Network Agility
&
Network Services/Management

in

Demand Response/Sensor Networks

{P.A.Subrahmanyam, Bob Brodersen, John Wawrzynek, Sue Mellers, Mubaraq Mishra}

Acknowledgements

- Many thanks for their patience & support!
  - CEC/CIEE
    - Gaymond Yee
    - Ron Hofmann
      - Technical Advisory Committee (TAC)
  - Team
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    - Prof John Wawrzynek
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    - Profs Dave Auslander, Ed Arens, Jan Rabaey, R. White, Paul Wright
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- Industry Partners

Agenda

- Project overview
- Agile Radio Node
  - Broadband Capability
    - SDR/RF front end design
  - Interference Mitigation
    - Cognitive Techniques
      - Coexistence of WiMax & UWB (Ultra Wide Band)

Network Agility: Why? And Why Now?….

Context:
Demand Response & Energy Efficiency: Key to Strategic Energy Policy Imperatives

- Business & Application Drivers (Demand Response & Advanced Metering Infrastructure)
  - Proliferation of (radio) standards for Personal, Home, Local, Metropolitan, Wide Area Networks
  - Need to support future proofing
    - Trade-offs vary: Infrastructure vs. terminals vs. consumer devices vs. sensors
      - Metrics include: Life span, power, cost, flexibility, business processes…
  - Need for lifecycle support of service/product: provisioning, monitoring, management

MOTIVATION FOR THIS RESEARCH

- Enabling Technologies
  - Agile Radios: (Re)configurable, Software Defined, Cognitive
  - Reconfigurable systems
  - Networking: Hand off, Cross-layer optimization,
  - Service Delivery & Management, …

What is (Network) Agility?… and Why it is important in the Demand-Response Context?

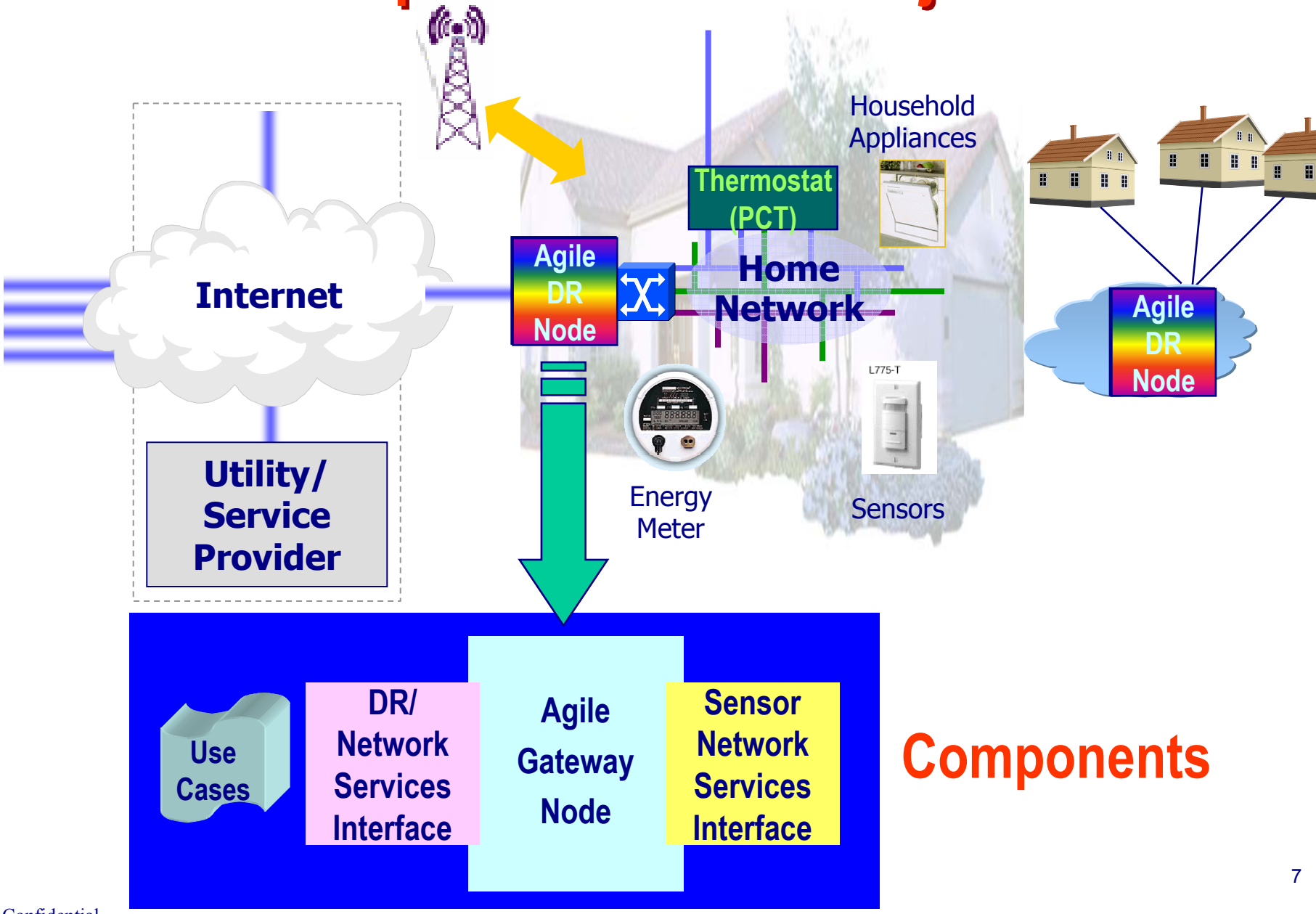
- An Agile (Radio/Gateway) Node has the ability to communicate over more than one Air Interface (Wireless Protocol/Standard).
  - E.g., Bluetooth, IEEE 802.11 b/g, IEEE 802.15.4, …
  - Flavors of agility:
    - Protocol Agility (choose from multiple networks/protocols)
    - RF Agility (operate in more than one frequency bands)
    - Cognitive (Spectrum) agility (leverage underutilized spectrum bands)
- A Software Defined Radio node has the further ability to have its air interfaces defined and provisioned in the field.

- The use of agility in a Demand Response network can
  - Help reduce stranded assets by supporting legacy radio/sensor interfaces, (Reduce Capex)
  - "Future-proof" deployments and reducing operational costs by enabling software download of new radio functionality, and enhanced services. (Reduced Capex & Opex)
  - Provide a superior ability to manage, upgrade and provision new services.

What is Network Services & Management? …Relevance in the DR context

- A utility (e.g., PG&E) needs to
  - Define the DR services that are offered to a customer
  - Provision the specific service that is offered to/chosen by the customer …
- The menu of services may change over time.
  - New services/capabilities, value added features, …
- Network Services Delivery and Management involves the delivery, provisioning, deployment and ongoing management of network services.

