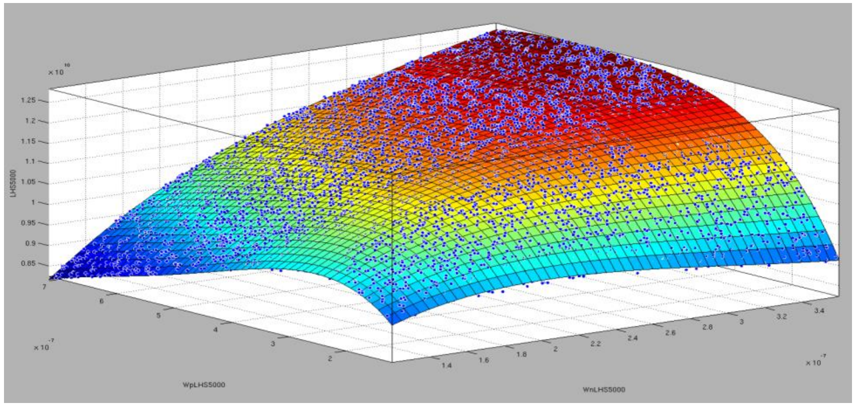
Monte Carlo



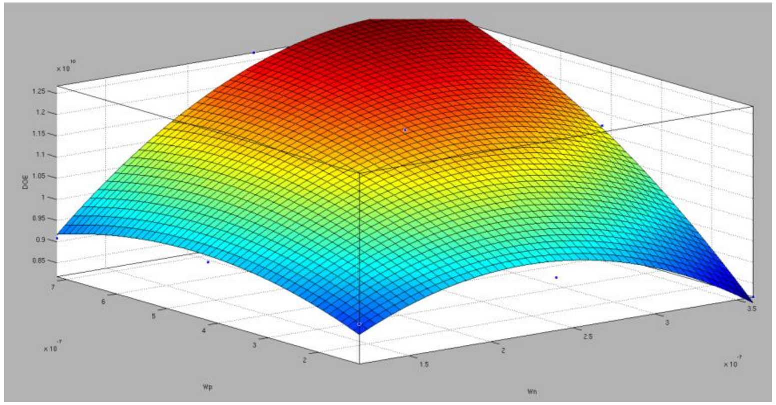
MLHS



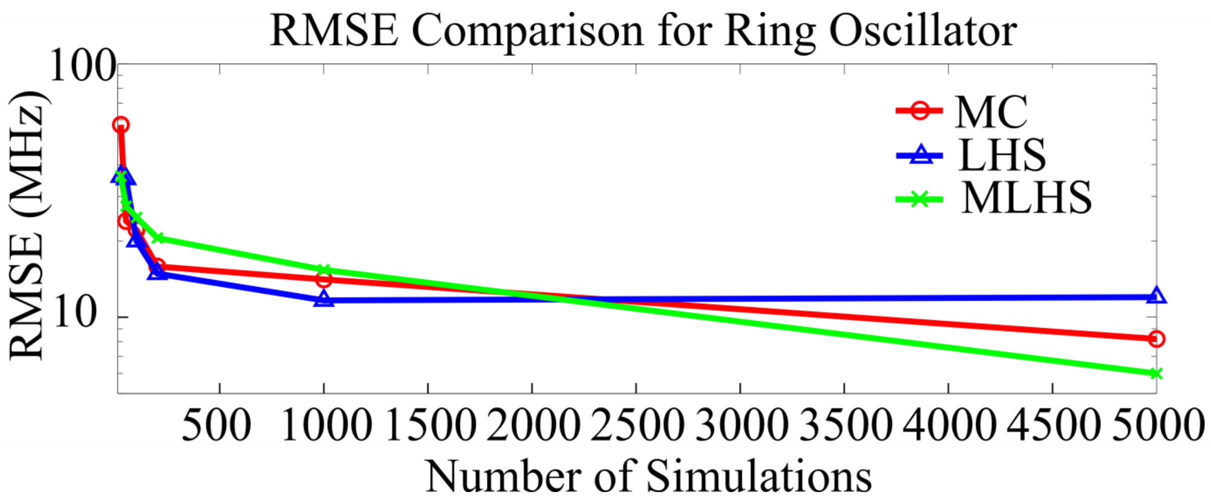
LHS

