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Robert H. Morelos-Zaragoza

San Jose State University, robert.morelos-zaragoza@sjsu.edu

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Cognitive Radio: Fundamentals and Opportunities

Robert H. Morelos-Zaragoza
Department of Electrical Engineering
San Jose State University

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Outline

1. Software-defined radio (SDR)

- a) Black-box approach
- b) Components and attributes (Mitola)

2. Cognitive radio (CR)

- a) Definition and overview (Mitola)
- b) CR features (FCC)

3. Unlicensed TV spectrum usage and WRANs

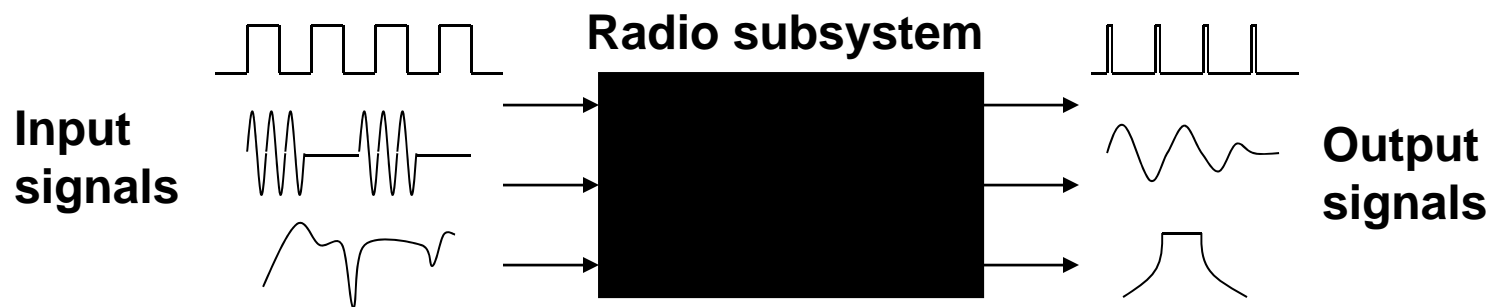
4. Digital channel detection in the 915 MHz ISM band (demo)

5. Opportunities and technical challenges

1. SDR: The black box approach

Software-defined radio (SDR) idea [1]:

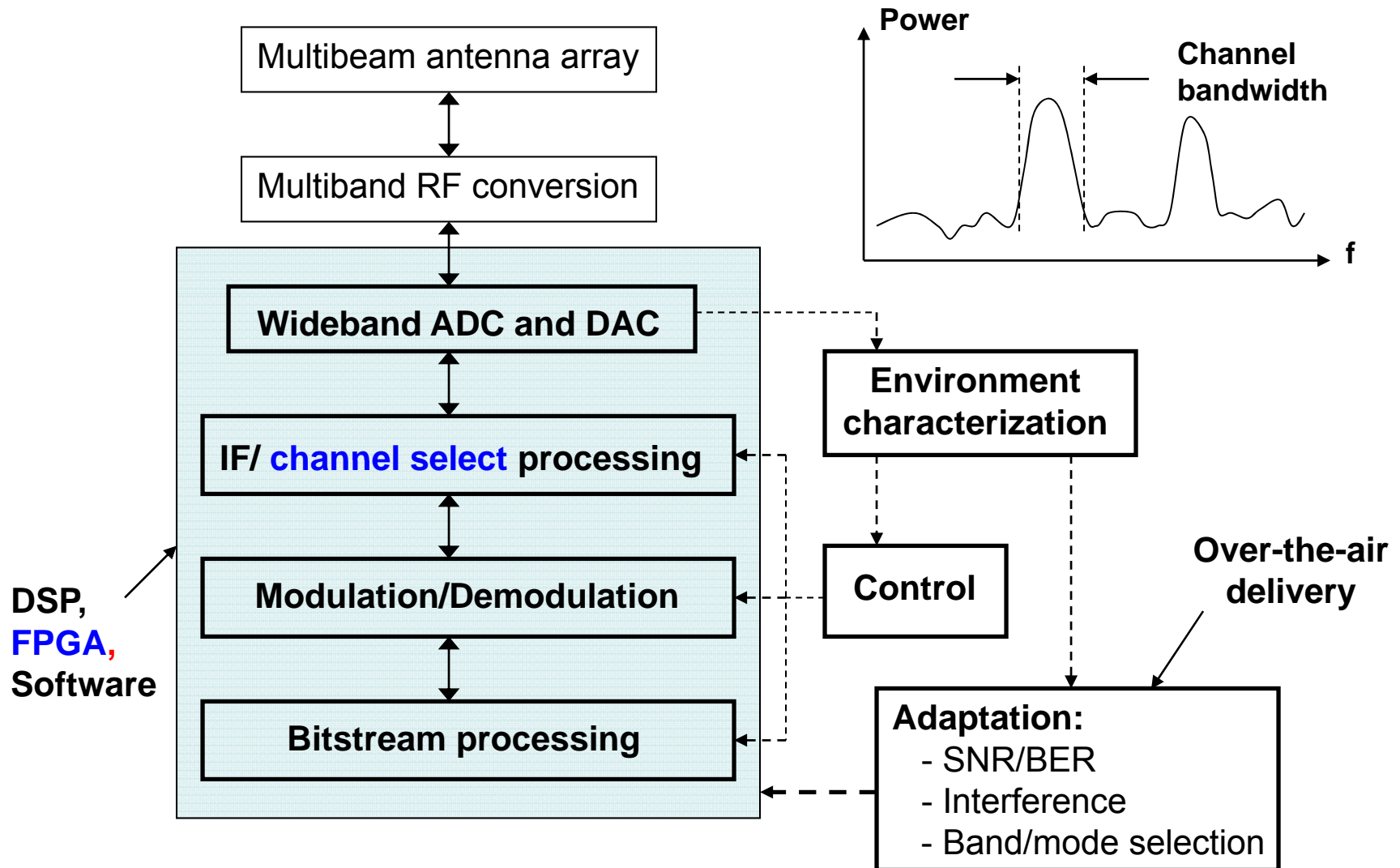
Specify input/output signals at the boundaries of a subsystem, and not the internal components.