Demand-Response Context :Project Goals

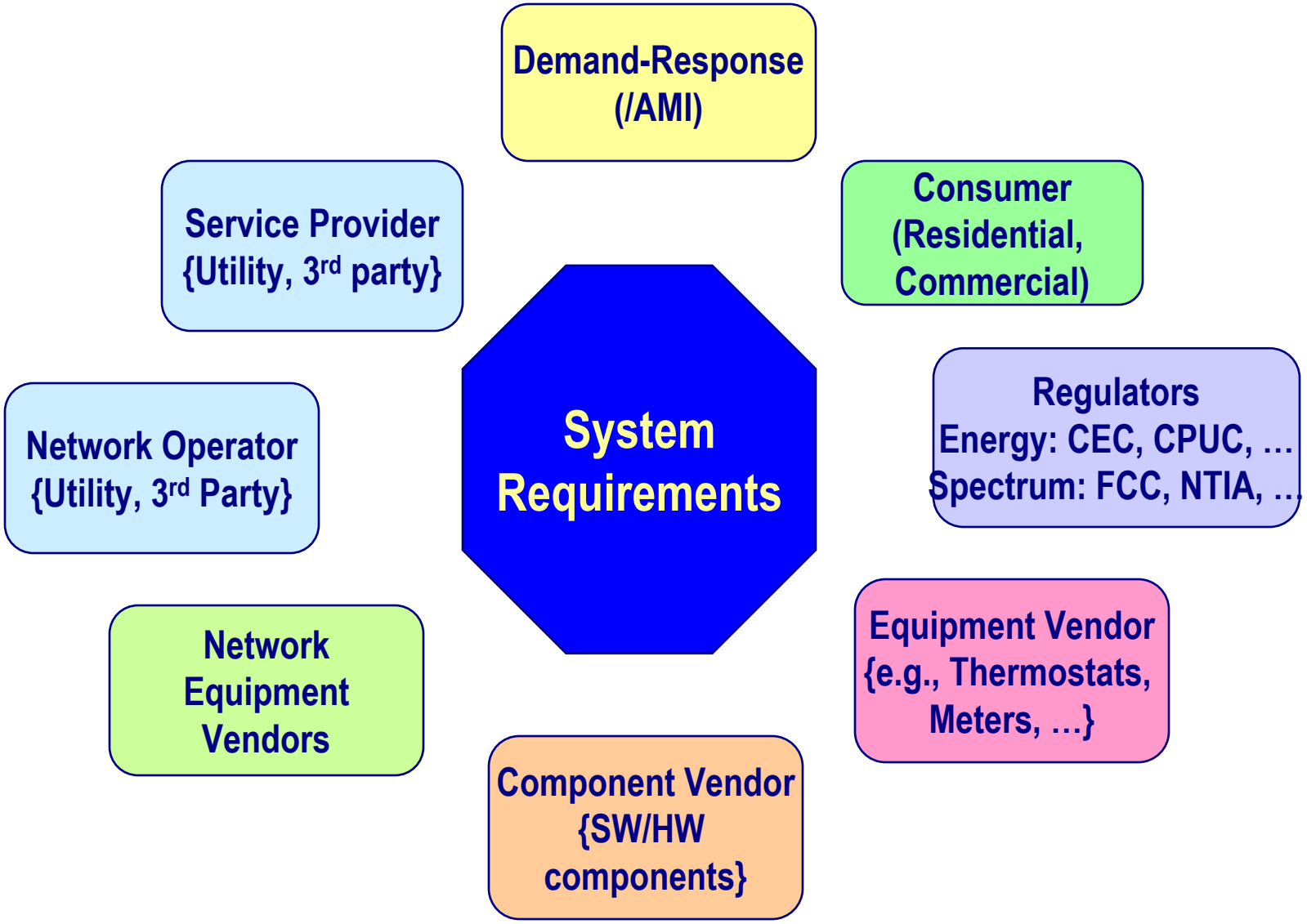


Use Case Scenarios

Perspectives of various actors in the DR context

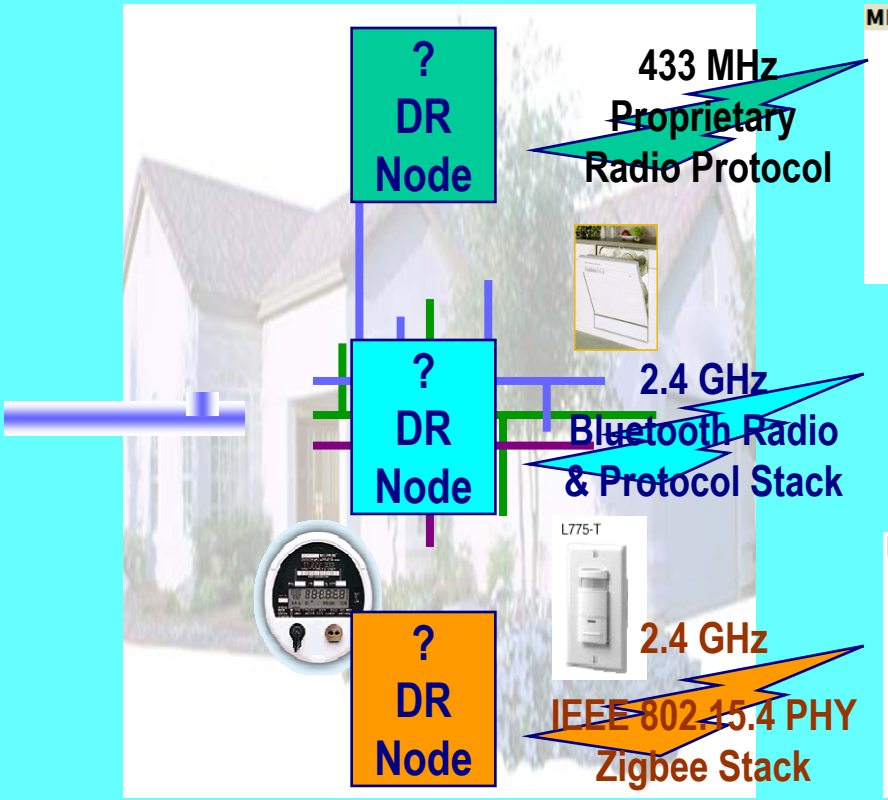
➔System Requirements / Capabilities Needed

Use Case Scenarios: Actors & Perspectives



Traditional (Non-Agile) DR Gateway Node: Communication within the Home.

Several (Incompatible) Deployment Alternatives just during (2000-05) would have resulted in "Stranded" devices/HW/SW/…, meters, infrastructure, …



TOSHIBA Bluetooth Enabled Dryer, A/C, Microwave, …

Others standards: e.g.,

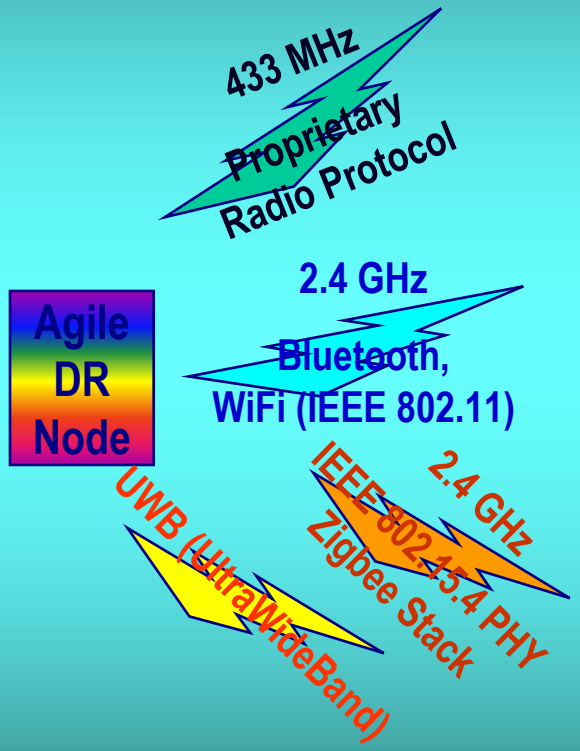
2.4 GHz/5.x GHz

IEEE 802.11 a/b/g/l/n/…, Z-wave, …

Agile Radio DR Gateway/Platform Goals:
Agility in External/Internal Communications within the Home.

Multiple Protocols can be remotely provisioned/downloaded

➔ Dramatic reduction in "Stranded" devices/HW/SW/infrastructure, …



TOSHIBA
Bluetooth Enabled
Dryer,
A/C, Microwave, …

Internal

Agile Radio DR Gateway/Platform Goals:
Agility in External/Internal Communications within the Home.

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800-900 MHz
1.8-1.9 GHz

2G, 3G,
CDMA, WCDMA,
UMTS,

Mobile cellular or satellite link

433 MHz
Proprietary Radio Protocol

MEP410CA– Micro Climate Multi-Sensor Node

- 433 MHz Radio
- Proprietary Protocol

Wi Fi

2.4 GHz
IEEE 802.11b

- 2.4 GHz Radio
- IEEE 802.11b

IEEE 802.11 b/g/n/…

Agile DR Node

2.4 GHz
Bluetooth,
WiFi (IEEE 802.11)

TOSHIBA
Bluetooth Enabled
Dryer,
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UWB (UltraWideBand)

IEEE 802.15.4 PHY
2.4 GHz
ZigBee Stack

MICAz - 2.4 GHz IEEE 804.15.4/ZigBee™ Compliant Mote

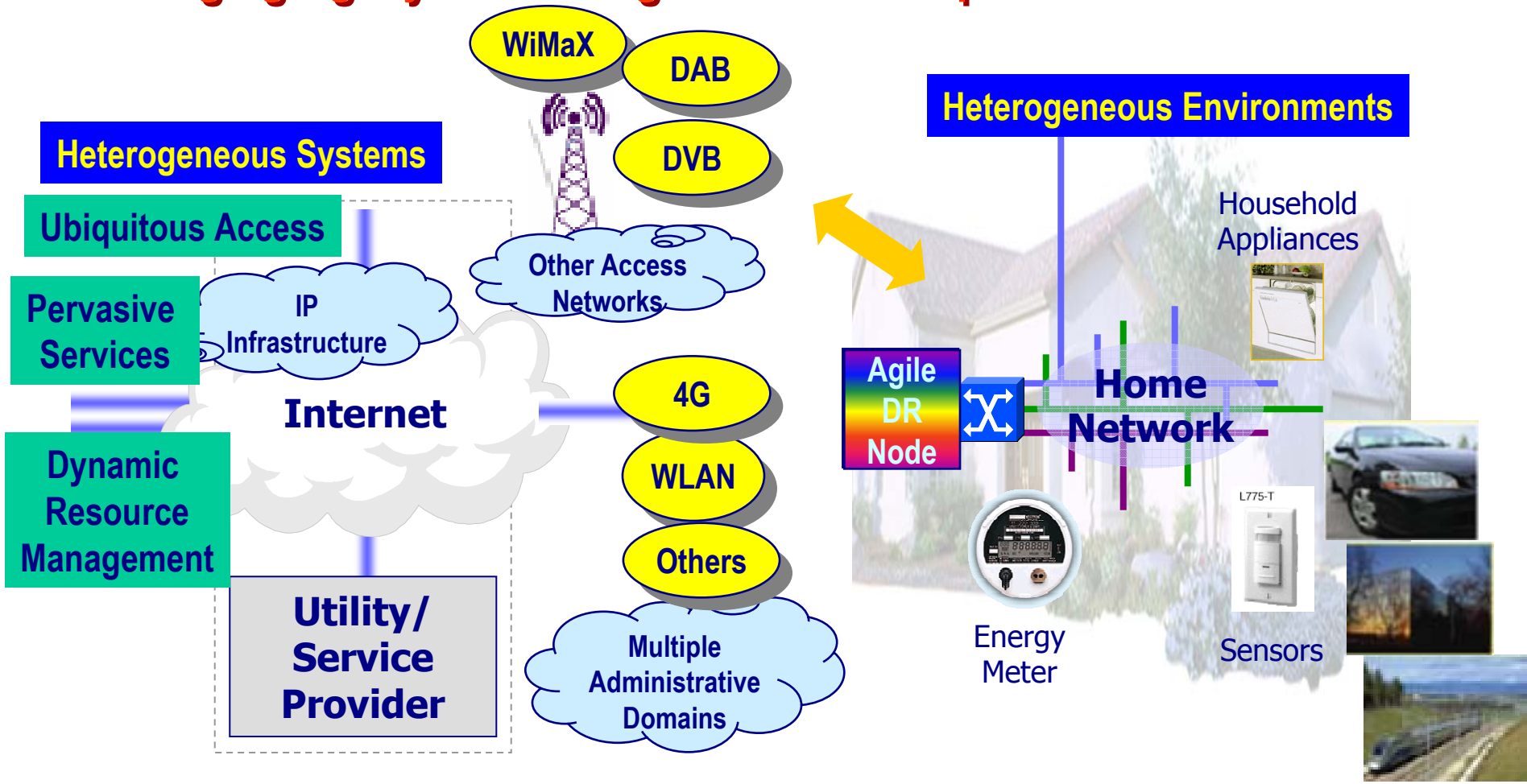
- 2.4GHz band
- IEEE 802.15.4/ ZigBee™ radio

2.5/… GHz

- 2.5/3.5/5.8 GHz Radio
- IEEE 802.16, WiMAX

External ← → Internal

End-to-end Reconfigurability –
Leveraging Agility & Enabling a seamless experience



Heterogeneous Devices

Use Case Scenarios: DR Perspective

- Demand-Response context (DR/AMI)
  - Agile platform should support evolution of devices/standards internal/external to the home.
    - Most likely in the gateway, AMI, …
      - And in the network infrastructure (Basestations/APs)
  - In particular,
    - Support for 1-way & 2-way communication w/utility and ISO.
    - Enable a progression from PCT to (Advanced meter + Distributed Thermostat) deployment.
  - Other short-term "niche" needs may include RDS & a utility-specific broadband mechanism (wired/wireless)

