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Electromagnetic Energy Harvesting for Wireless Body Area Networks with Cognitive Radio Capabilities



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Outline

✂ Introduction.

✂ BodyNet with CR Capabilities:

□ PHY Layer;

□ MAC Layer;

□ Network Layer.

✂ Indoor and Outdoor Spectrum Opportunities.

✂ RF Energy Harvesting Scenario with Dedicated Transmitters.

✂ Conclusions.



Introduction

- ❏ Cognitive radio (CR) is a promising technique for Body Area Networks (BodyNets) enabling unlicensed (secondary) users to exploit the spectrum allocated to licensed (primary) users in an opportunistic manner.
- ❏ Future BodyNets will be sustained by radio frequency (RF) energy harvesting devices, which convert RF energy to direct current (DC), providing an alternative source to power supply the Wireless Sensor Network (WSN) devices.
- ❏ In the framework of the Prototypes for Efficient Energy Self-sustainable Wireless Sensor Networks (PROENERGY-WSN) project, field trials were conducted showing that the most promising band are: 79 to 96 MHz, 391 MHz, 935 to 960 MHz, 1855 to 1868 MHz and 2115 to 2160 MHz for both indoor and outdoor scenarios.



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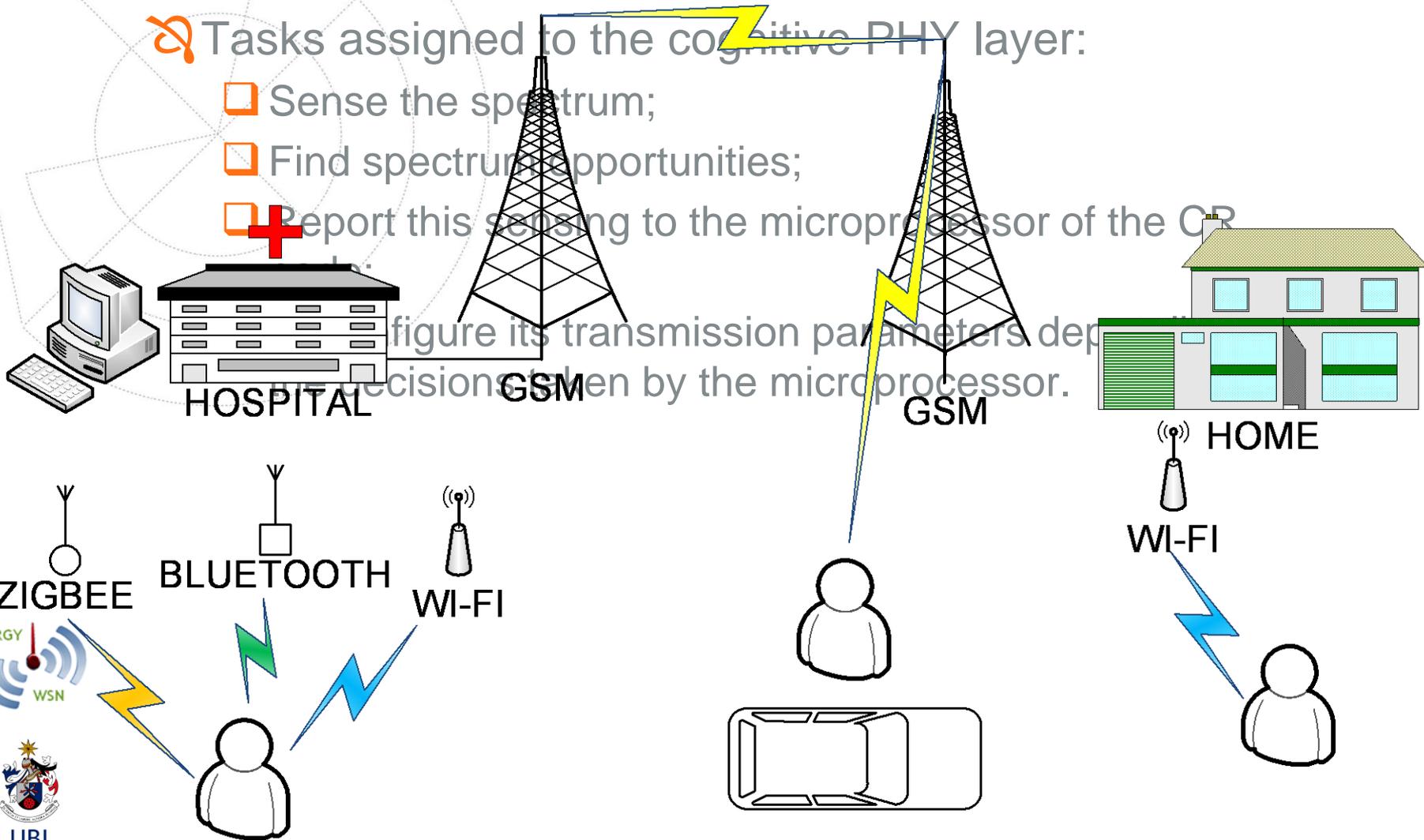
✂ Conclusions.



