Evaluation of Body Sensor Network Platforms

A Design Space and Benchmarking Analysis

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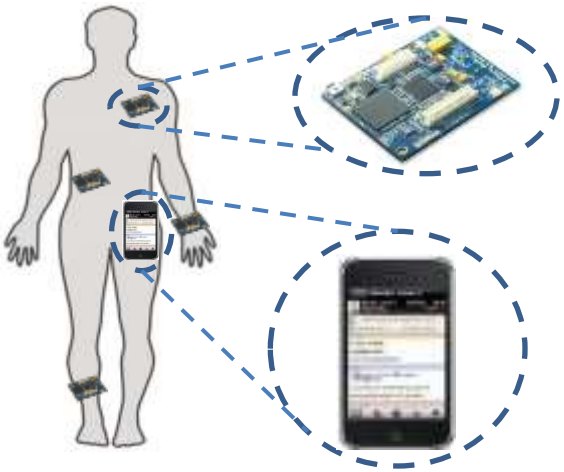
Outline

- Background and Motivation
- Proposed Evaluation Framework
  - Design Space Determination
    - Design Coordinates, Metrics and Benchmarking
  - Design Space Exploration
- Case Study
- Conclusion and Future Work

Pervasive Health Monitoring

Components Used

Miniature sensors, gateway device



Services Enabled

- **Continuous, remote** patient monitoring: No time & space restrictions
- Utilize wearable and in-vivo **medical sensors**
- Reduced medical errors
- **Early detection** of ailments and actuation through automated health data analysis

Nano-scale Blood Glucose level detector @ UIUC

L:ifeshirt @ Vivometrics

Temperature Tele-sensor @ Oak Ridge National Lab

Applications

Home-based care

Medical Facility Management

Sports Health Management

Computer Assisted Rehabilitation

Principal enabling technology: Body Sensor Networks (BSNs)

BSN Platforms

- **Components:** Microprocessor, radio, onboard memory, power supply interface, etc.
- **Applications:** Used for BSN research experiments and clinical trials.

BSN node v3

Radio – CC2420+ miniaturized chip antenna
Processor – MSP430

Shimmer

Radio – CC2420 (802.15.4) + RN-42 (Bluetooth)
Processor – MSP430

TelosB

Radio – CC2420 + Inverted-F antenna
Processor – MSP430

Imote2

Radio – CC2420 + Surface mount antenna
Processor – Intel Xscale

Diversity in available platforms- How to choose?

Job Hiring Example

EMPLOYER

- Knows job requirements
- Defines candidate qualifications
- Reviews multiple candidates
- Checks performance
- Selects most suitable candidate

CANDIDATES

- Provide resume
- Understand market requirements and peer competition
- Acquire new skills to improve

Standard evaluation method and well-understood performance metrics enable candidate selection

BSN Platform Selection

BSN PLATFORM USER

- Uses BSN platforms for research or clinical trials
- Knows application requirements
- Need to map to platform specifications
- Need to quantify platform performance

PLATFORM DESIGNERS

- Provide datasheet
- Need to improve design based on new, emerging applications
- Need to objectively compare performance of multiple platforms