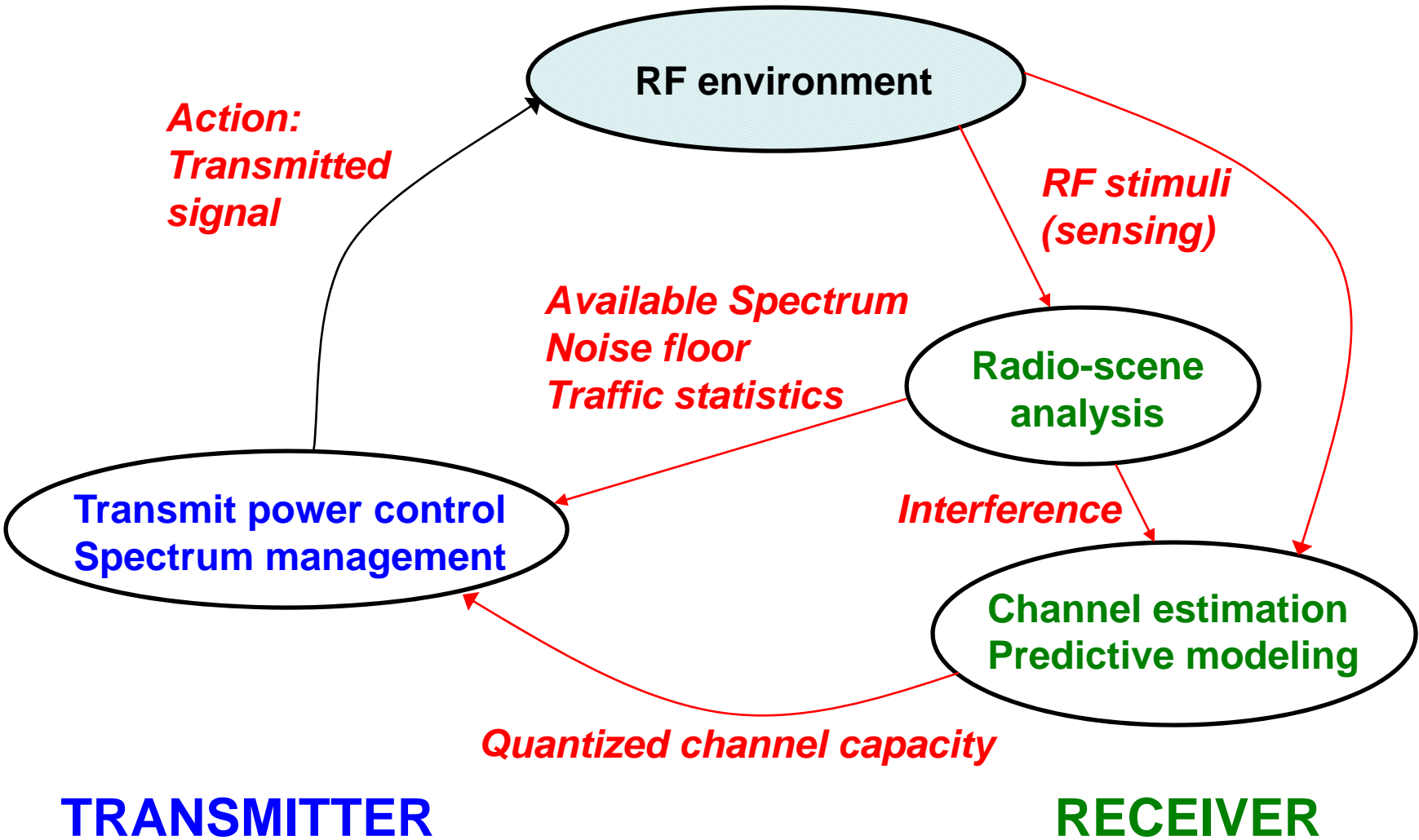
Improved security/reliability:

Specification on components replaced by **functionality**
Programmability is not only possible but essential

Software radio components [1]



A Basic Cognitive Cycle [2]



SDR component attributes [1]

Functional component	Attributes
Source coding/decoding	Audio, video and data
Service/network	Multiplexing, services and networking
Information security	Transmission security, authentication, non-repudiation, privacy, data integrity
Channel coding/decoding	Bit error rate
Modulation/demodulation	Baseband modem, timing and carrier recovery, equalization, waveforms
IF processing	Beamforming, diversity combining, spatial multiplexing , channel estimation
RF access	Antenna, diversity/MIMO, RF conversion
Channel sets	Simultaneity, multiband propagation
Multiple personalities	Multiband, multimode, agile services
Joint control	Source/channel, QoS vs, load, integration

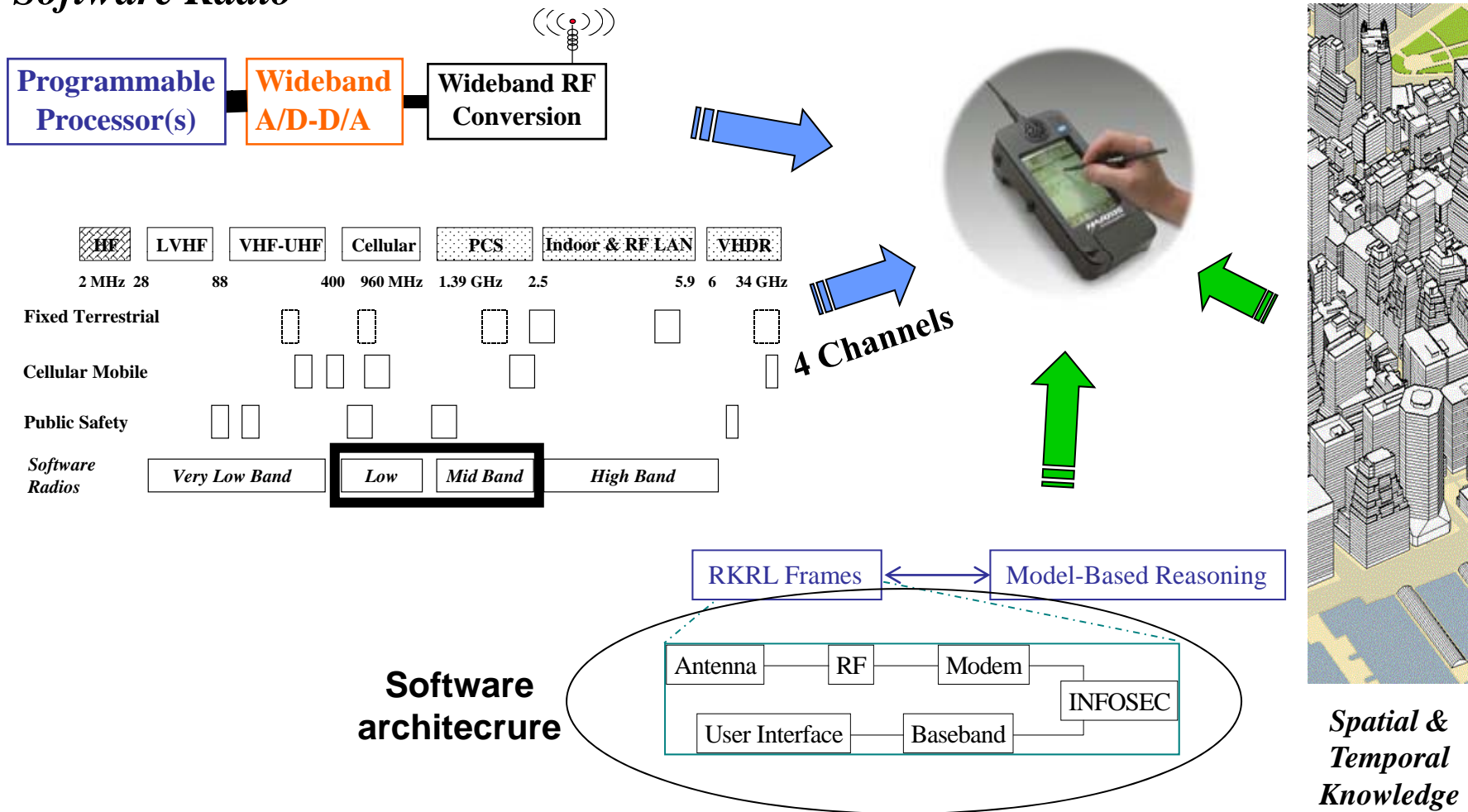
2. Cognitive radio definition (Mitola)

“A radio frequency transceiver designed to intelligently detect whether a particular segment of the radio spectrum is in use, and to jump into (and out of) the temporarily unused spectrum very rapidly, without interfering with the transmission of other authorized users.” [3]

Quote: B. Fette, “Three obstacles to cognitive radio,” EE Times, Aug. 2004

Cognitive Radio Overview [3]

Software Radio



Cognitive radio features – FCC [4]

- ***Frequency Agility*** - the ability of a radio to change its operating frequency to optimize use under certain conditions
- ***Dynamic Frequency Selection (DFS)*** – the ability to sense signals from other nearby transmitters in an effort to choose an optimum operating environment

Cognitive radio features – FCC (cont.)

- **Location Awareness** - *the ability for a device to determine its location and the location of other transmitters, and first determine whether it is permissible to transmit at all, then to select the appropriate operating parameters such as the power and frequency allowed at its location.*
- **Negotiated Use** - *a cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of a prearranged agreement between a licensee and a third party (lessee).*

Cognitive radio features – FCC (cont.)

- ***Adaptive Modulation*** – *the ability to modify transmission characteristics and waveforms to exploit opportunities to use spectrum*
- ***Transmit Power Control (TPC)*** – *to permit transmission at full power limits when necessary, but constrain the transmitter power to a lower level to allow greater sharing of spectrum when higher power operation is not necessary*