Physical Layer aspects

Tasks assigned to the cognitive PHY layer:

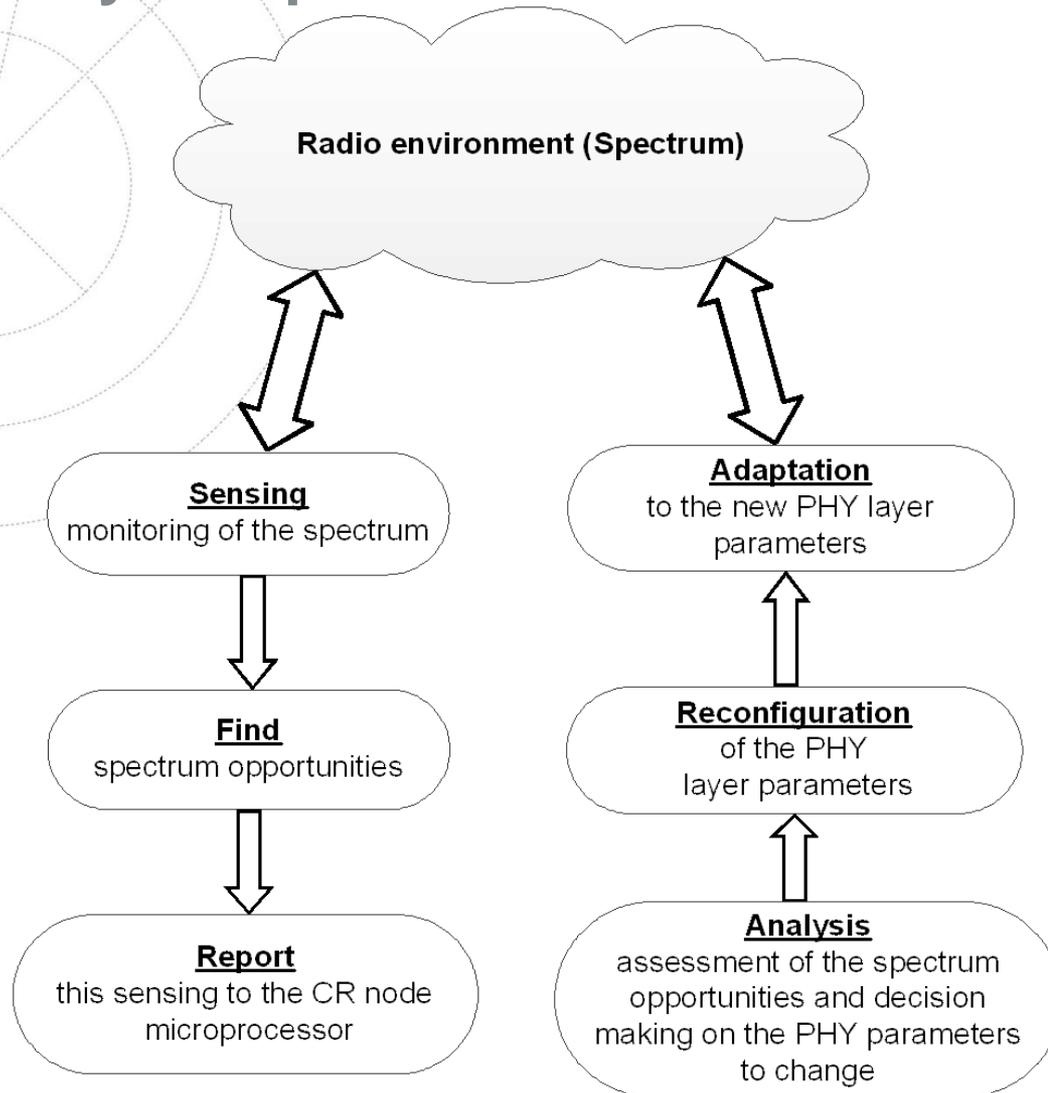
- ☐ Sense the spectrum;
- ☐ Find spectrum opportunities;
- ☐ Report this sensing to the microprocessor of the CR