Use Case Scenarios: AMI/Home Networking Perspective

- AMI/Home Networking/DR Perspective
  - Should support emerging communication modalities, since it is long lasting infrastructure (~15-20 years)
    - Need to support (or interface with) gateway functionality for external and internal communications
      - Internal: PAN, LAN, HAN,
        - » Benefit from agile radio platform/components, capable of supporting 802.11, Zigbee, WiMax, UWB, …
      - External: MAN, WAN
  - Should support service deployment and management

Use Case Scenarios: Operator/Service Provider Perspective

- Network Operator/Service Provider Perspective
  - Enable new services to be delivered
  - Lifecycle support for services/products
    - Network Services Management and Delivery
    - Enable remote monitoring of the devices and home network.
      - Subject to privacy and security requirements and specifications.
- ➔ Support for end-to-end reconfigurability

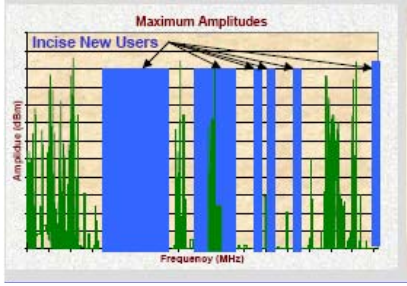
Use Case Scenarios: DR Specific Recommendations

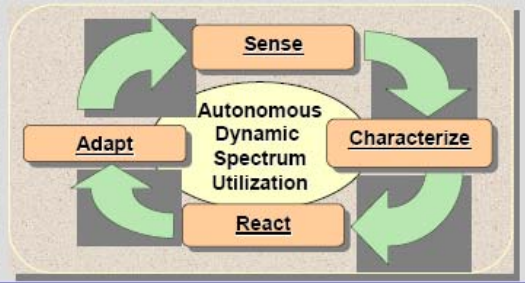
- Desirable capabilities in the context of DR/AMI/HAN
  - Agile operation in the 2.4 GHz, and 900 MHz ISM bands
  - Support for protocols such as
    - WiFi
    - ZigBee, ZWave, …
    - Bluetooth,
    - UWB
    - WiMAX
  - Ability to support updates to these standards
  - Service Delivery and software download/update support

Agile Radio Platform

- As a result of our investigations related to use case scenarios, we target agility across the 900 and 2.4 GHz ISM bands. (+ 700 MHz TV bands).

Two faces of Agility: Broadband Agility & Interference Mitigation





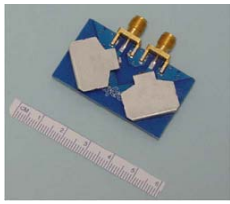
- Agile = {Software Defined, Cognitive}
- Research focus: Two aspects of Agility
  - Capability to communicate
    - over a broad range of frequencies (transmit, receive)
    - using new air interface standards as they evolve (software downloadable, agile baseband)
  - Mitigating interference
    - While communicating over a broad range of frequencies
      - Being cognizant of interference with other modalities/frequencies
        - » E.g., UWB is an emerging indoor technology, WiMax is an emerging metropolitan LAN/broadband access technology.
      - What are the co-existence issues involved?

Agile Radio: Broadband Radio Platform. *Components*

- Agile Platform Components
  - Antenna (Broadband)
    - Electromagnetic Waves → Analog Electrical Signal
  - RF Front End (Broadband)
    - Analog Electrical Signal (RF) → Digitized Signal in Band/Channel of interest
  - Baseband
    - Processes digitized signal
      - Modem, Protocols, Applications, …

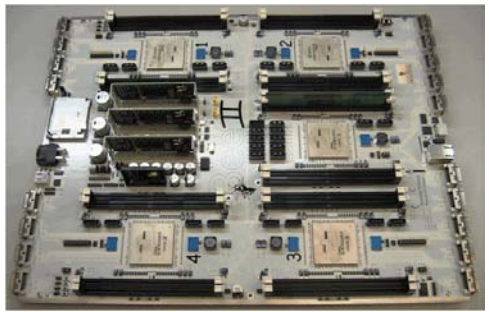
Agile Radio: Broadband Radio Platform. *Approach*

- Antenna
  - Approaches:
    - Existing “traditional” antennas in lab (2.4 GHz, …)
      - » Initial approach
    - Evolving to Smaller set of Broadband (small profile) antennas
      - » Emerging arena. Set of antennas identified.

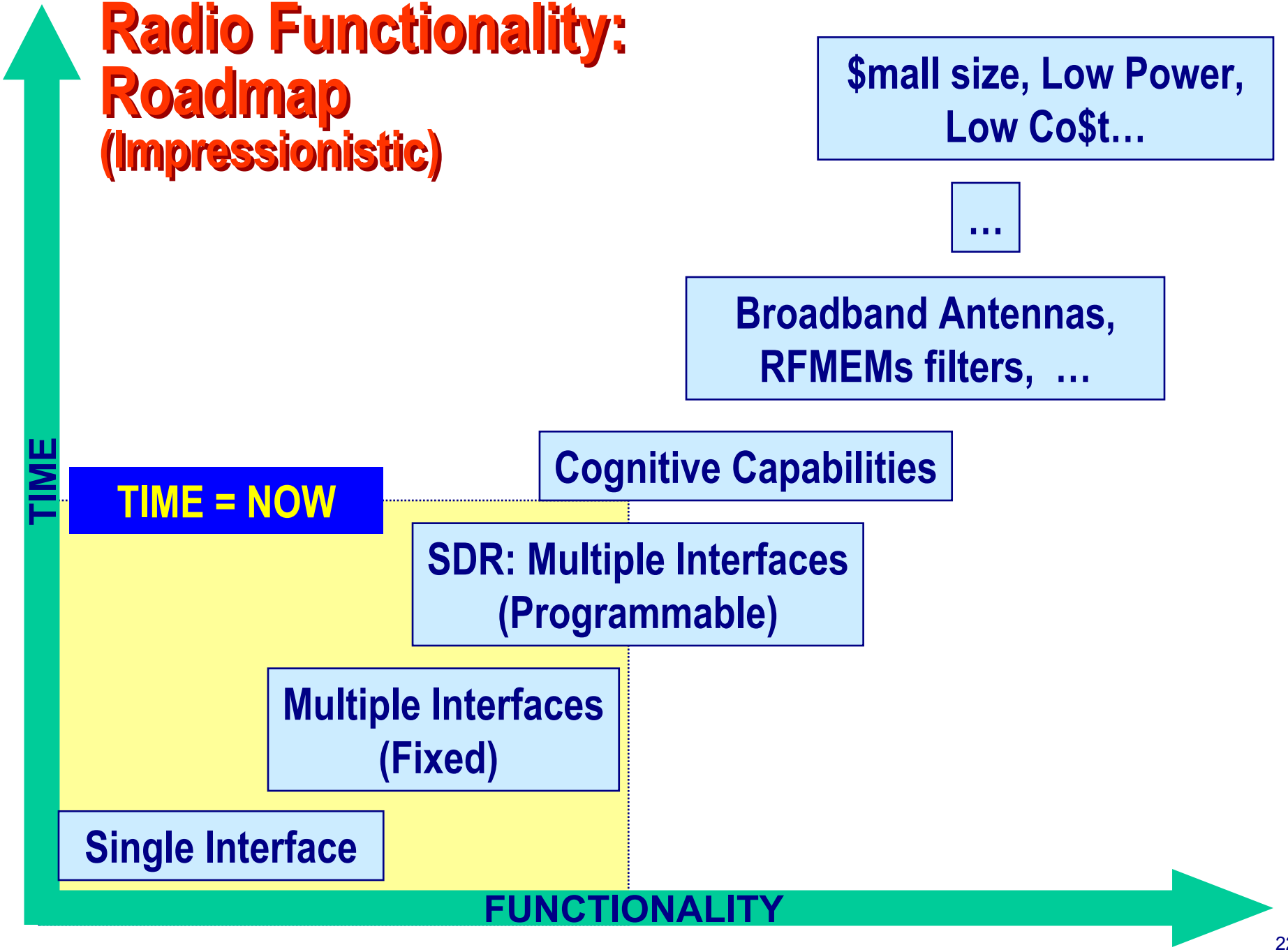


- RF Front End (Broadband)
  - Approaches:
    - “Broadband” Front ends
      - » SDR Architecture with Multiple front ends in initial experiment

- Baseband:
  - Leverages BEE2 (Berkeley Emulation Engine 2)
    - Configurable compute platform, high speed I/O, S/W
  - Eventually: Compact, low power, low cost ASIC?



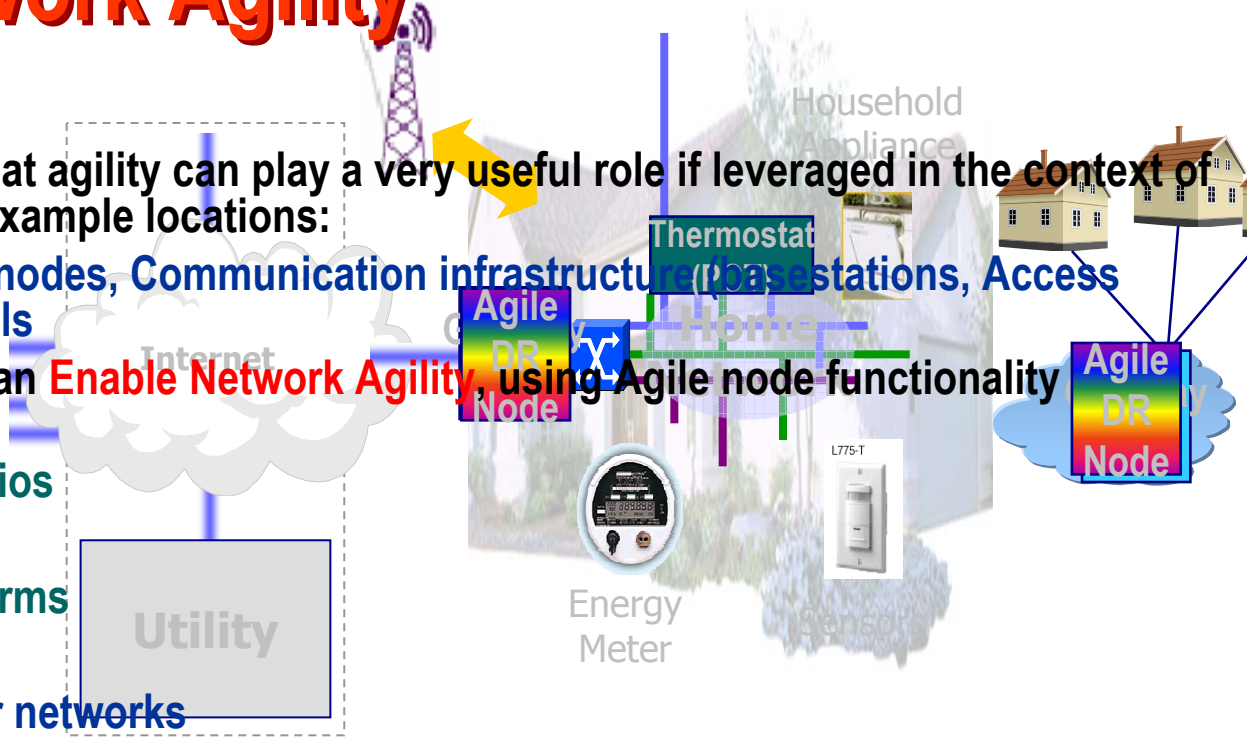
Radio Functionality: Roadmap (Impressionistic)



Agile Radio: Cognitive Capabilities for Interference Mitigation.