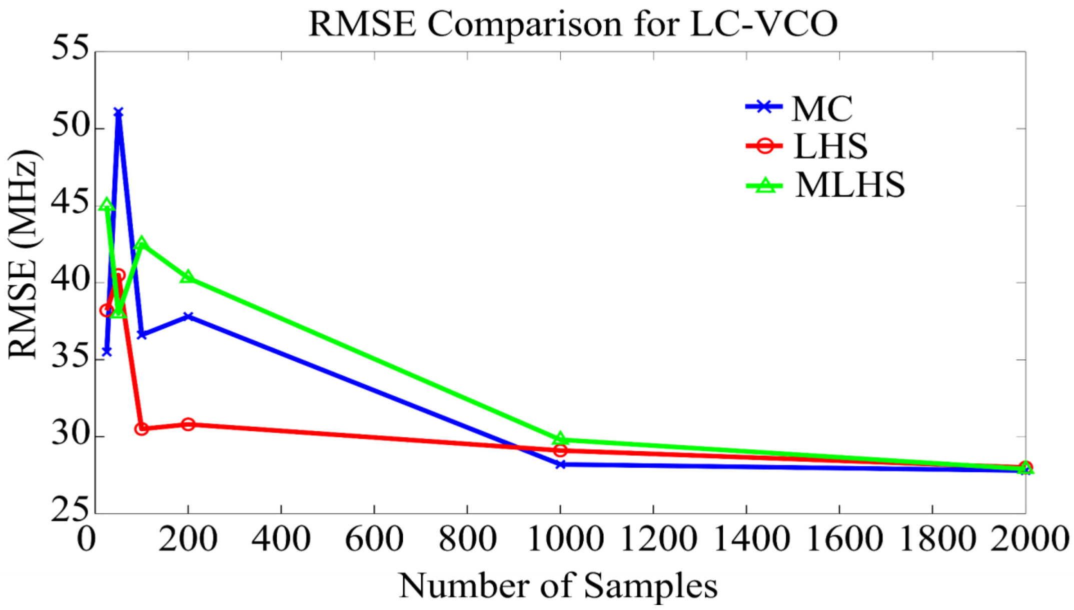


DOE



Sampling Comparison: RO / LC-VCO

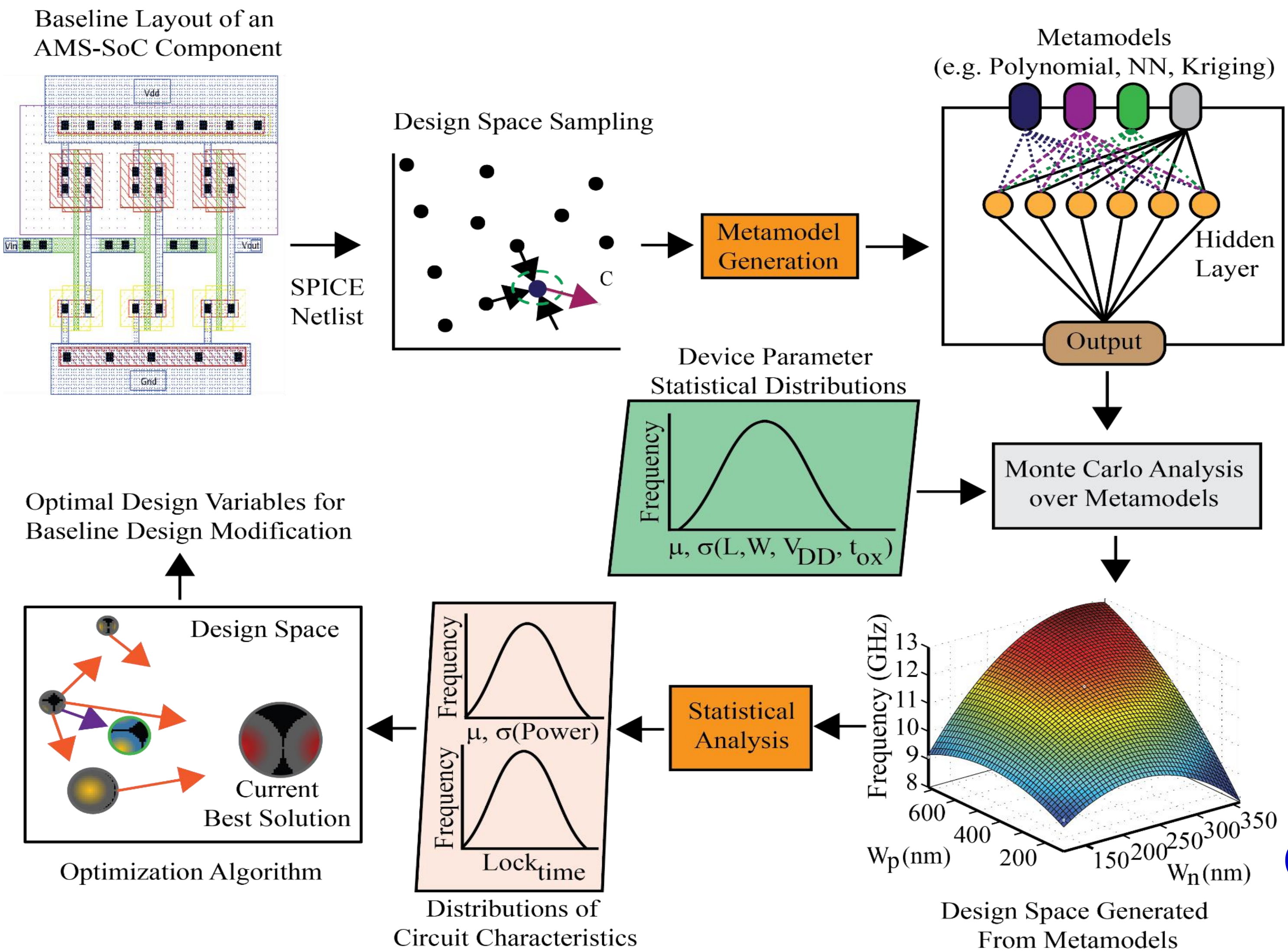




What do we with iVAMS ?