Lack of standard evaluation method and performance metrics

Main Idea

Available Platforms

Application Requirements

Common set of parameters

Desirable parameter values

Select platform satisfying most/all constraints

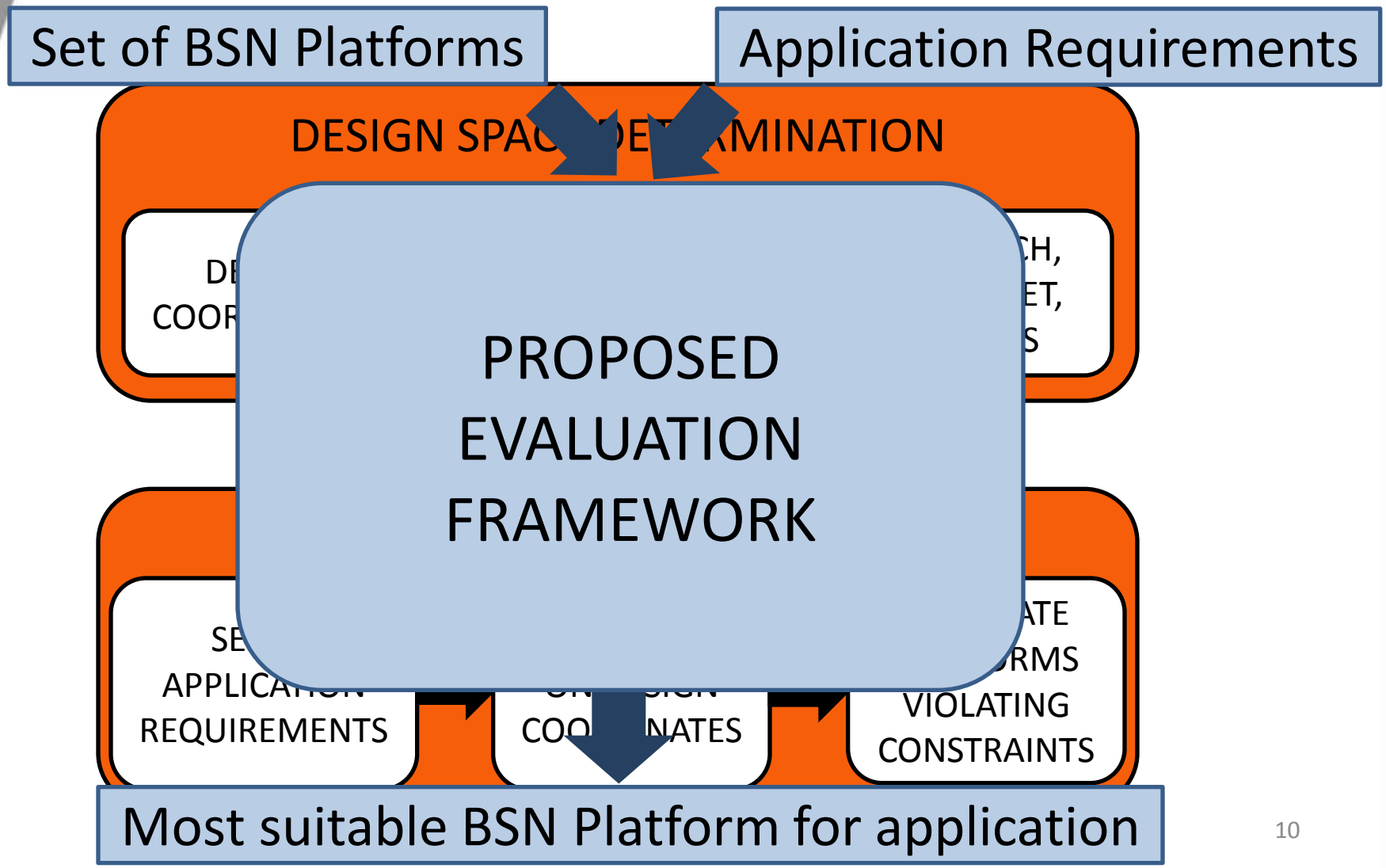
Research Challenges

- Mapping diverse platforms to common evaluation ground
  - ***Design Coordinate:*** A feature of the BSN platform that determines its performance, e.g. Available Memory.
  - ***Design Space:*** The space defined by the design coordinates
- Quantify design coordinates, performance parameters
  - ***Evaluation Metrics,*** e.g. kB of RAM, W of power consumed
- Measure performance in real application scenarios
  - Develop ***benchmarks*** based on BSN applications
- Search design space for suitable platform