- Cognitive techniques enable heterogeneous systems to coexist, and improve spectrum utilization.
- Secondary system (e.g., UWB) must be cognitive radio enabled and must sense and avoid the Primary system (e.g., WiMax)
- Cognitive Radio functionality can be incorporated into existing radios with minimal area impact (~ 1mm^2)
- WiMax/UWB can function together with minimal impact on performance of either system

Summary: Network Agility



- Use-case scenarios suggest that agility can play a very useful role if leveraged in the context of Demand-response networks. Example locations:
  - Gateways, Neighborhood nodes, Communication infrastructure (basestations, Access points), Advanced terminals
- Developed technologies that can Enable Network Agility, using Agile node functionality leveraging
    - Software Defined Radios
    - Cognitive techniques
    - Reconfigurable Platforms
  - Service delivery
  - Management of DR/sensor networks
- Benefits:
  - Manage differences in attributes of components technologies deployed: half-life, reliability, business processes, costs, …
    - E.g., Utility infrastructure (15-20 yrs) ⇔ Consumer (1/2/5 – 10+ yrs).
  - Reduces Capital and Operating Expenditures
  - Future Proofing: "Gracefully" evolution in the DR/AMI/HAN contexts.
  - Enables lifecycle support for service/product: provisioning, monitoring, management
- Phased Approach: Concepts and Architecture (Phase I) ➔ Prototype components (Phase II)

Agile Radio Platform:
SDR Front End Design

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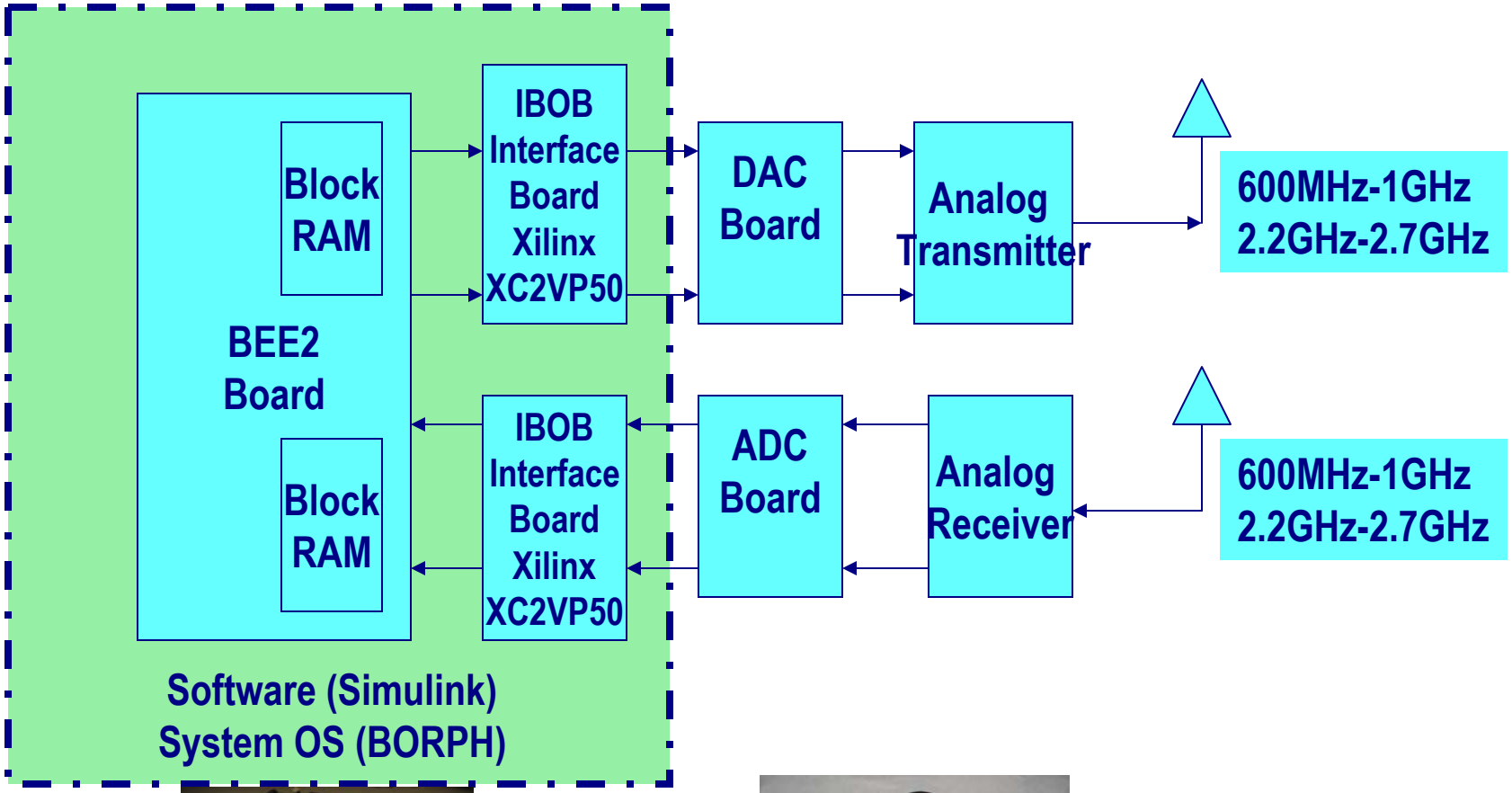
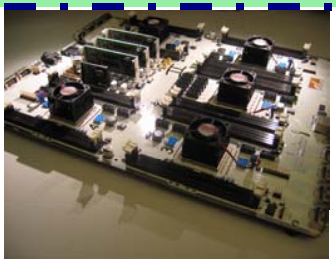
•2.4GHz ISM band
•IEEE 802.15.4/ ZigBee™ radio