- Use for accurate design verification
- Use for ultra-fast design optimization

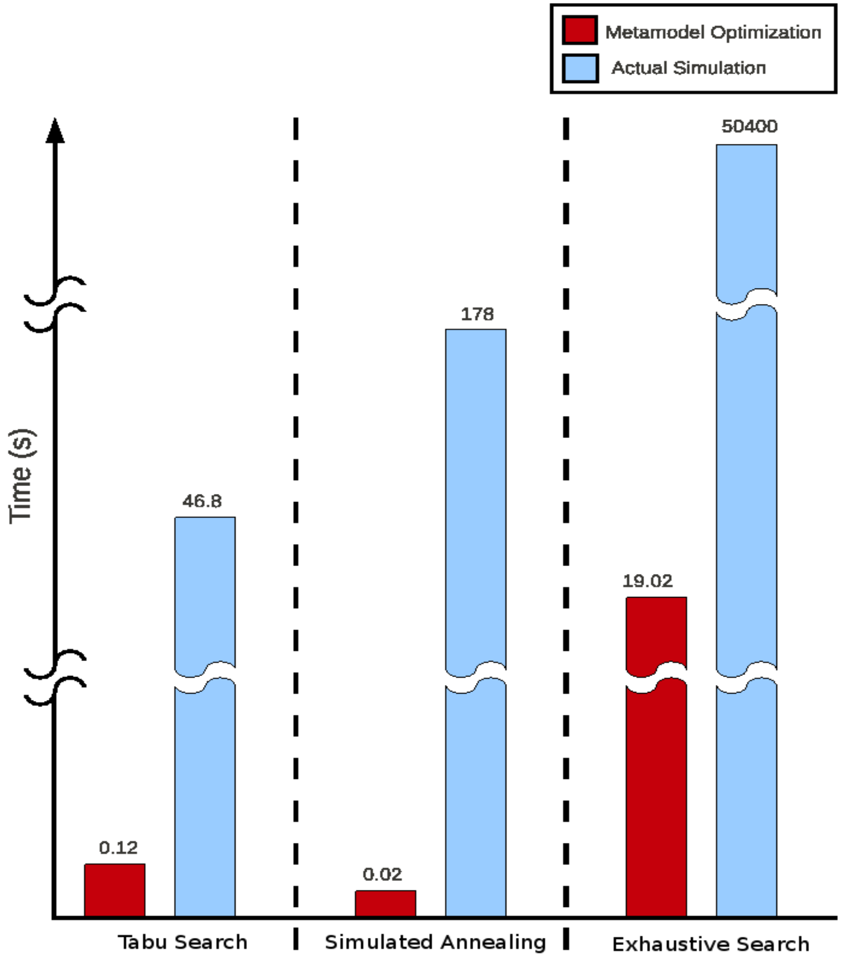
iVAMS-Based Ultrafast Design Flow



iVAMS Generated

Optimization over iVAMS

Comparison of the Running Time: 45nm RO Optimization



- **Optimization without metamodels:** the tabu search optimization is faster by ~1000× than the exhaustive search and ~4× faster than the simulated annealing optimization.
- **Optimization with metamodels:** the simulated annealing optimization is faster by ~1000× than the exhaustive search and ~6× faster than the tabu search optimization.