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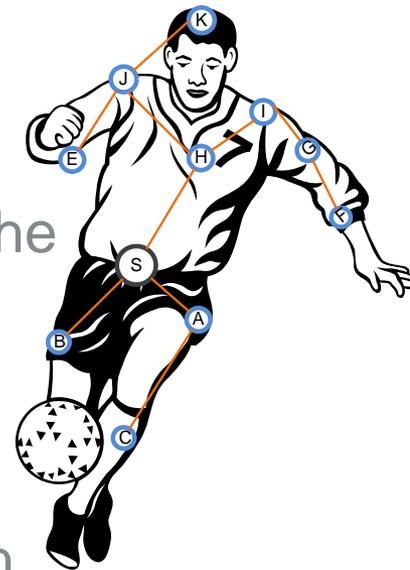
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Physical Layer aspects



Physical layer requirements (CR constraints)

- ✘ Present a current draw of 400 μA and 1 μA for the active and idle modes, respectively.
- ✘ The surrounding environment of the BodyNets impose special concerns in the restriction of the transmitting power for the radio transceiver.
- ✘ The IEEE 802.15.6 group advises the safe transmission power depending on the location of the sensor node.



Physical layer requirements (CR constraints)

- ✘ Effects due to the human body must be taken into account (i.e., body shadow effect phenomena).
- ✘ Another propagation effect that must be considered is the multi-path, caused by the ground and surrounding objects.
- ✘ Antenna constraints such as the coupling effect appears and depends much on the relative positions of the sensor nodes in human body.



Additional Physical layer design considerations

- ✎ In *situ* reconfiguration without replacing hardware by means of software defined radio (SDR) based RF front-end transmitters and receivers.
- ✎ SDRs consume more power, therefore due to the scarce power supply of the nodes in BodyNets the energy harvesting solutions are required.
- ✎ Spectrum sensing is a highly demanding signal processing task which envisages the development of dedicated and efficient digital signal processing (DSP) hardware.
- ✎ Development of transmission power and interference adaptive algorithms that cope with the interference problem that may arise in the deployment of CR sensor nodes over the human body.