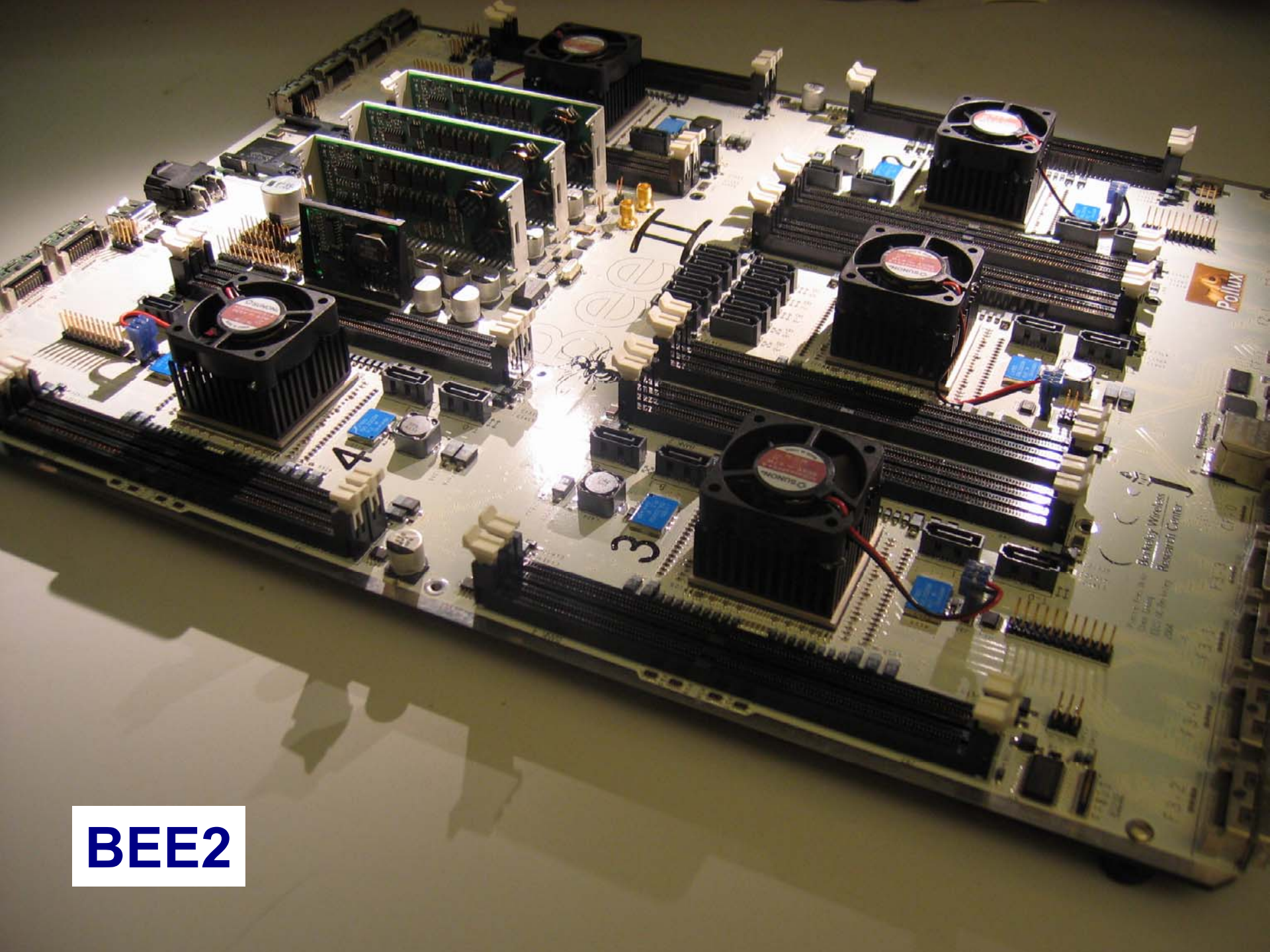
2.5/… GHz

•2.5/3.5/5.8 GHz Radio
•IEEE 802.16, WiMAX

Wide Band Frontend System



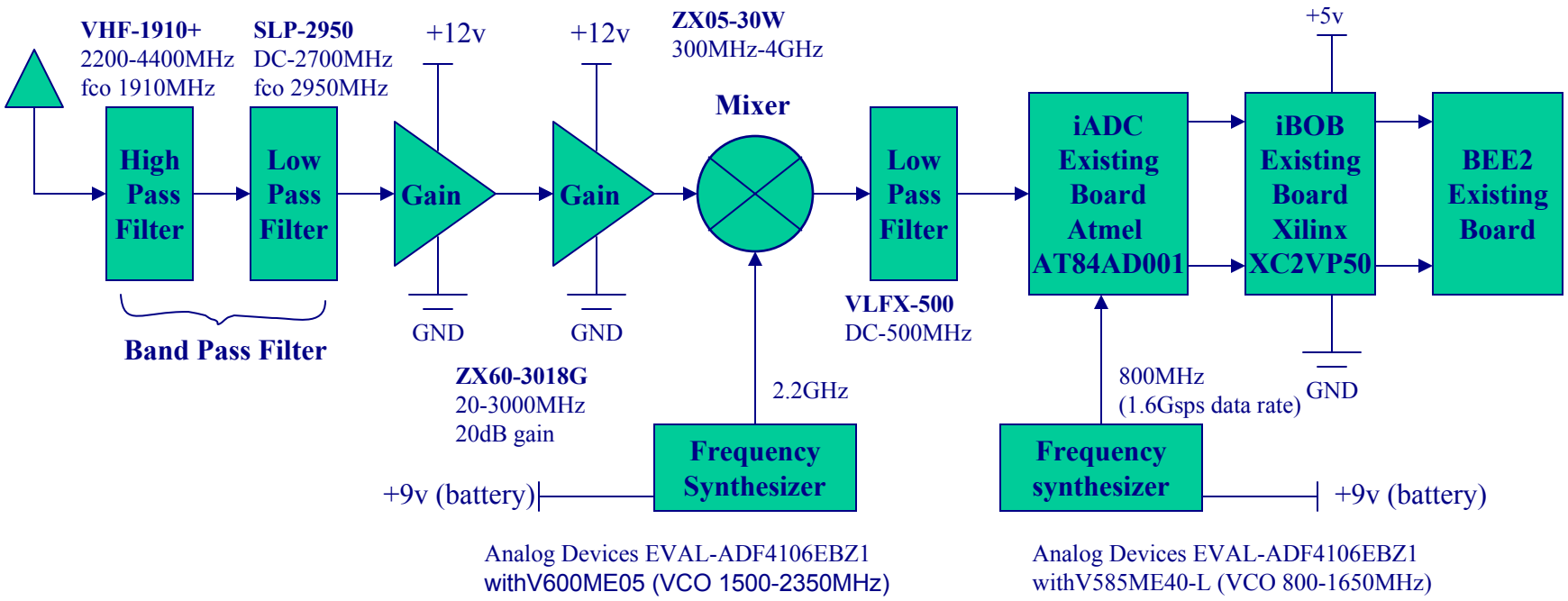



BEE2

Analog Hardware

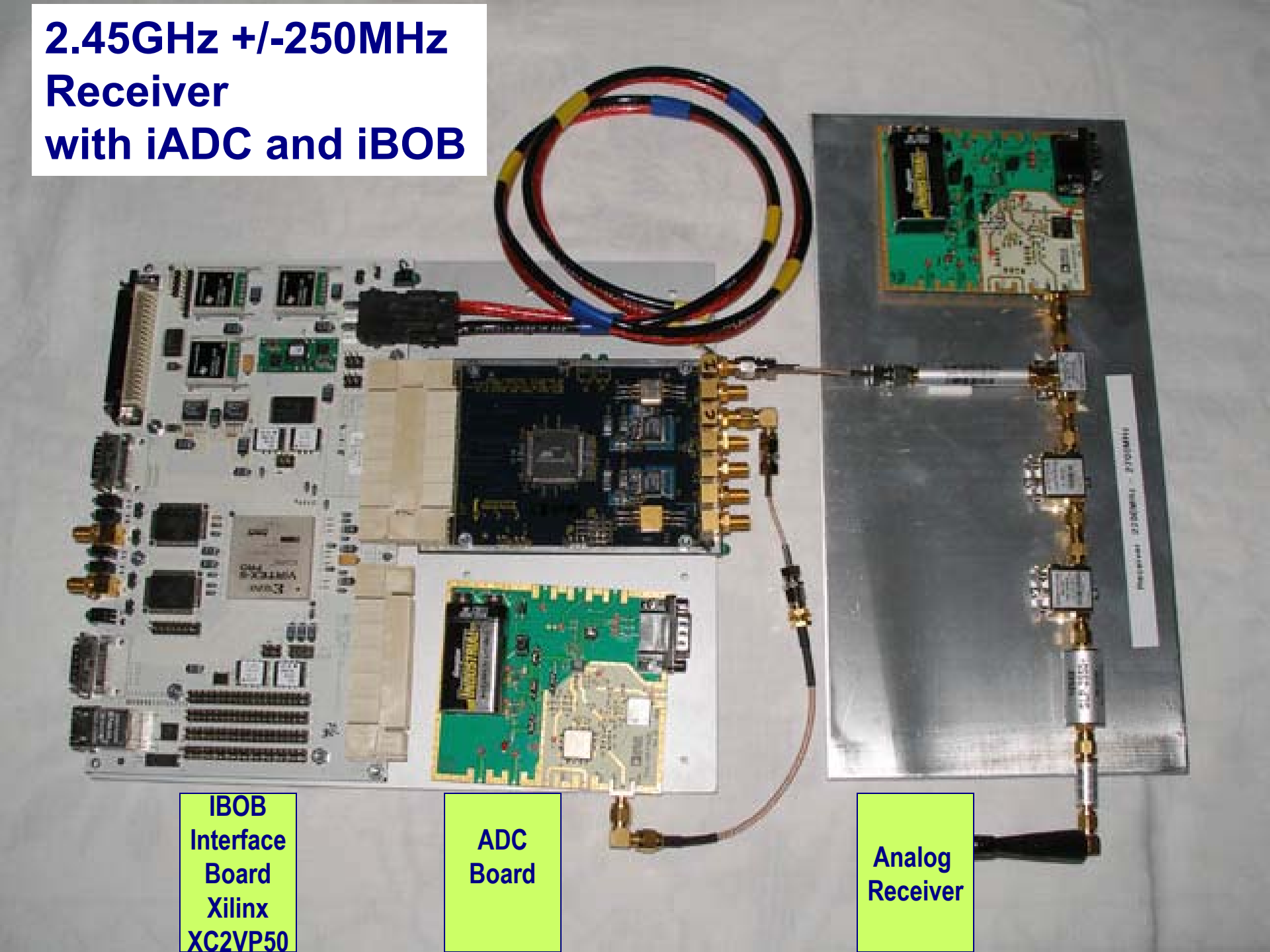
- 2.45GHz band: 2.2GHz – 2.7GHz Receiver
- 2.45GHz band: 2.2GHz – 2.7GHz Transmitter
- TV + ISM band: 600MHz - 1GHz Receiver
- TV + ISM band: 600MHz - 1GHz Transmitter

2.45GHz +/-250MHz Receiver



Notes:
All part nos: Minicircuits
unless otherwise indicated

2.45GHz +/-250MHz Receiver with iADC and iBOB

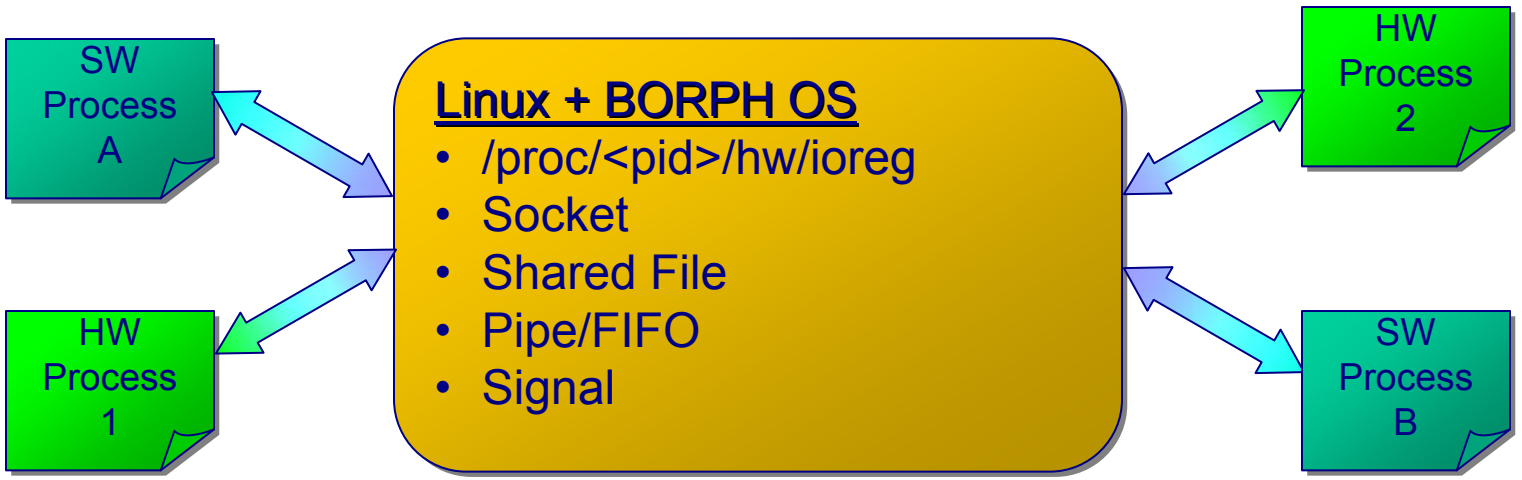


Digital Hardware

- iBOB
  - Interface board with preprocessing capability
  - 2 XAUI – 20 GBits per sec full duplex
  - 1 Xilinx 2VP50
- ADC
  - Dual ADC with 8-bit resolution,
  - 1Gsps Sampling Rate, 2Gsps Interleaved mode
- DAC
  - Full bandwidth of DAC: 550MHz
  - Sample rate 1.2Gsps
  - 10 bit resolution
- BEE2
  - 5 FPGAs
  - 18 XAUI ports (10Gbit)
  - #mips