Optimization in PLL: Poly Vs NN

Bee Colony Optimization Results

FoM	Polynomial Metamodel	NN Metamodel
Average Power	3.9 mW	3.9 mW
Frequency	2.69 GHz	2.70 GHz

Bee Colony Optimization Time Comparison

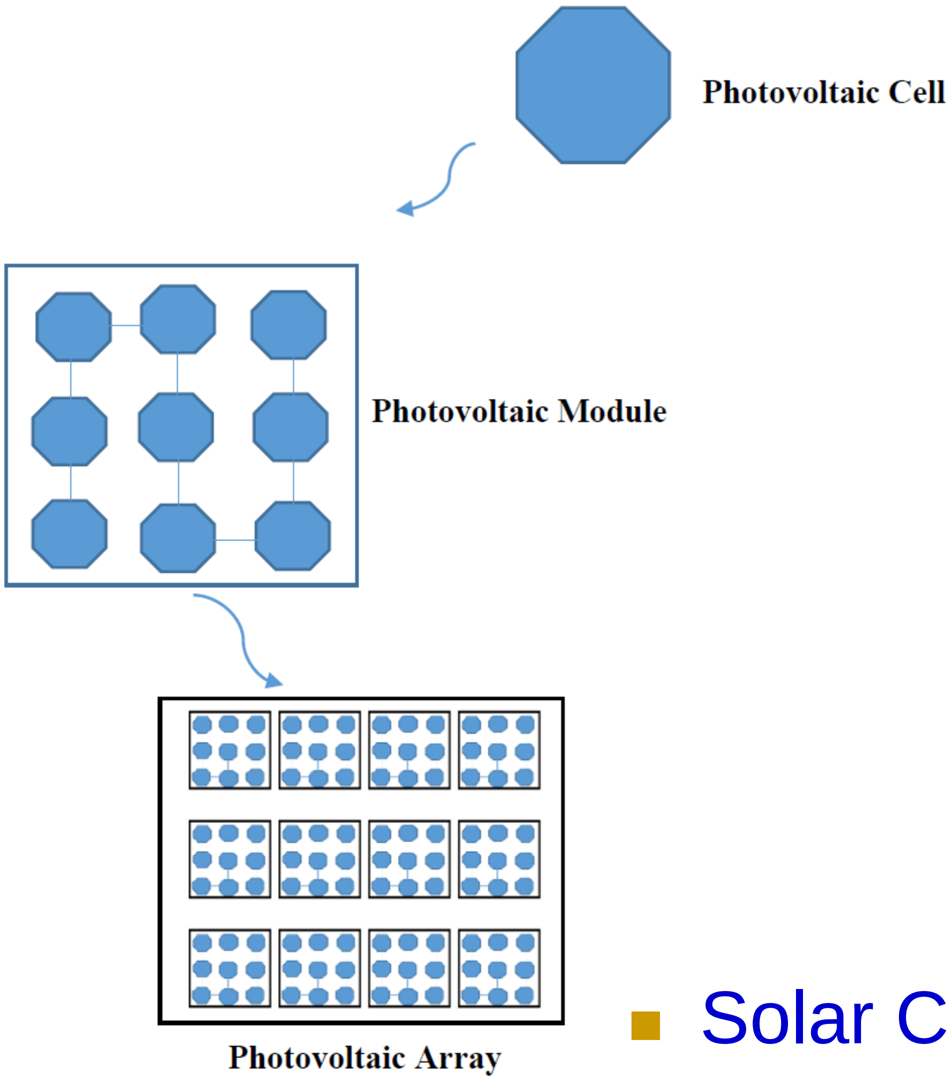
Algorithm	Circuit Netlist	Polynomial Metamodel	NN Metamodel
Bee Colony (100 iterations)	#bees(20) * 5 min * 100 iteration = 10,000 minutes = **7 days (worst case)**	5 mins	0.12 mins
Metamodel Generation	0	11 hours for LHS + 1 min creation	11 hours for LHS + 10mins training and verification.