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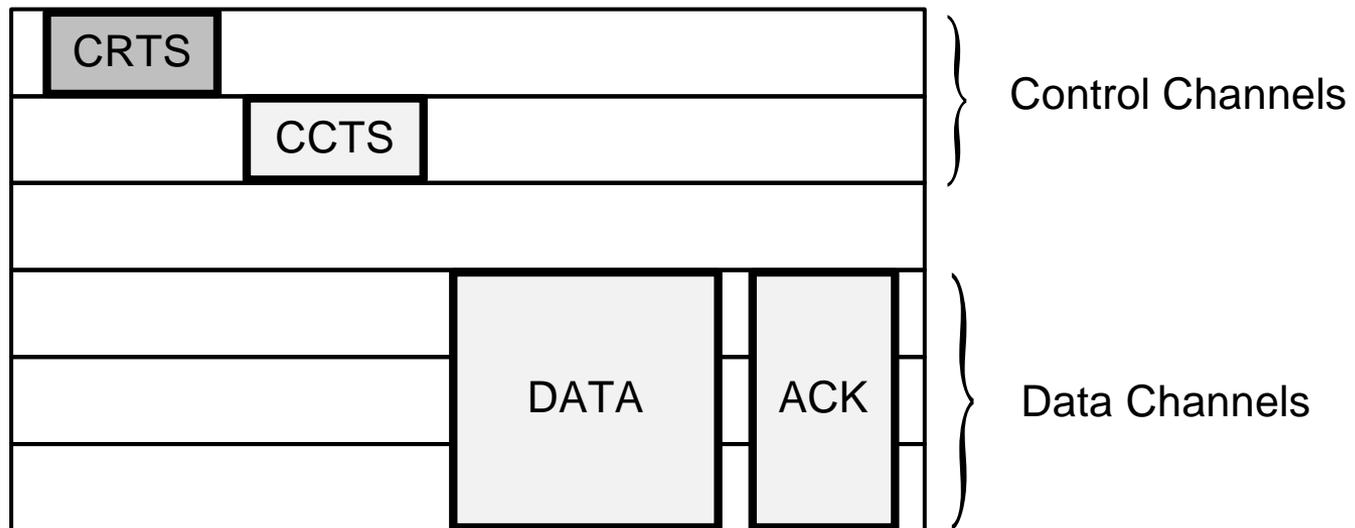


MAC Layer aspects

✎ The medium access control (MAC) layer must address additional challenges due to the coordination of dynamic spectrum access as outlined below:

□ Spectrum Sensing and decision results

- The CR MAC protocol must include mechanisms to share information with higher priority. Therefore, nodes must share extra control information.



MAC Layer aspects

□ Minimum overhead:

- Having a cognitive radio sensor network (CRSN) with minimum exchange of control packets and without the need of additional hardware requirements is envisaged.

□ Adaptive duty cycle:

- Based on the spectrum sensing measurements we can increase the duty cycle;
- It means more opportunities to cover multiple neighbours with one forwarding;
- Radio frequency (RF) energy to power supply the sensor nodes is envisaged based on the available energy and CR opportunities.



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Network Layer aspects

✎ The network layer is responsible for packet forwarding, node addressing, and choose the best path for packets.

✎ Traditional networks use:

- One frequency;
- Hop count as metric;
- RSSI as metric;
- QoS parameters as metric.

✎ Cognitive features brings additional complexity:

- Two nodes might communicate using different bands;
- Path calculation must include the frequency selection which introduces a more complex computation.



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Network Layer aspects

- ✎ Requirements for CR routing protocol:
 - ❑ Spectrum awareness;
 - ❑ Adaptive and QoS awareness;
 - ❑ Dynamic route maintenance and repair.

- ✎ Current solutions:

- ❑ Zhou et al. use graph theory, in which each frequency is represented by a different colour;
- ❑ Using hop count as metric, while making computationally light, they were unable to solve the problem of neighboring interference;
- ❑ Xie et al. use relays to mitigate interference, in which they achieve reasonable gains in terms of delay and energy consumption.

X. Zhou, L. Lin, J. Wang, and X. Zhang, "Cross-layer Routing Design in Cognitive Radio Networks," *Wireless Personal Communications*, vol. 49, no. 1, pp. 123–131, Apr. 2009.

M. Xie, W. Zhang and K.-K. Wong, "A Geometric Approach to Improve Spectrum Efficiency for Cognitive Relay Networks," *IEEE Transactions on Wireless Communications*, vol. 9, no. 1, pp. 268–281, Jan. 2010.