Software

- Simulink
  - A graphical hardware description language used to configure the FPGA to receive data from the ADC and forward the data to BEE2 using the XAUI interface
  - Simulink and Verilog libraries used to program the FPGA of the iBOB or BEE2
- BORPH – system control
  - Simplifies the interface to using the BEE2 boards
  - Mixed hardware/software inter-process communication with BORPH



Cognitive Radio Technology for UWB/WiMax coexistence

Mubaraq Mishra
Berkeley Wireless Research Center

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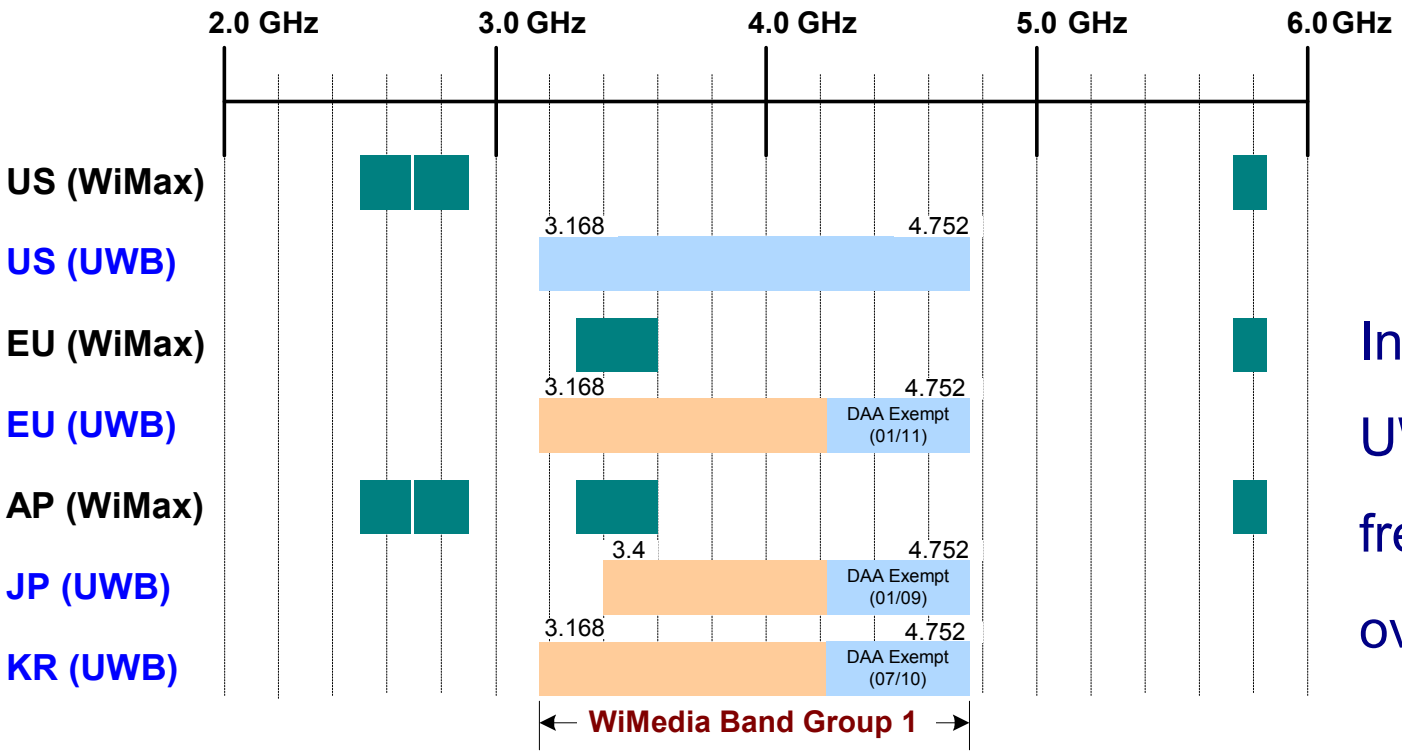
Coexistence Issues ?



In Europe and Asia, UWB and WiMax frequency bands overlap

UWB spectrum DAA required

UWB spectrum DAA exempt

WiMax spectrum

JP- Japan

KR- Korea

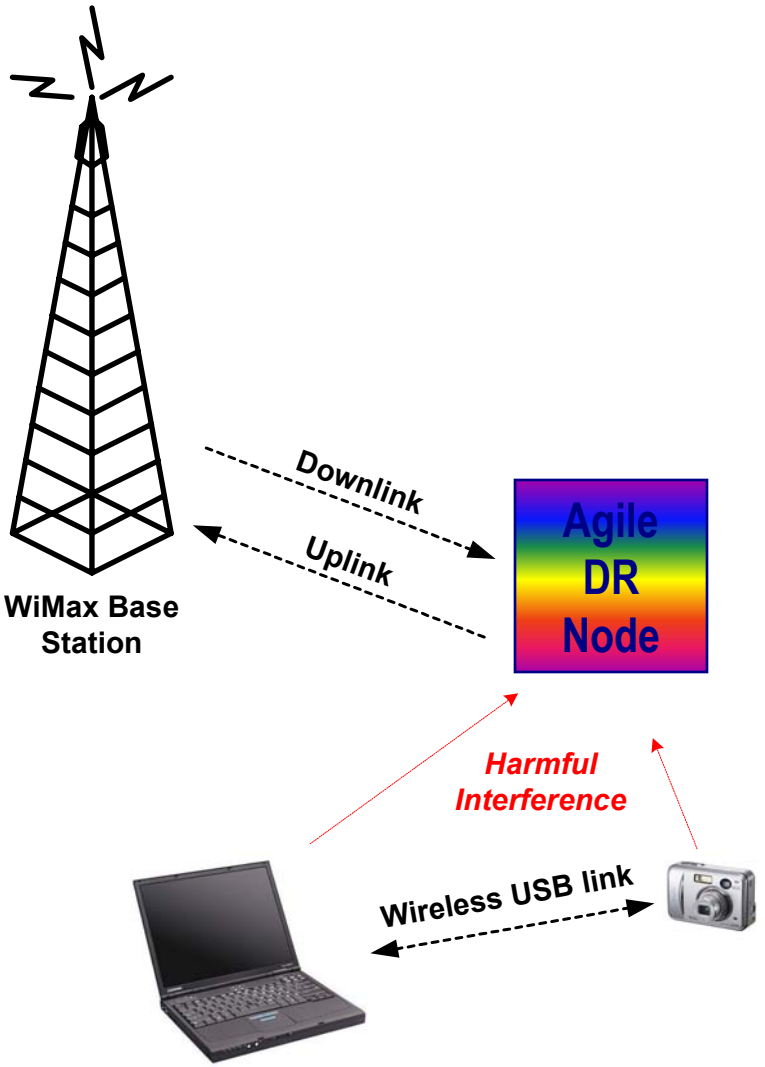
AP - Asia Pacific

US - United States

EU - Europe

Interference to WiMax?

- WiMax and UWB on Agile DR Node
  - Interference can be managed internally
- UWB devices on different sensors/laptops in proximity to DR Node
  - Interference is a problem

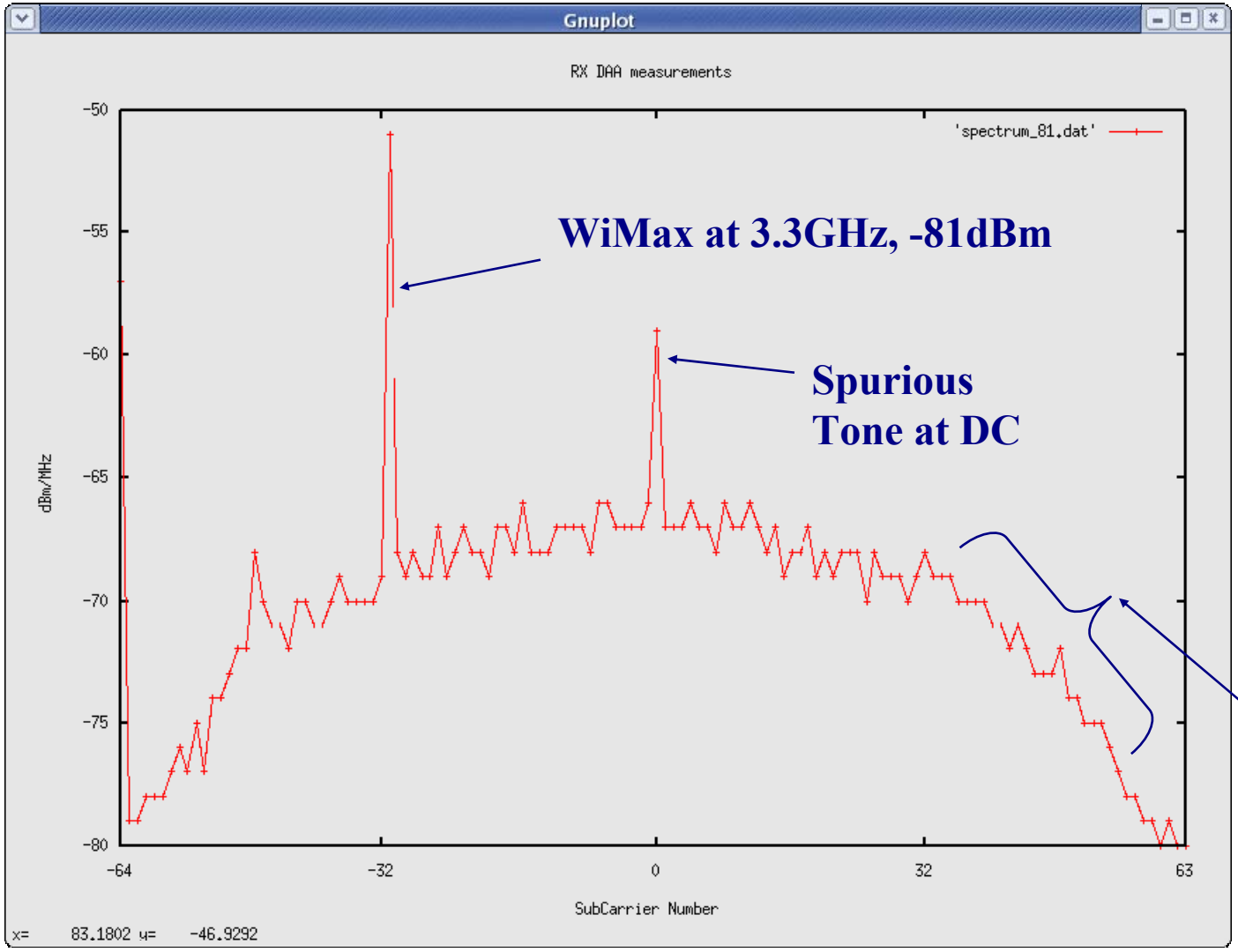


Cognitive Radio functionality to enable UWB/WiMax Coexistence

- **Definition: "A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which is operates" - [FCC NPRM - 03-322]**