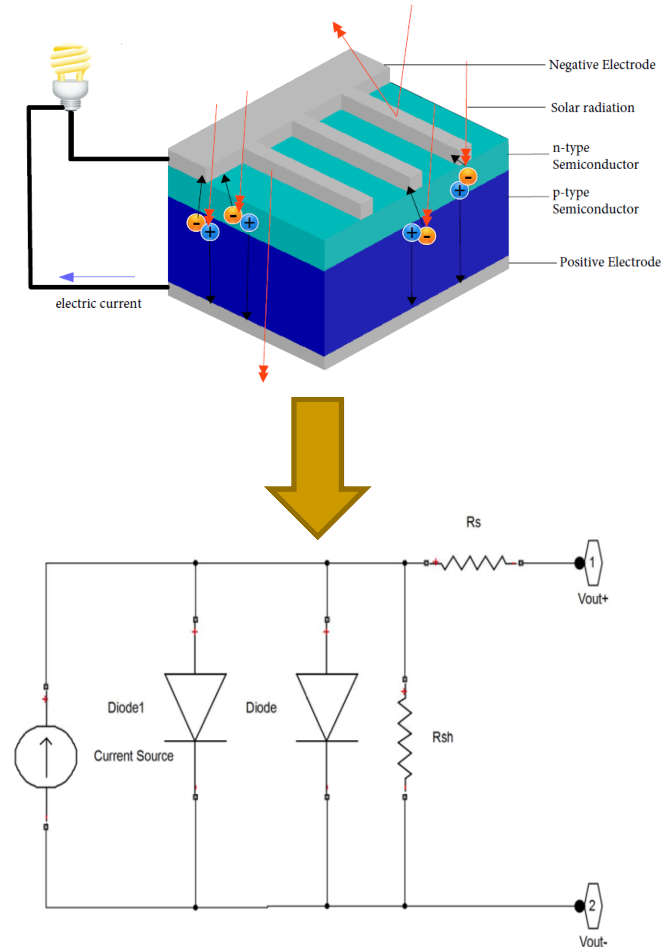
OP-AMP: Optimization Results

Performance	Constraint	$\text{Optimal}_{\text{POM}}$	$\text{Optimal}_{\text{SCH}}$
A_0 (dB)	> 43	56.4	52.8
BW (kHz)	> 50	58.9	85.5
PM (degree)	> 70	84.4	87.7
SR (mV/ns)	> 5	7.1	8
	Objective		
P_D (μW)	~ 65	65.5	68.1

Performance	$\text{Optimal}_{\text{SCH}}$	$\text{Optimal}_{\text{POM}}$
Power Reduction	$\times 3.71$	$\times 3.86$
Number of iterations	1200	1200
Computation Time	12.5 h	2.6 s
Normalized Speed	1	$\times 17120$