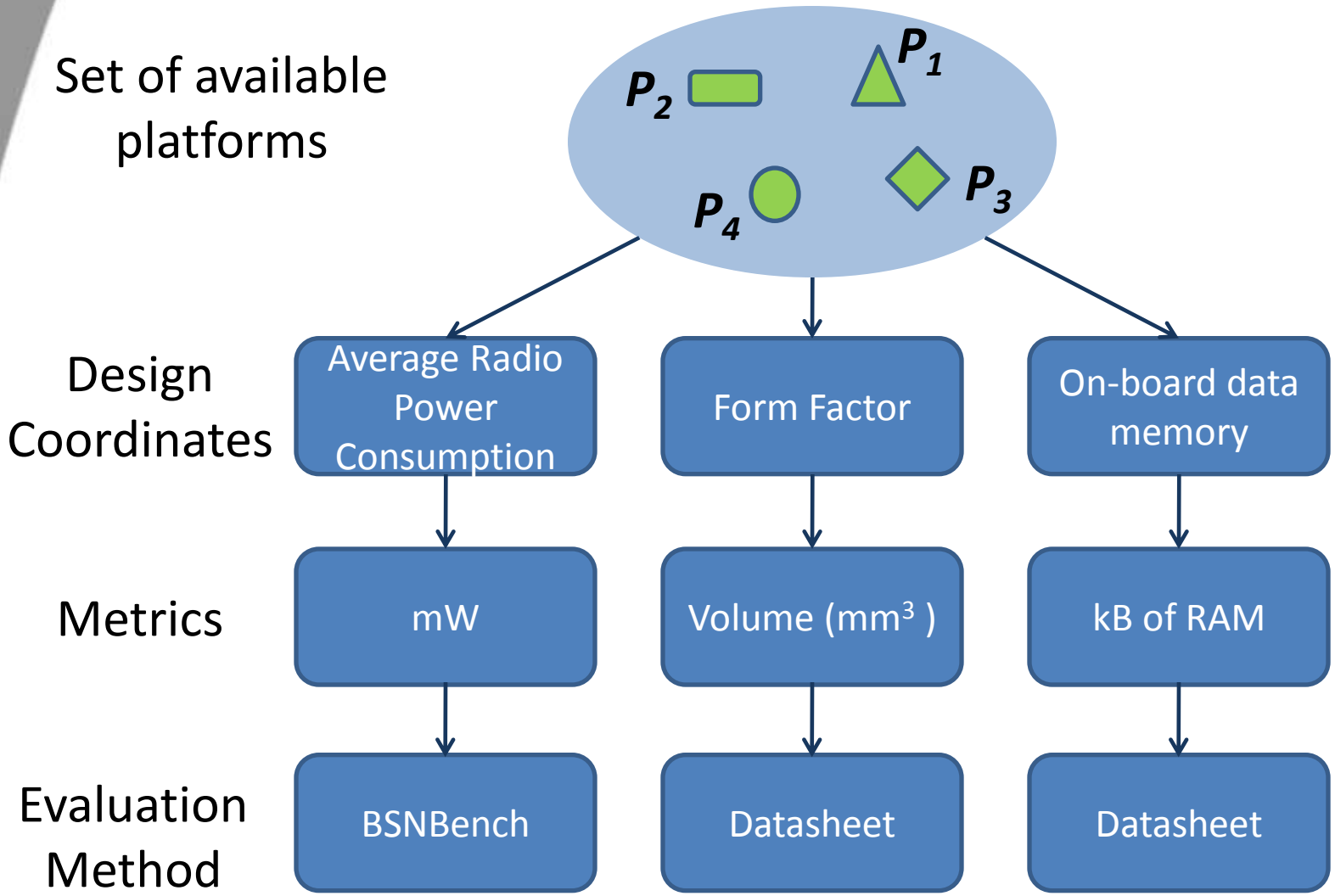
Goal and Contributions

- **Goal:** Evaluation Framework for BSN platforms
- **Contributions:**
  - Identify **design coordinates** for BSN platforms
  - Map a given platform to a point in the design space:
    - Use metrics to quantify design coordinates, **define two new metrics** for BSN platforms.
    - Develop BSN-specific benchmarking suite: **BSNBench**
  - Provide a method to **search the design space**