- **Cognitive radio properties for UWB**
  - Sensing: **RF technology that "listens" to huge swaths of spectrum**
    - **UWB can listen to entire 1.5GHz band**
  - Cognition: **Ability to identify primary users**
    - **Can distinguish WiMax from spurious tones**
  - Self-modification capability : **Ability to change power levels, frequency ranges, modulation parameters to best use white spaces and minimize interference to primary users**
    - **Avoid/Notch out frequency bands where WiMax is detected**

Sensing and Cognition

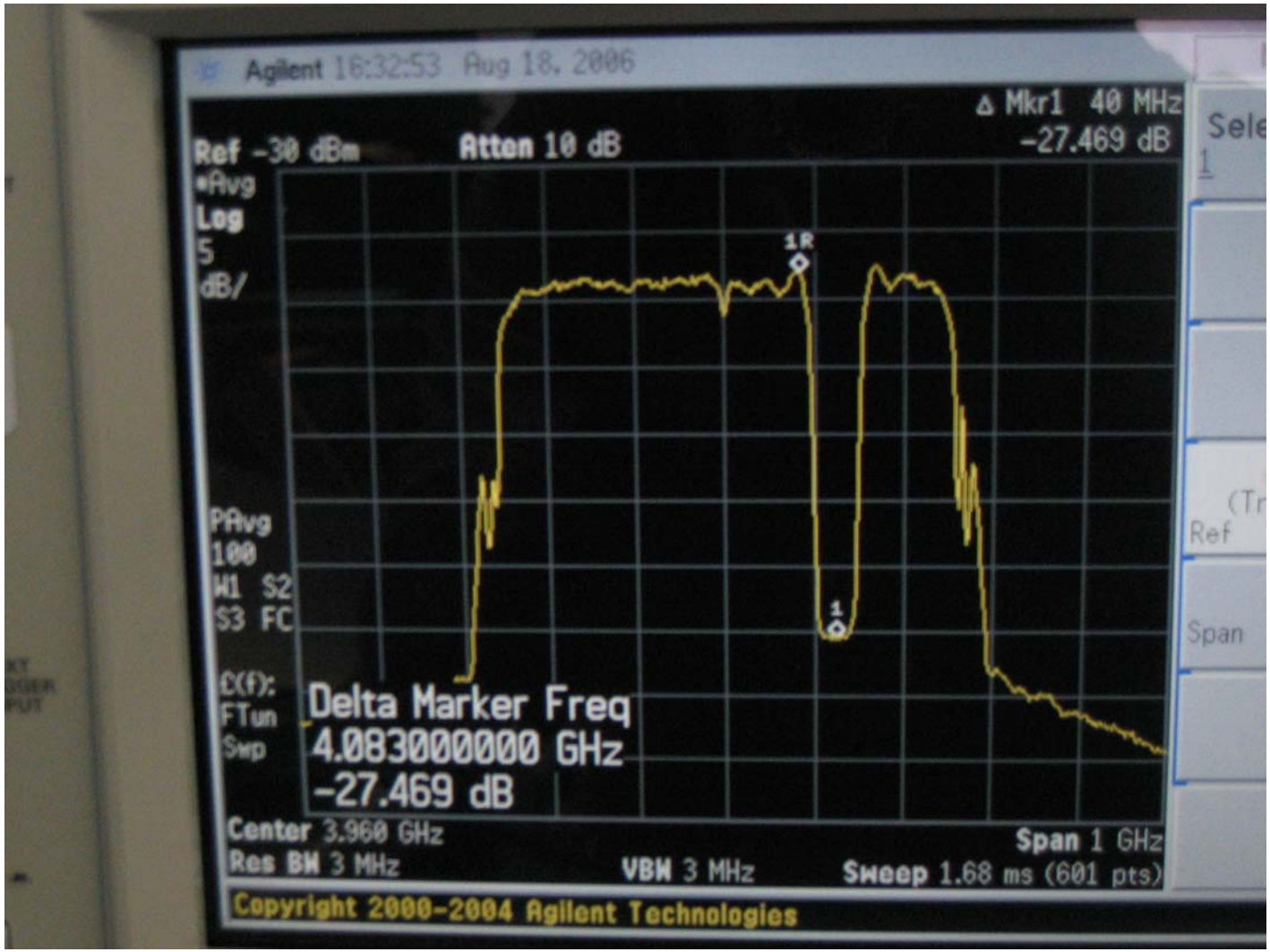


Sensing task: Detect WiMax signal

Cognition: Distinguish WiMax from Spurious time

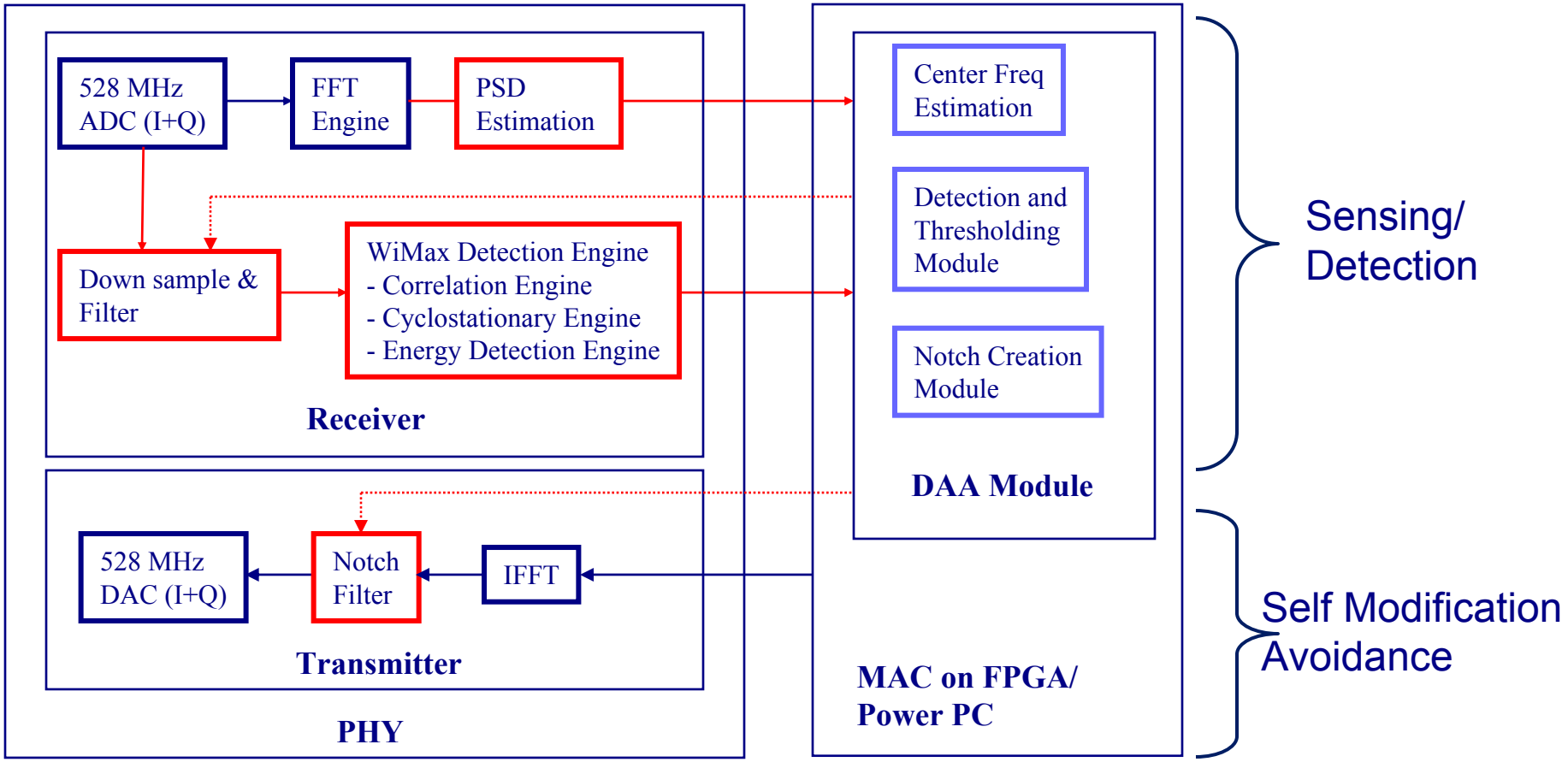
Shaped Noise floor

Self Modification Capability



Introducing a spectral notch of 28dB to protect WiMax

On Chip* Sensing, Cognition and Avoidance



A — CR Specific Hardware Block

B — CR Specific Firmware/Software Module

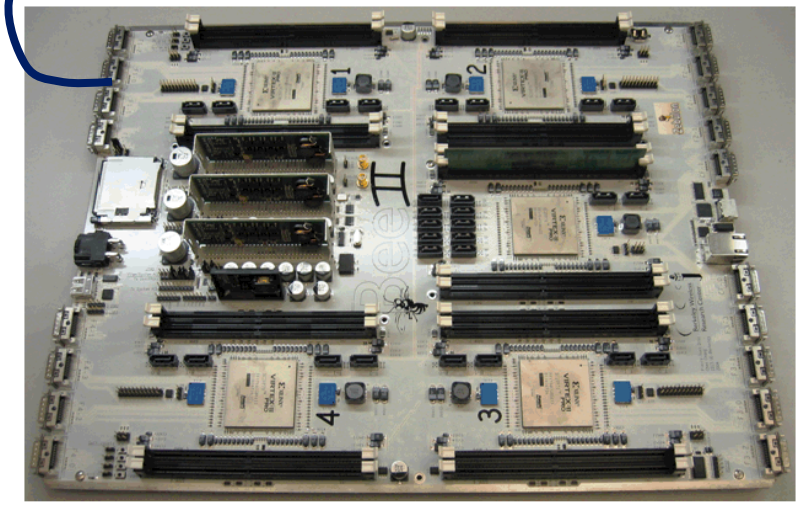
CR Control Flow

CR Data Flow

*Wionics Research – Realtek group's WiMedia compliant RF/Baseband UWB chip

UWB Radios with the BEE2

Infiniband connection



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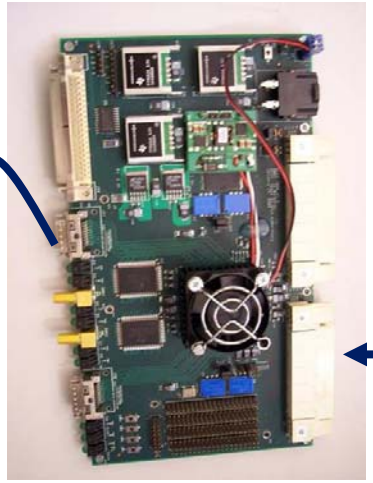
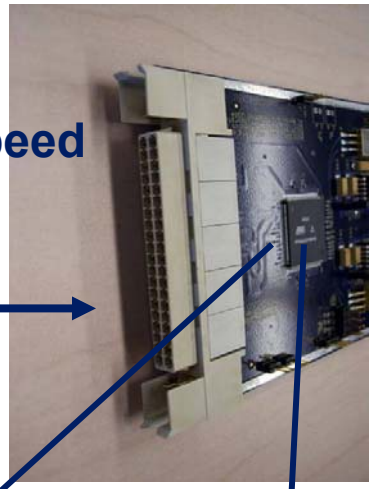
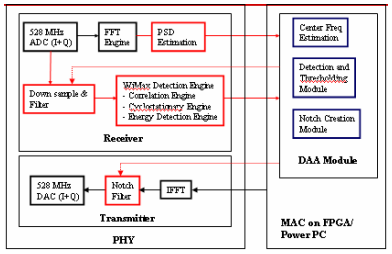


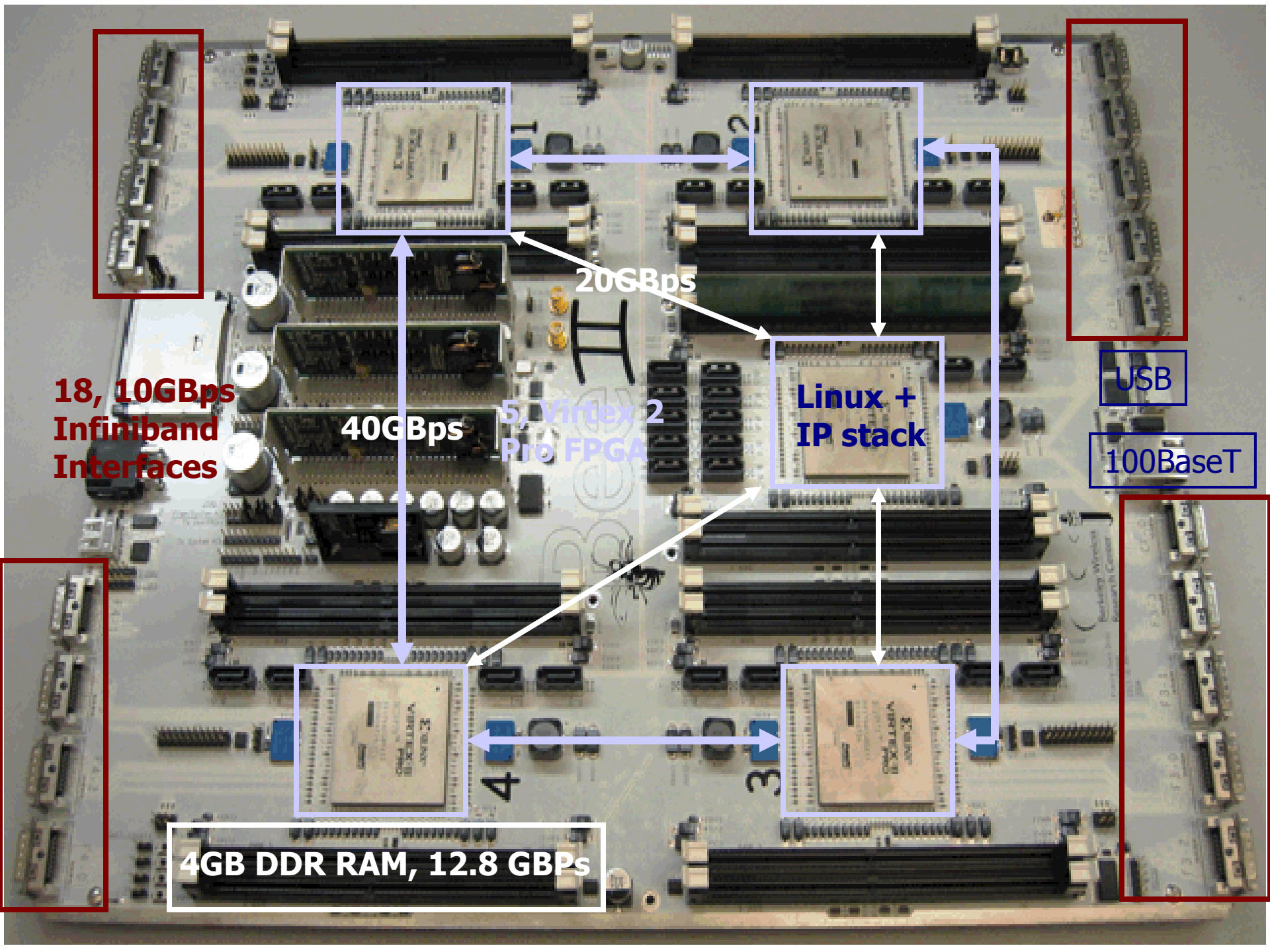
Infiniband
Break out Board
(IBOB)

High speed
Parallel
(ZDOK)



WiMedia complaint
RF/Baseband
UWB chip with DAA



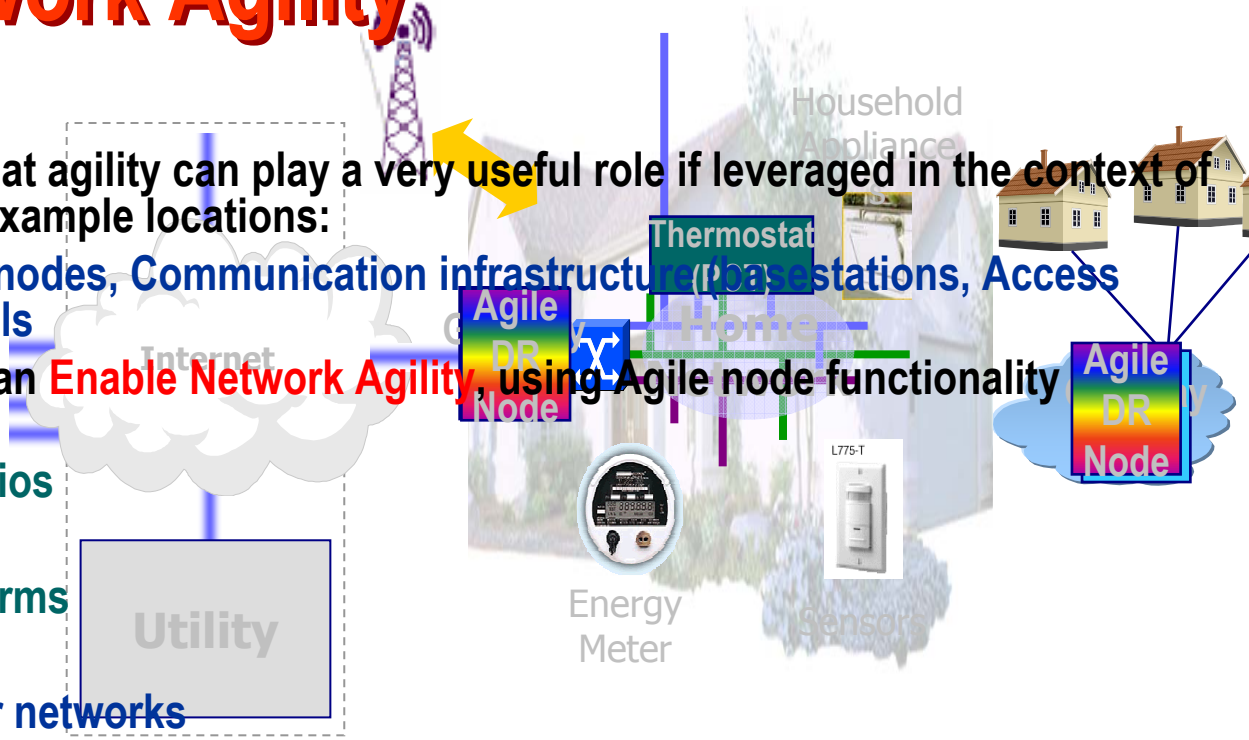

18, 10GBps
Infiniband
Interfaces
40GBps
20GBps
5, Virtex 2
Pro FPGA
Linux +
IP stack
USB
100BaseT