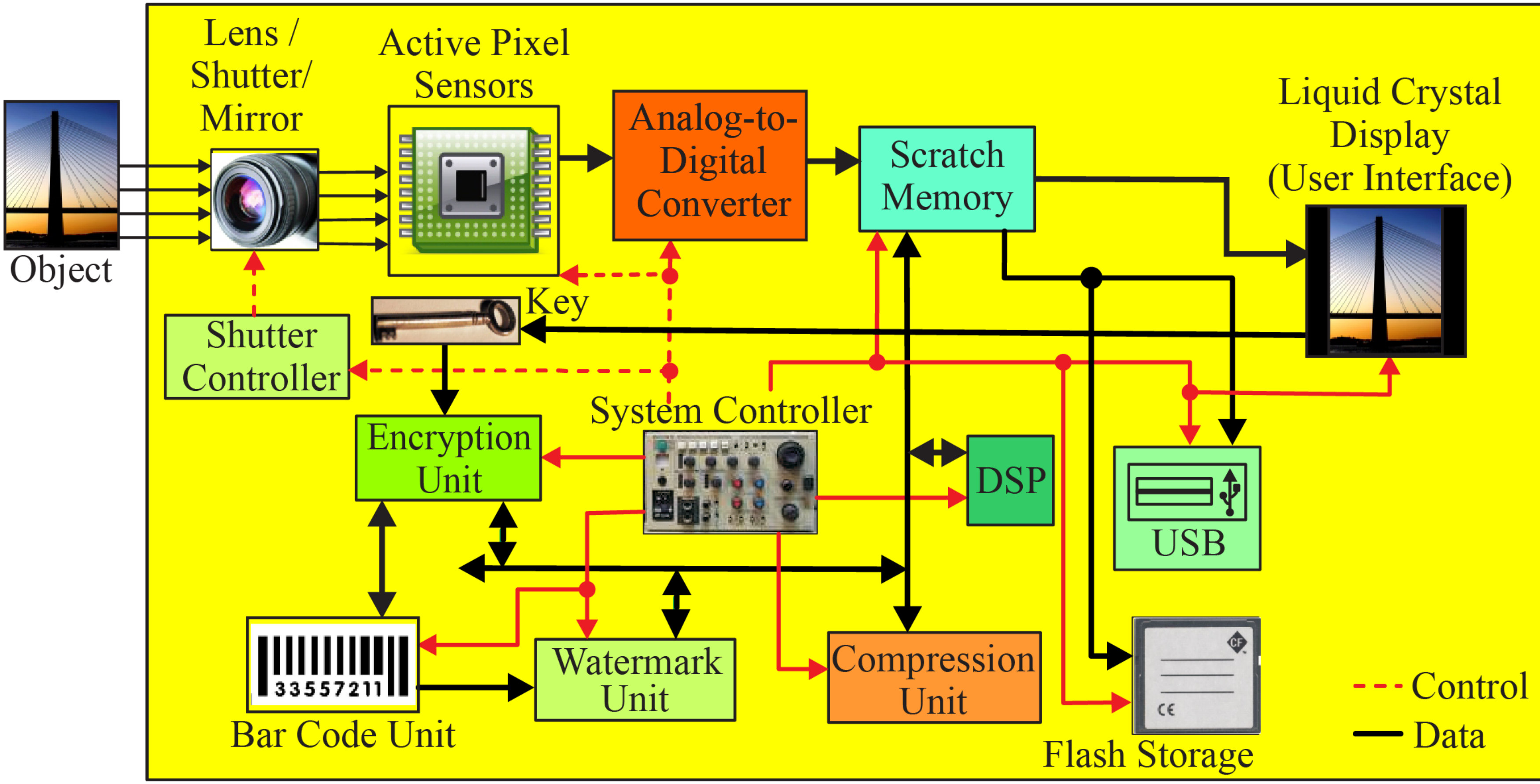
Ongoing: iVAMS for other "Things"





