Physical-layer improvements for adaptive communications

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Issues: Demand for faster data rates and denser mobile networks puts strain on the limited portions of the electromagnetic spectrum used for wireless communications.

Solution: Develop *flexible hardware* and *intelligent software* to better handle communications tasks

Cognitive Radio: The bigger picture idea of building radios which can intelligently sense their environment, adapt their communication schemes accordingly, and learn from prior experience [1,2]

| Physical layer manipulations & spectrum sensing | ⟷ | Communication protocols & network cooperation |

Decision making
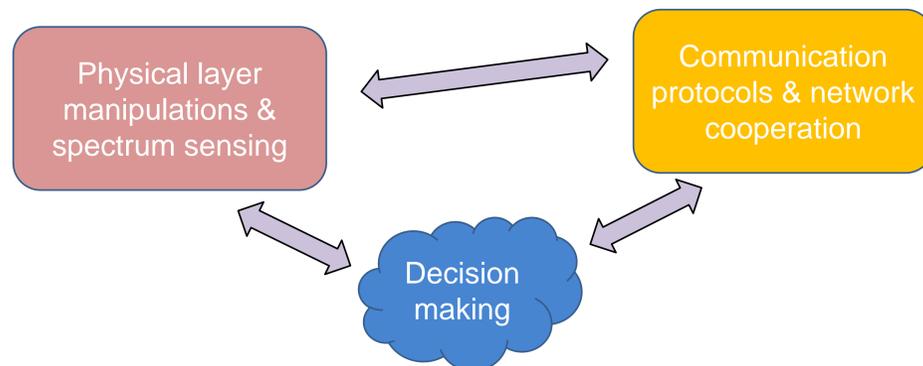
Software Defined Radio (SDR): Utilize high-speed A/D converters and digital signal processing to replace much of the fixed hardware in radios. By moving processing into software, **simple hardware** can carry out a **wide variety of communication tasks.**


LNA — ADC — Software Processing

PA — DAC

Software Processing: Filtering, frequency conversion, modulation, demodulation, data formatting, hardware control
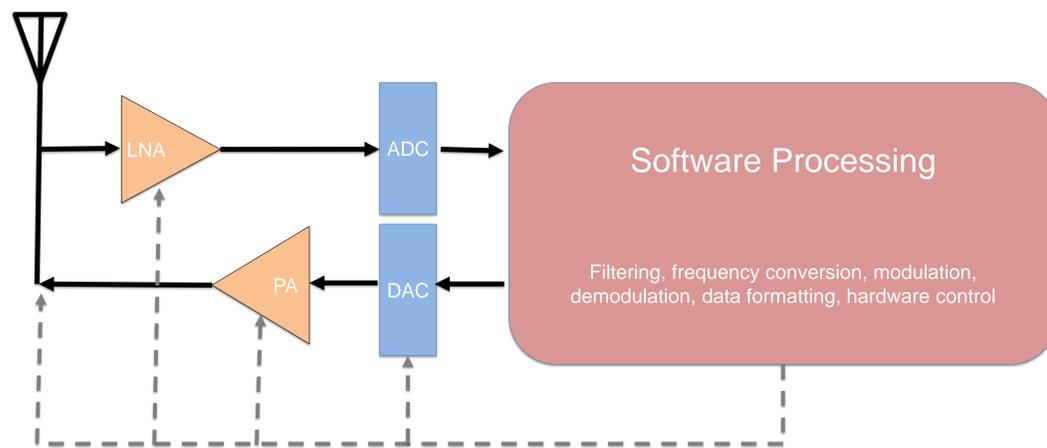
Antennas and the physical layer: Despite advancements in SDR and receiver technology, any radio still needs an interface with the physical world. The antenna on any receiver determines:
- **Spatial selectivity**
- **Frequency capability**
- **Polarization sensitivity**

Incorporation of *reconfigurable antennas* will close the loop and allow for **real-time control** over these properties, leading to **enhanced functionality and adaptability**.

Benefits of including advanced antenna technology: Besides being a necessary component of a radio, antennas can enable unique functionality:
- Collocated channel diversity for MIMO communications
- Improved localization of users and network members without GPS
- Directive relaying and cooperative beamforming

Localization: comparison of RSS localization performance using omnidirectional, directional, and pattern-reconfigurable antennas.

CDFs of errors in 1000-trial MLE localization in 200 m x 200 m search space
$N_a = 8$, $\sigma_{dB} = 4$

Legend: Omnidirectional, Dipole, 2-state reconfigurable

Results indicate that very large capacity improvements are possible, especially at low values of SNR.