4GB DDR RAM, 12.8 GBPs

UWB with BEE2 for multi-radio experiments

Coexistence: Conclusions

- In the future heterogeneous systems will coexist on the same frequency
  - Cognitive Radios enable heterogeneous systems to coexist – improve spectrum utilization – DR nodes need to contain such technology
- Cognitive Radio functionality can be incorporated into existing radios with minimal area impact (~ 1mm^2)
- System coexistence tests at Intel show that WiMax/UWB can function together with minimal impact on performance of either system

Summary: Network Agility



- Use-case scenarios suggest that agility can play a very useful role if leveraged in the context of Demand-response networks. Example locations:
  - Gateways, Neighborhood nodes, Communication infrastructure (basestations, Access points), Advanced terminals
- Developed technologies that can Enable Network Agility, using Agile node functionality leveraging
    - Software Defined Radios
    - Cognitive techniques
    - Reconfigurable Platforms
  - Service delivery
  - Management of DR/sensor networks
- Benefits:
  - Manage differences in attributes of components technologies deployed: half-life, reliability, business processes, costs, …
    - E.g., Utility infrastructure (15-20 yrs) ⇔ Consumer (1/2/5 – 10+ yrs).
  - Reduces Capital and Operating Expenditures
  - Future Proofing: "Gracefully" evolution in the DR/AMI/HAN contexts.
  - Enables lifecycle support for service/product: provisioning, monitoring, management
- Phased Approach: Concepts and Architecture (Phase I) ➔ Prototype components (Phase II)

Thank you!