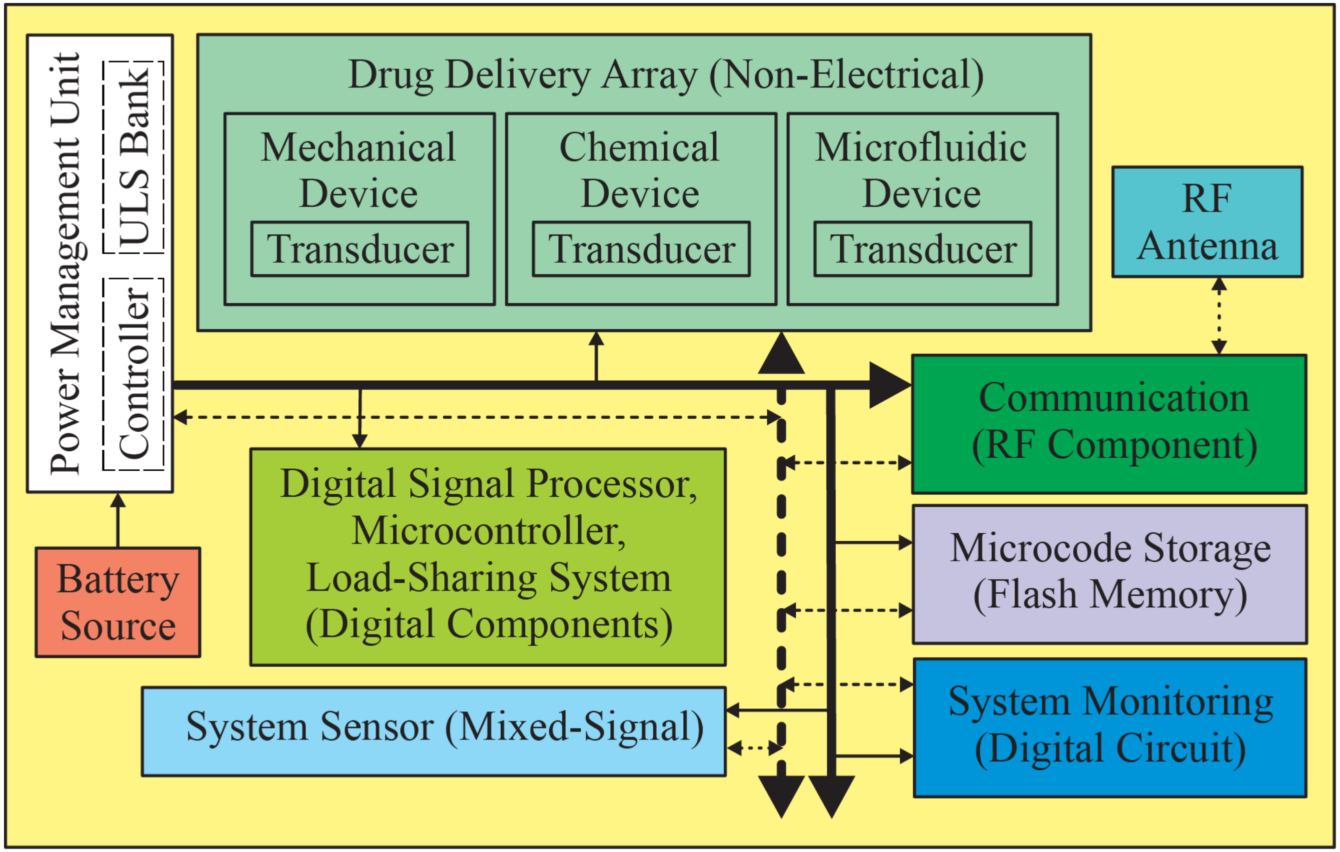
- Solar Cells → Smart Grids

Ongoing: iVAMS for other “Things”



- Secure Digital Camera: For Secure Imaging/Video

Ongoing: iVAMS for other "Things"