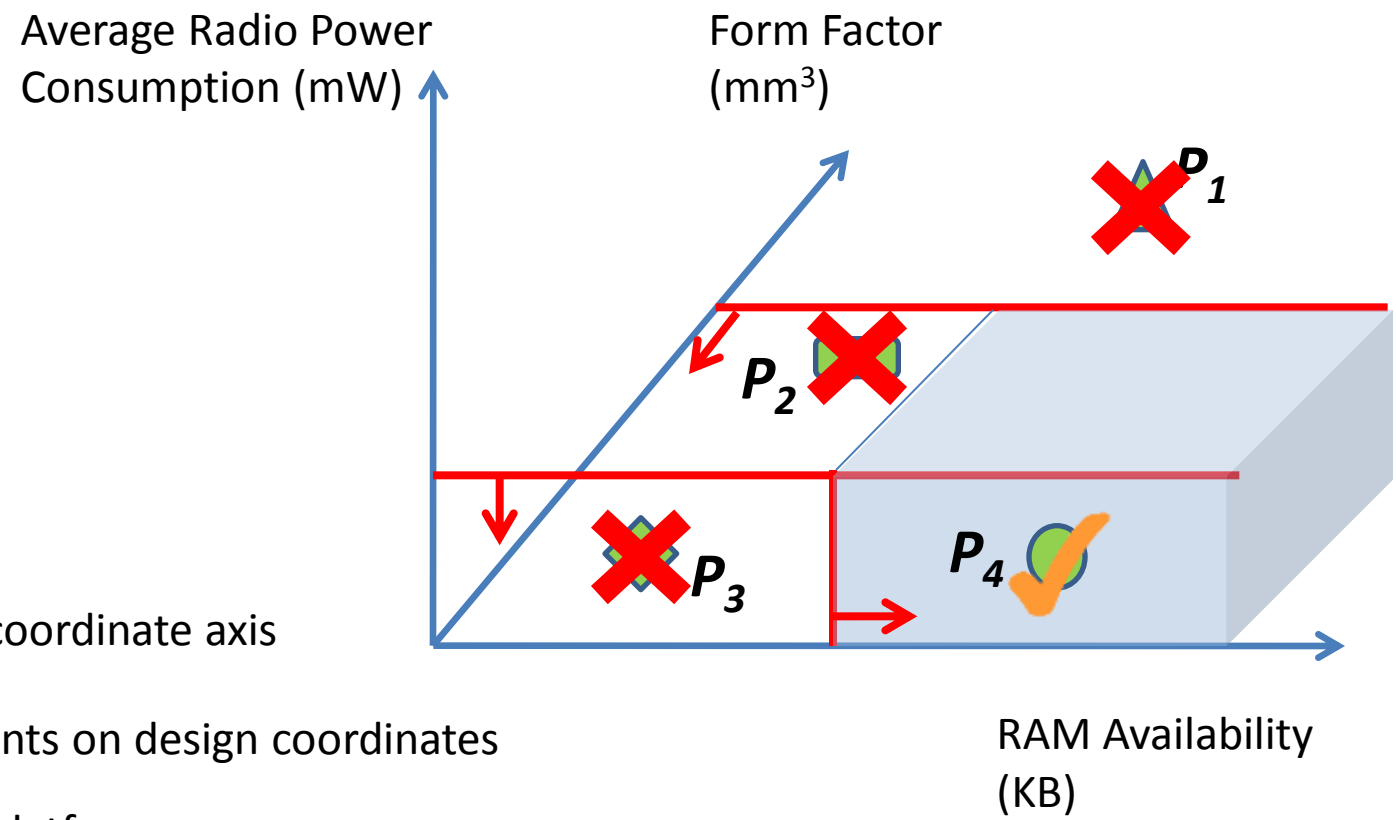
Proposed Evaluation Framework



Example: Design Space Determination

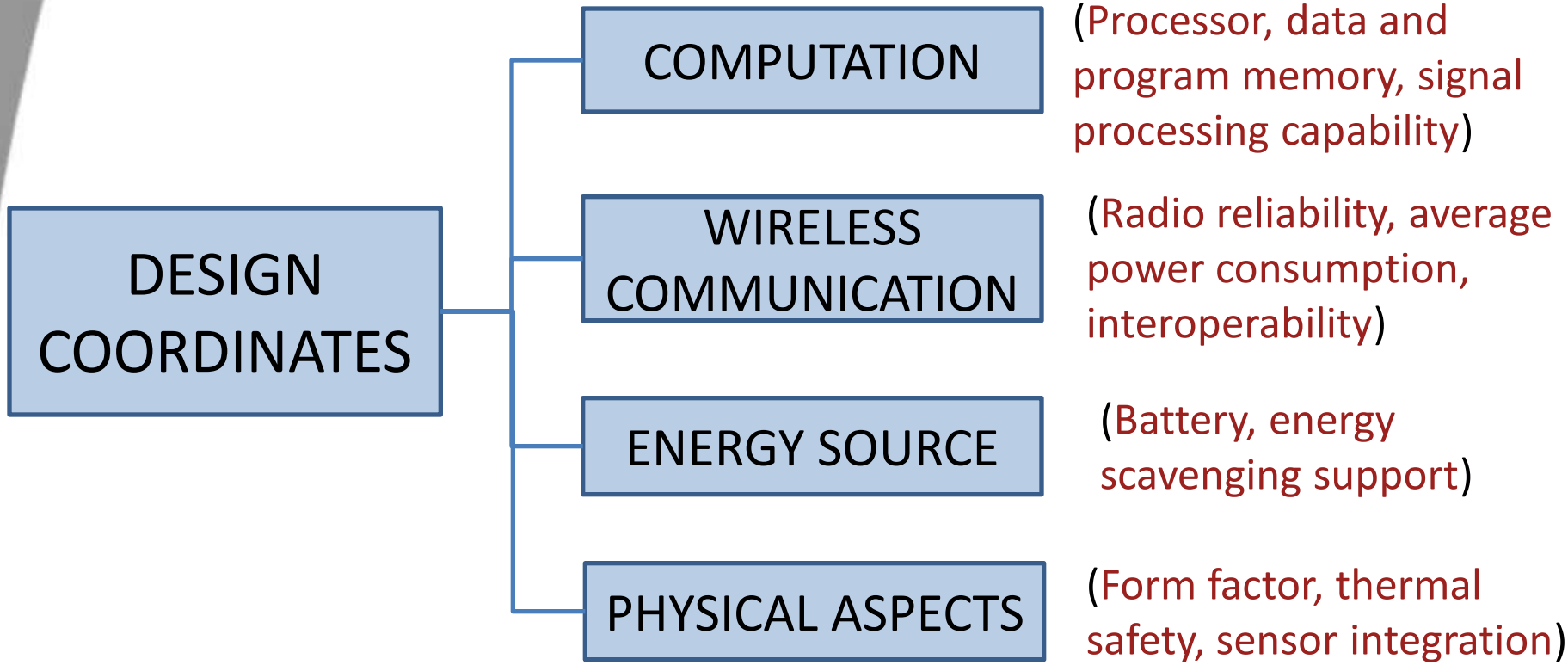


Example: Design Space Exploration



Design Coordinates

- Based on typical BSN application requirements
- Decompose platform functionality into individual modules



Evaluation Metrics

- Use suitable metrics to quantify design coordinates:

Design Coordinate	Metric
Radio Reliability	On-body PDR [1]
Battery	Capacity (mAh), size (mm^3)

- Some traditional metrics are independent of the target applications. e.g. MIPS, MIPS/W
- Consider BSN application characteristics to develop more suitable metrics.
  - For example, processor speed measured in units of samples processed per second

[1] A. Natarajan, B. Silva, K. Yap, and M. Motani. To hop or not to hop: Network architecture for body sensor networks. In IEEE SECON, 2009.