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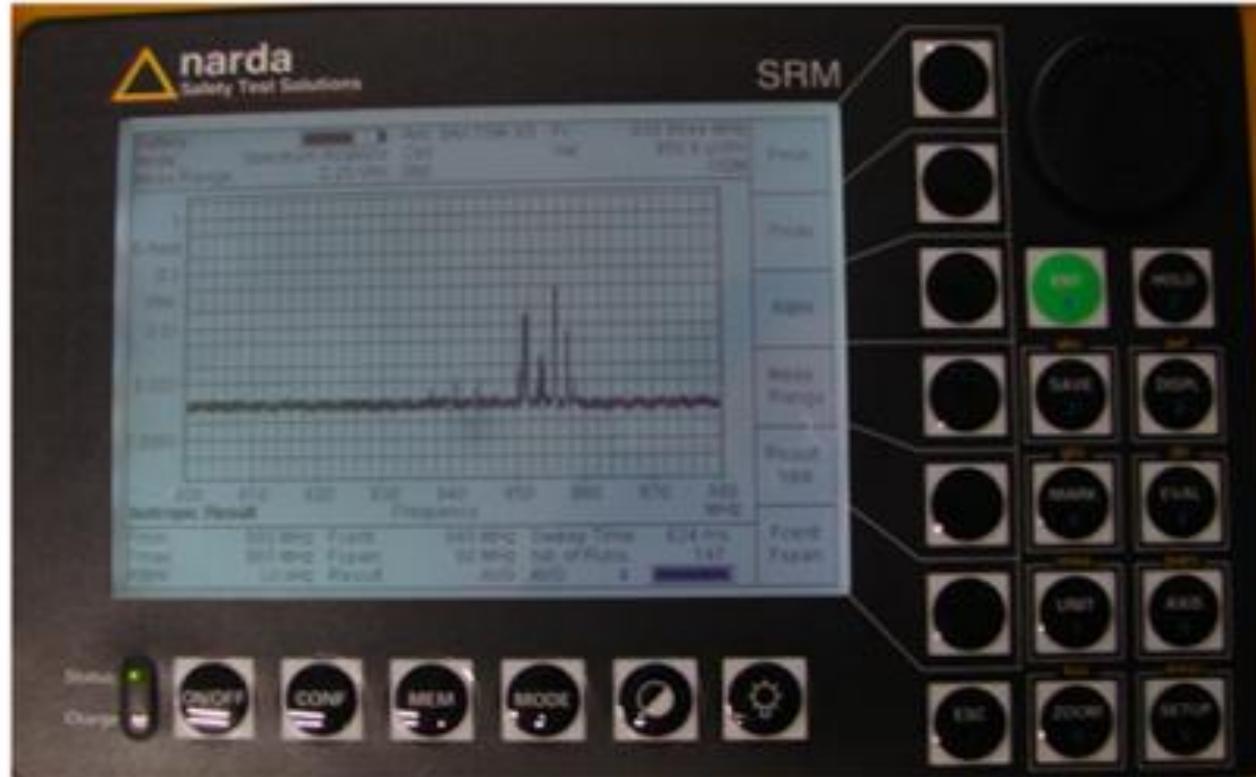
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✂ Conclusions.



Energy scavenging Scenario



PROENER



Extracted from:
<http://www.e-projects.ubi.pt/proenergy-wsn/>

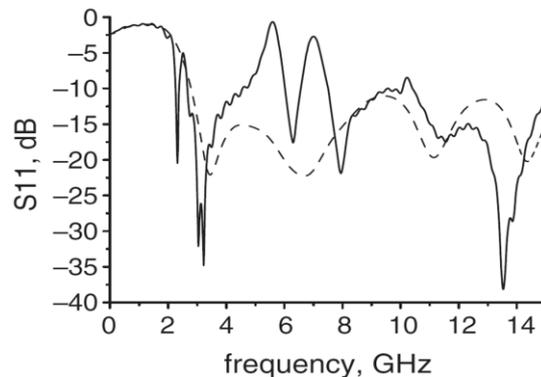
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Indoor and Outdoor Spectrum Opportunities

- ✂ We conducted indoor and outdoor field trial measurements in Covilhã, Portugal by using the NARDA spectrum analyser.
- ✂ We have analysed the power density measurements in 36 different locations.
- ✂ The measurements allow for identifying the spectrum opportunities to conceive multi-band antennas.