Legend: RDDR Percent Improvement, DRRD Percent Improvement, DDDD Capacity, RDDR Capacity, DRRD Capacity
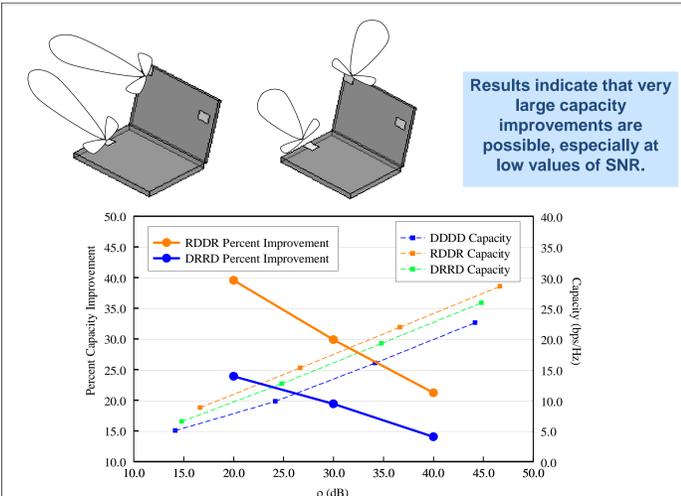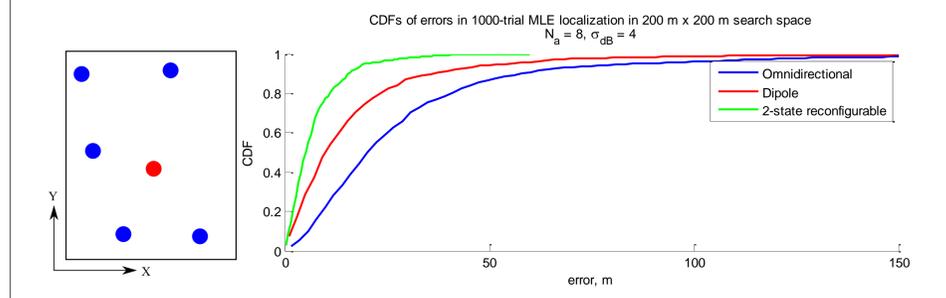
Channel capacity: improvements (over fixed omni-directional antennas) are dependent on the propagation environment – but are likely to be significant in high scattering (indoor) environments where SNR is limited and multipath effects are significant [3]

Reconfigurable Antennas

Controllable antennas have impedance or radiation properties dependent on some outside control. Could provide flexible performance for otherwise limited small antennas in mobile applications.

Such antennas let a SDR have direct control over a radio system's **interface with the physical world** and **allow the radio to sense, react, and compensate to changing environments**
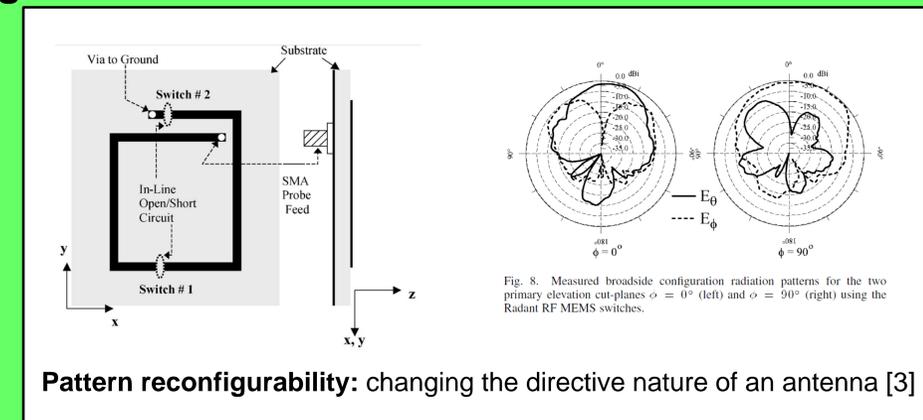
Pattern reconfigurability: changing the directive nature of an antenna [3]
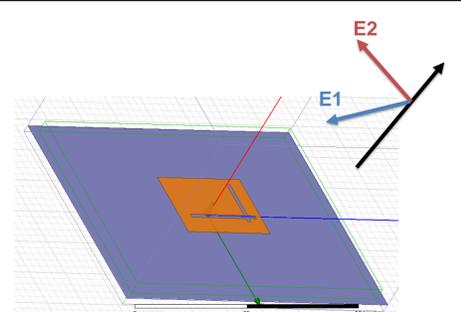
Polarization reconfigurability: using control signals to change the polarization of radiated fields
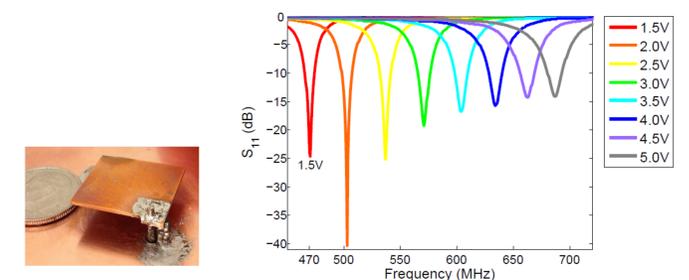
Frequency tuning: accessing a broad range of frequencies on an electrically small, instantaneously narrowband antenna

References
[1] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 2, pp. 201-220, Feb 2005.
[2] J. Mitola *et al.*, "Cognitive radio: Making software radios more personal," *IEEE Pers. Comm.*, vol. 6, no.4 pp. 13-18, Aug. 1999.
[3] J. Boerman and J.T. Bernhard, "Performance study of pattern reconfigurable antennas in MIMO communication systems," *IEEE Transactions on Antennas and Propagation*, Jan. 2008
[4] G. H. Huff and J. T. Bernhard, "Integration of packaged RF MEMS switches with radiation pattern reconfigurable square spiral microstrip antennas," *IEEE Trans. On Antennas and Propagation*, vol. 54, no. 2, Feb. 2006.