SPSW Metric for Processor

- SPSW (Samples Processed per Second per Watt) is defined as:

$$SPSW = \frac{(\text{No. of Samples Processed})}{(\text{Time taken})\,(\text{Power consumed})}$$

- Captures tradeoff between processor speed and power consumption.
- "Processing a sample" is application-specific.
- For example, a platform motes calculates mean of 1000 data samples in 100 ms and consume 25 mW power. Then,

SPSW = 1000/(100 X 25) = 400 samples/mJ

EPC Metric for Radio

- Radio power consumption depends on radio specifications as well as duty cycle.
- EPC (Expected Power Consumption) is defined as:

$$EPC = \sum_{\text{all states}} \left[\text{Fraction of time in state S} * \text{Power consumed in state S} \right]$$

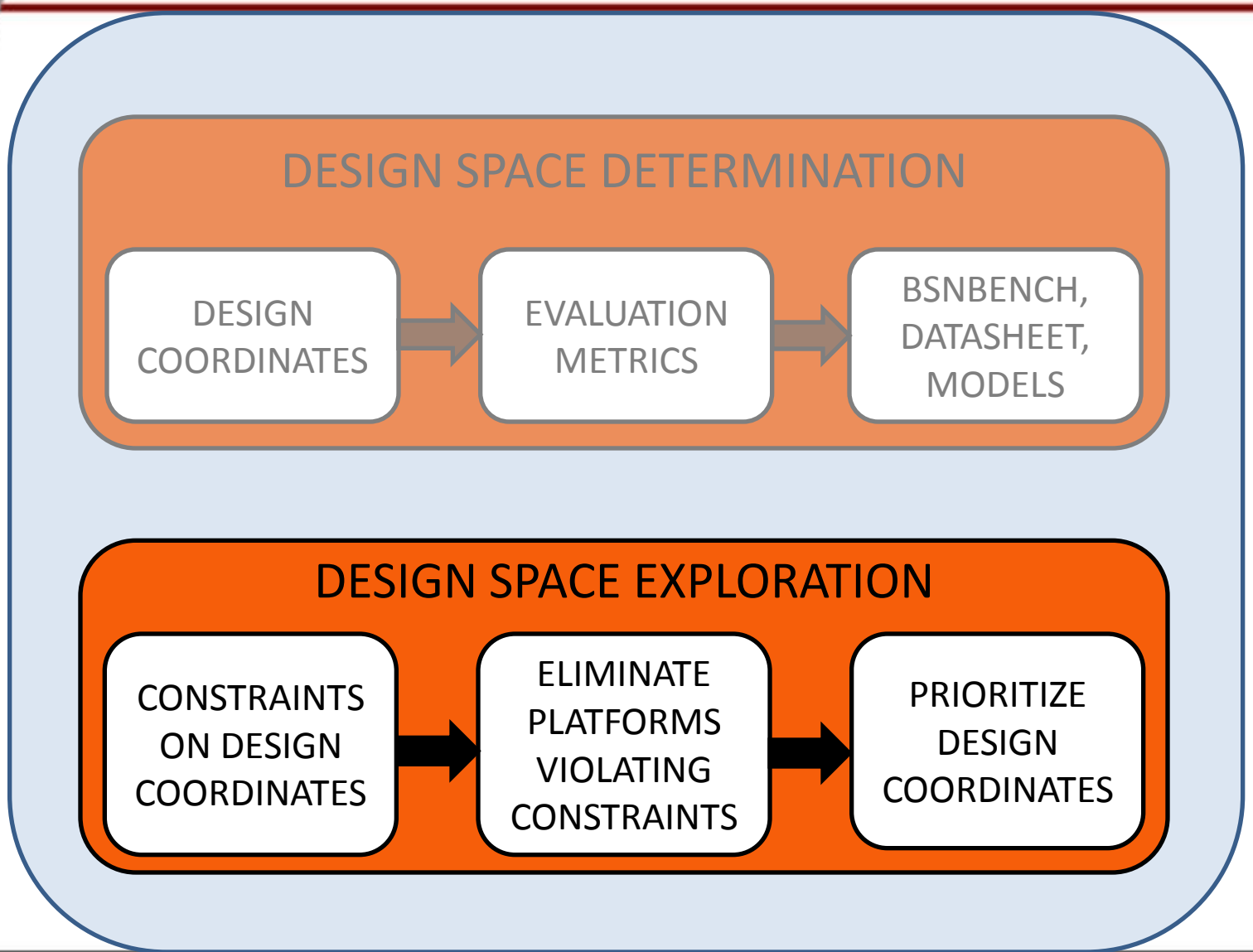
- For example, if radio transmits for 5% time, with power draw 10 mW and is in SLEEP state for remaining 95% time, with power 0.1 mW,