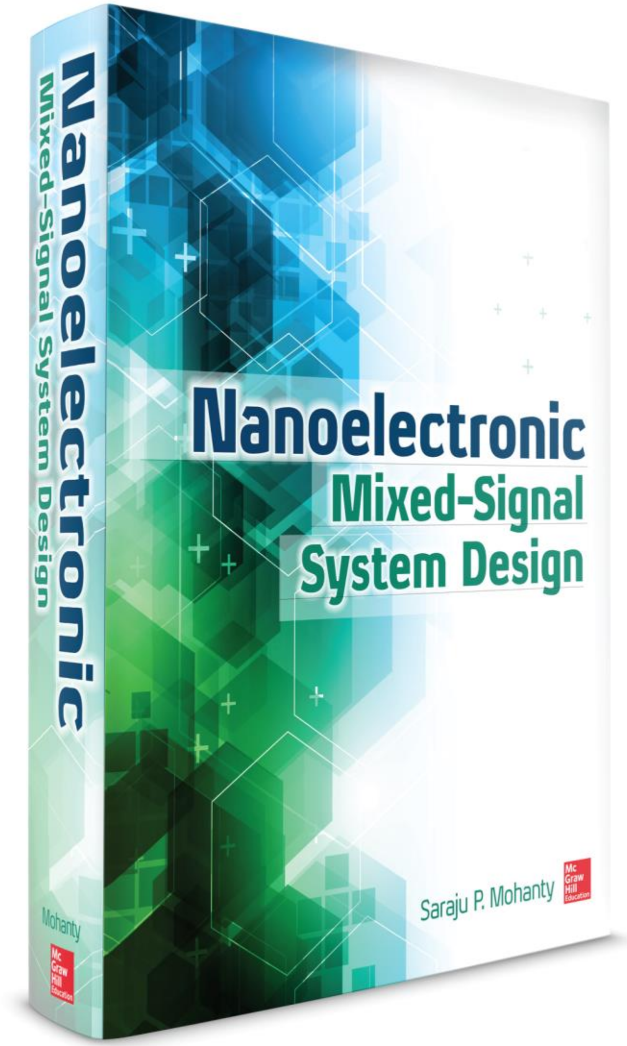


- Nano-Electro-Mechanical-Systems (NEMS) → Smart Health Care

Conclusions

- IoT components and "Things" have multifold challenges.
- Intelligent Verilog-AMS (iVAMS) is a unique framework for IoT components simulation, verification, and optimization.
- iVAMS can be used for individual components and architecture following hierarchical approach.
- Use of iVAMS and optimization algorithm speed up the design-space exploration for the design.
- Polynomial metamodels are easier create but can be applied for small designs.
- Increase in accuracy is observed using feed forward neural network over polynomial metamodels.
- Kriging and NN metamodels can handle large designs.
- iVAMS for "multidiscipline" "things" needs research.

Some Advertisement



- Winner of the Association of American Publishers' 2016 PROSE Award in the Textbook in Physical Sciences & Mathematics category.

- Cutting-edge nanoelectronic mixed-signal system design methods

Design discusses mixed-signal circuit and system design based on existing and emerging nanoelectronic technologies. The book features coverage of both digital and analog applications using nanoscale CMOS and post-CMOS. Key techniques required for design for excellence and manufacturability are discussed in this practice-driven text.

- **Color lecture slides are available.**

References

- S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", *IEEE Consumer Electronics Magazine*, July 2016, pp. .
- S. P. Mohanty, Nanoelectronic Mixed-Signal System Design, McGraw-Hill, 2015, ISBN-10: 0071825711, ISBN-13: 978-0071825719.
- J. A. Stankovic, "Research Directions for the Internet of Things", *IEEE Internet of Things Journal*, Volume: 1, Issue: 1, February 2014.
- O. Okobiah, S. P. Mohanty, and E. Kougianos, "Fast Layout Optimization through Simple Kriging Metamodeling: A Sense Amplifier Case Study", *IEEE Transactions on Very Large Scale Integration Systems*, Volume 22, Issue 4, April 2014, pp. 932--937.
- S. P. Mohanty and E. Kougianos, "Incorporating Manufacturing Process Variation Awareness in Fast Design Optimization of Nanoscale CMOS VCOs", *IEEE Transactions on Semiconductor Manufacturing*, Volume 27, Issue 1, February 2014, pp. 22--31.
- O. Garitselov, S. P. Mohanty, and E. Kougianos, "A Comparative Study of Metamodels for Fast and Accurate Simulation of Nano-CMOS Circuits", *IEEE Transactions on Semiconductor Manufacturing*, Vol. 25, No. 1, Feb 2012, pp. 26--36.
- O. Okobiah, S. P. Mohanty, and E. Kougianos, "Exploring Kriging for Fast and Accurate Design Optimization of Nanoscale Analog Circuits", in *Proceedings of the 13th IEEE Computer Society Annual Symposium on VLSI*, 2014, pp. 244--247.
- G. Zheng, S. P. Mohanty, E. Kougianos, and O. Okobiah, "Polynomial Metamodel Integrated Verilog-AMS for Memristor-Based Mixed-Signal System Design", in *Proceedings of the 56th IEEE International Midwest Symposium on Circuits & Systems*, 2013, pp. 916--919.
- G. Zheng, S. P. Mohanty, E. Kougianos, and O. Okobiah, "iVAMS: Intelligent Metamodel-Integrated Verilog-AMS for Circuit-Accurate System-Level Mixed-Signal Design Exploration", in *Proceedings of the 24th IEEE International Conference on Application-specific Systems, Architectures and Processors*, 2013, pp. 75--78.

Thank You !!!

Slides Available at:

http://www.smohanty.org