Extracted from:

L. Y. Cai, G. Zeng, H. C. Yang and Y. Z. Cai, "Integrated Bluetooth and multi-band ultra-wideband antenna," *Electronics Letters*, vol. 47, no. 12, pp. 688-689, Jun. 2011.

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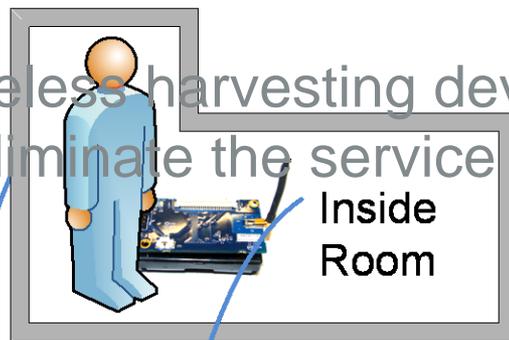


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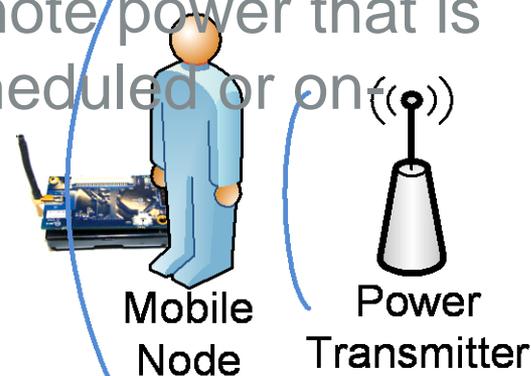
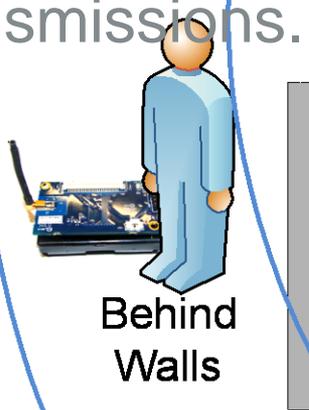
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RF Energy Harvesting Scenario with Dedicated Transmitters

By using RF-based wireless harvesting devices and dedicated transmitters, we can eliminate the service downtime caused by depleted batteries.



Dedicated transmitters provides remote power that is controllable through continuous, scheduled or on-demand power transmissions.



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RF Energy Harvesting Scenario with Dedicated Transmitters

Management strategies must be implemented based on the CR frequency availability and electromagnetic energy harvesting opportunities (i.e., based on spectrum opportunities as well as energy available, data transmission will be balanced avoiding service downtime caused by depleted batteries).

A system with multiband antennas and different RF harvesting circuits is envisaged allowing for maximize the spectral efficiency based on medium access control opportunities as well increase the energy harvested.



Benefits:

- Transparent charging – no user action required;
- Reliability – durability is improved by reducing product failures.



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Conclusions

- ✘ In this work we have presented the PHY, MAC, and Network layer constraints of BodyNets.
- ✘ Our scenario considers a dynamic spectrum access (DSA) entity allowing for identify the CR opportunities, as well as collect energy to power supply the sensor nodes.
- ✘ By using RF-based wireless power devices we intend to eliminate the cost of replacing batteries of wireless sensors, as well as eliminate the service downtime caused by depleted batteries.
- ✘ A threshold must be implemented based on the available energy for harvesting versus CR opportunities.



Conclusions

- ✎ Harvested energy from radio waves can enable the system to transmit a wireless distress signal, which in turn could activate the power transmitter even if its in the sleep mode, to extend the battery lifetime.
- ✎ The most promising frequency bands for both indoor and outdoor are:
 - ❑ 79 to 96 MHz (radio broadcast stations);
 - ❑ 391 MHz (emergency broadcast stations);
 - ❑ 750 to 758 MHz (television broadcast stations);
 - ❑ 935 to 960 MHz (GSM 900 broadcast stations);
 - ❑ 1855 to 1868 MHz (GSM 1800 broadcast stations);
 - ❑ 2115 to 2160 MHz (UMTS broadcast stations).





**Thank you,
Questions are Welcome**



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