EPC = 0.05 * 10 + 0.95 * 0.1 = 0.595 mW

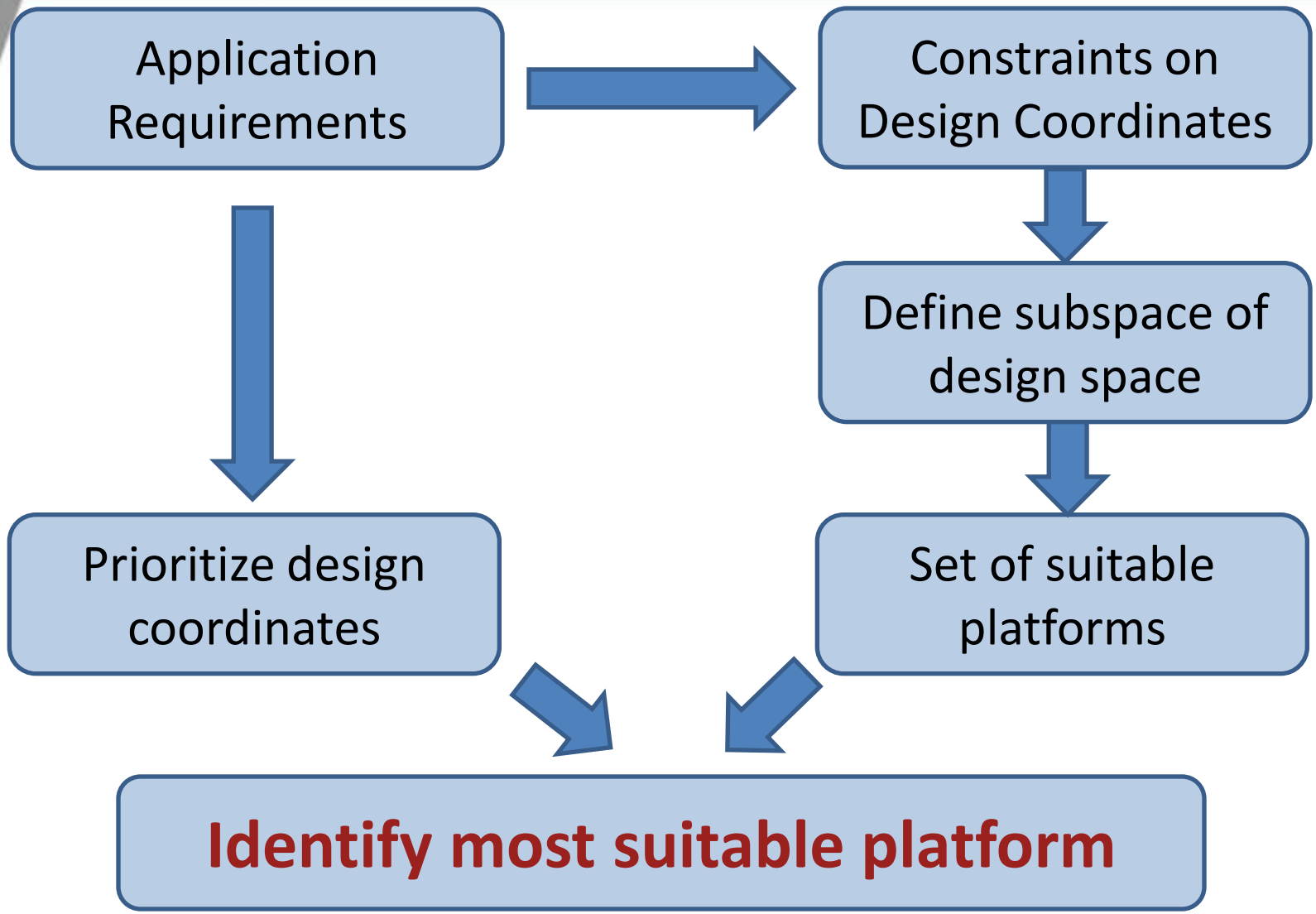
BSNBench: A BSN-specific benchmark

- **Key Observation:** In spite of diversity in BSN applications, some basic tasks are common.
- **Type of benchmark:** Microbenchmark
- **Composition:**
  - Data Operations (Statistics, Differential Encoding)
  - Signal Processing (FFT, Peak detection)
  - Radio Communication (Duty-cycled handshake)
  - Sensor Interface (Sensed Data Query)
- Implemented in TinyOS 2.0

Evaluation Framework Workflow



Design Space Exploration



Case Study

- We consider two typical BSN applications:

1. Continuous Glucose Monitoring (CGM):

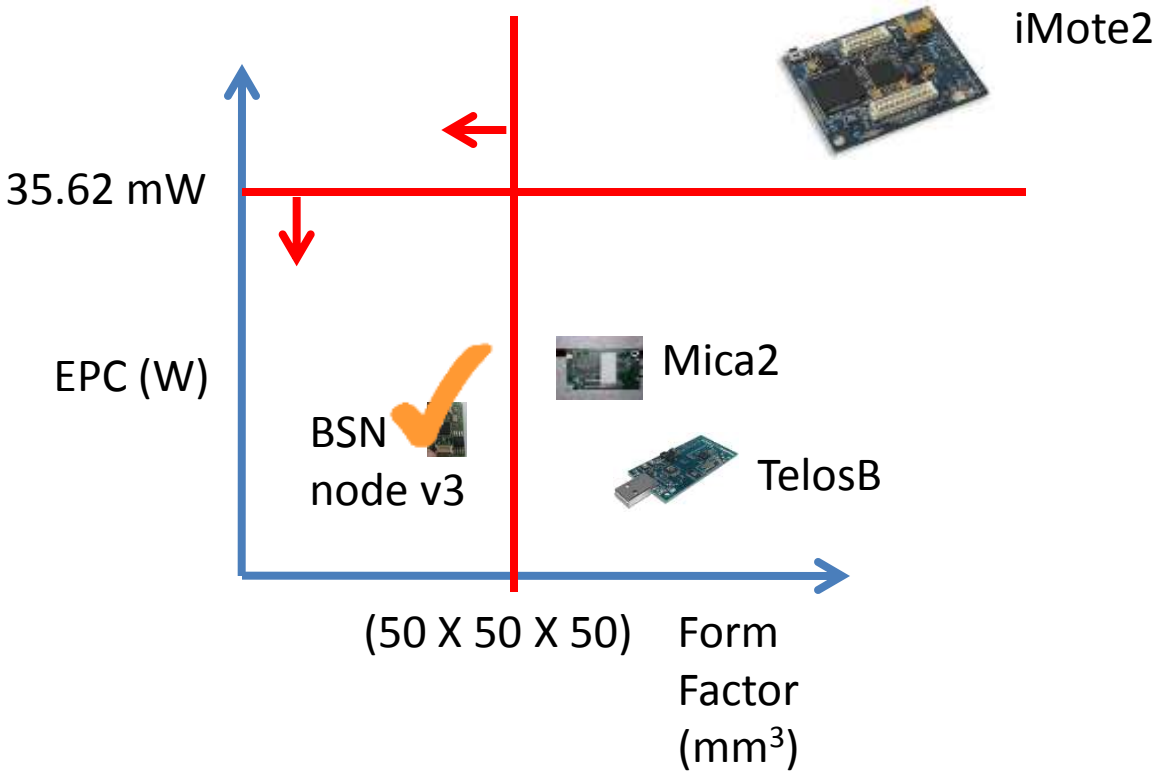
- Long term monitoring application
- Sensor measures the blood glucose level and transmits this data to a gateway device.

2. Epileptic Seizure Detection (ESD):

- Detect onset of epileptic seizures using an ECG sensor.
- Perform peak detection on ECG signal to calculate RR intervals.
- Intervals are converted to FFT coefficients and sent to the gateway device.

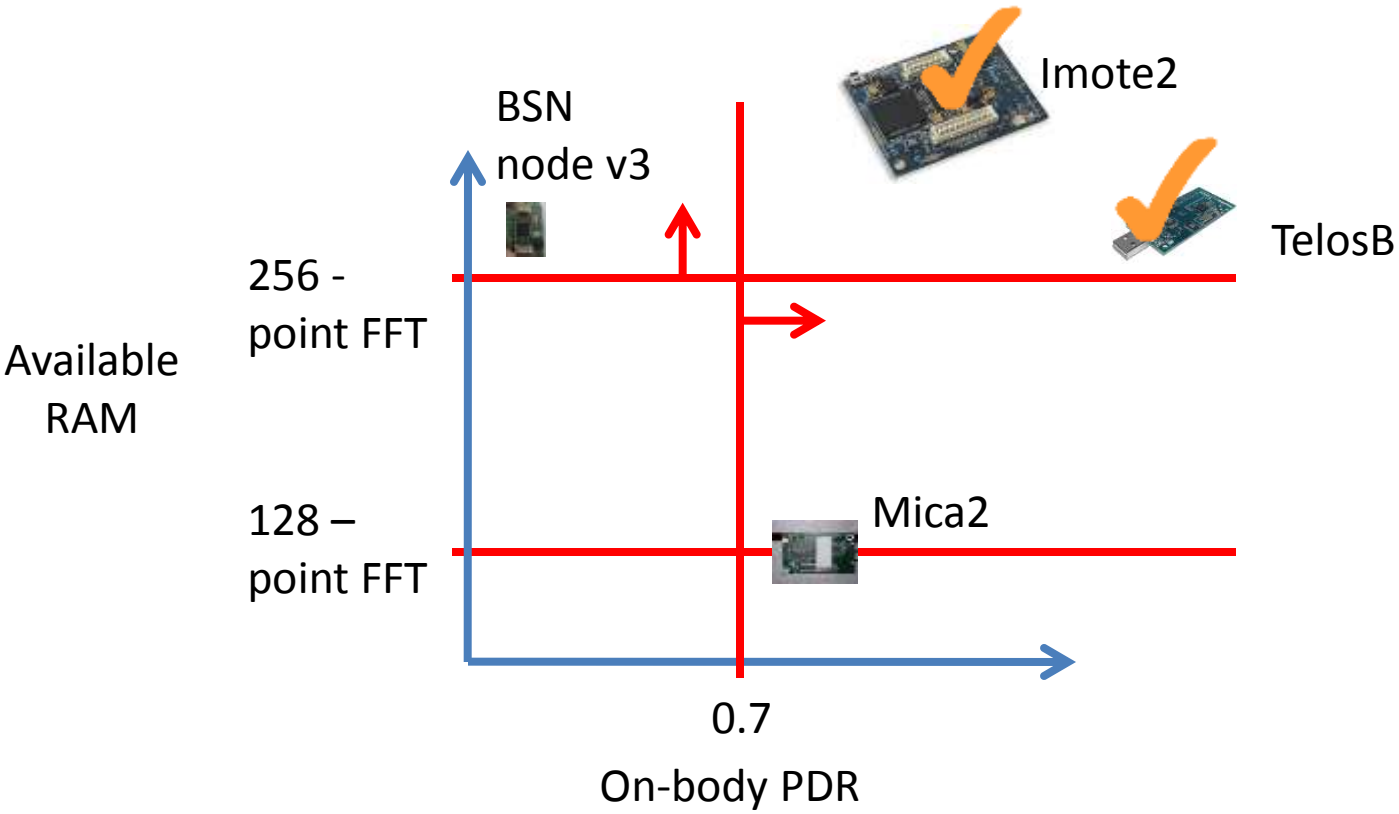
Case Study: CGM

- Set of platforms: TelosB, Mica2, Imote2 and BSN v3
- Constraints on EPC and Form Factor coordinates



Case Study: ESD

- Constraints on signal processing capability and communication reliability (on-body PDR)



Conclusion and Future Work

- Conclusion
  - Proposed design space approach for evaluation framework
  - Identified design coordinates for BSN platforms
  - Developed novel, BSN-specific metrics
  - Proposed benchmarking suite for BSNs
- Future work
  - Extend BSNBench by including data privacy tasks
  - Complex objective functions in design space exploration.
  - Extend set of design coordinates: fault tolerance, etc.
  - Explore metrics for human centric evaluation

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Thank You!

Questions and Comments?

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BSNBench: Composition

Section	Task	Example BSN Applications
DATA OPERATIONS	Statistics	Glucose Monitoring
	Out-of-Range	Posture monitoring (accelerometer)
	Differential Encoding	Temperature Recording
SIGNAL PROCESSING	Fast Fourier Transform	Electromyography (EMG) analysis
	FIR filtering	Motion analysis, De-noising data
	Peak detection	ECG analysis
RADIO COMMUNICATION	Duty-cycled handshake	All wireless BSN applications
	Reliable communication	Applications with on-body gateway device
SENSOR INTERFACE	Sensed Data Query	All sensing applications

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References

[1] http://ubimon.doc.ic.ac.uk/bsn/a1875.html

[2] K. Lorincz, B. Kuris, S. Ayer, S. Patel, P. Bonato, and M. Welsh. Wearable wireless sensor network to assess clinical status in patients with neurological disorders. In Proceedings of the 6th international conference on Information processing in sensor networks. ACM, 2007.

[3] C. Park, J. Liu, and P. Chou. Eco: an ultra-compact low-power wireless sensor node for real-time motion monitoring. In IPSN 2005., pages 398–403.

[4] M. Hempstead, M. Welsh, and D. Brooks. TinyBench: The case for a standardized benchmark suite for TinyOS based wireless sensor network devices. 2004.

[5] L. Nazhandali, M. Minuth, and T. Austin. SenseBench: toward an accurate evaluation of sensor network processors. In Workload Characterization Symposium, 2005. Proceedings of the IEEE International, pages 197–203

[6] A. Natarajan, B. Silva, K. Yap, and M. Motani. To hop or not to hop: Network architecture for body sensor networks. In IEEE SECON, 2009.