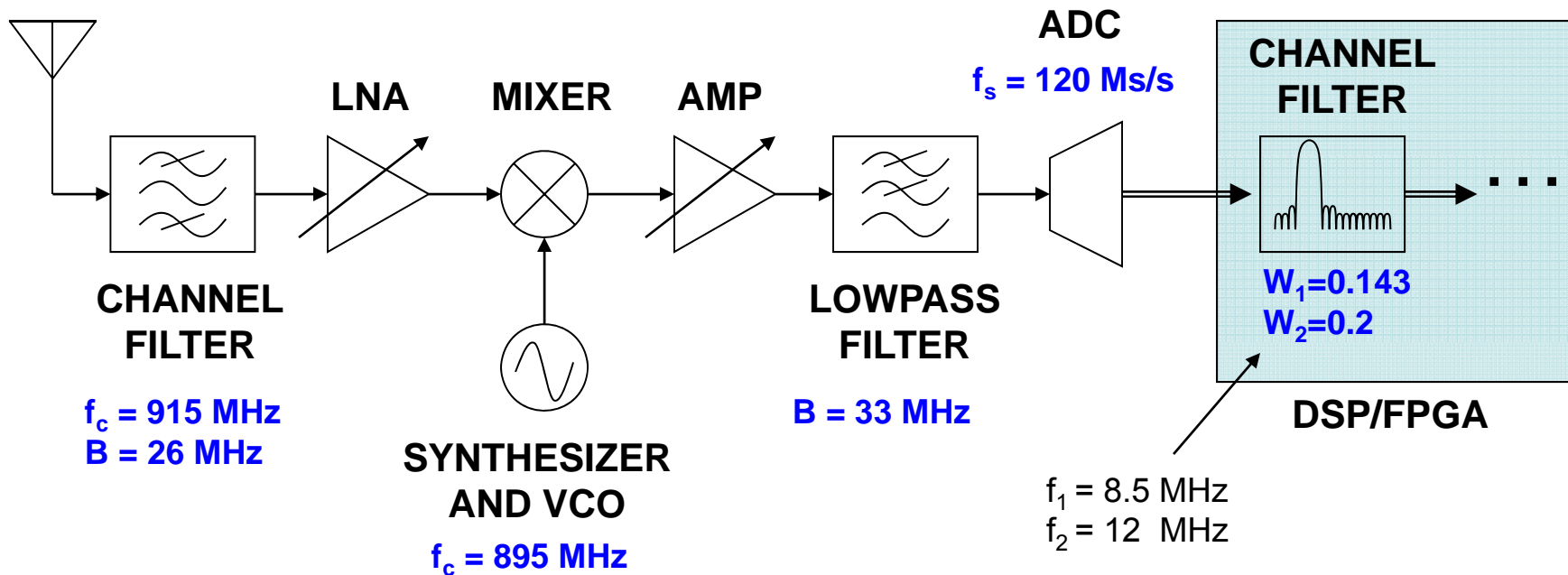
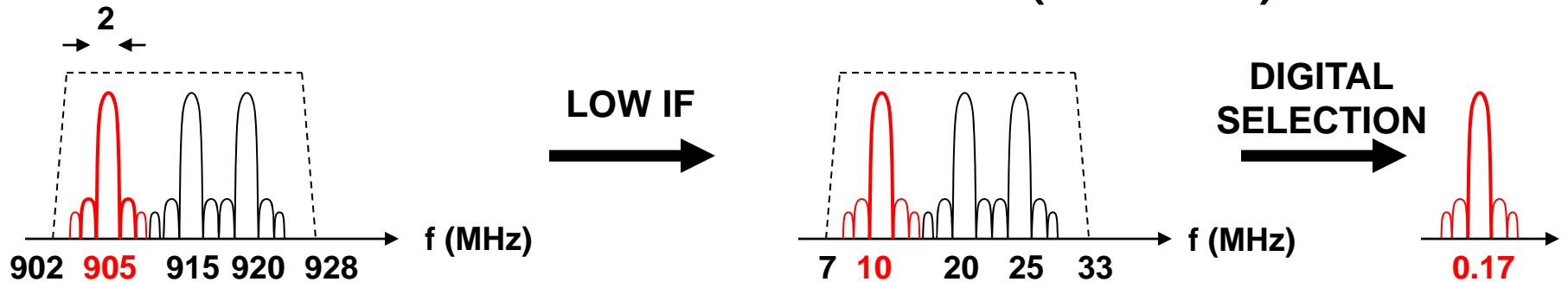
3. Unlicensed TV spectrum [5]

- Use unused channels in the VHF (54-88 MHz, 174-216 MHz) and UHF (470-638 MHz) analog TV bands (“white space”) in certain areas
- Greater range than WiFi/WiMax in rural areas
- FCC proposed three possible approaches:
 - Passive sensing: Listen-before-talk
 - GPS plus data base to determine free frequencies
 - Separate beacon transmitters indicating unavailable spectrum
- Related specification: 802.22 WRAN

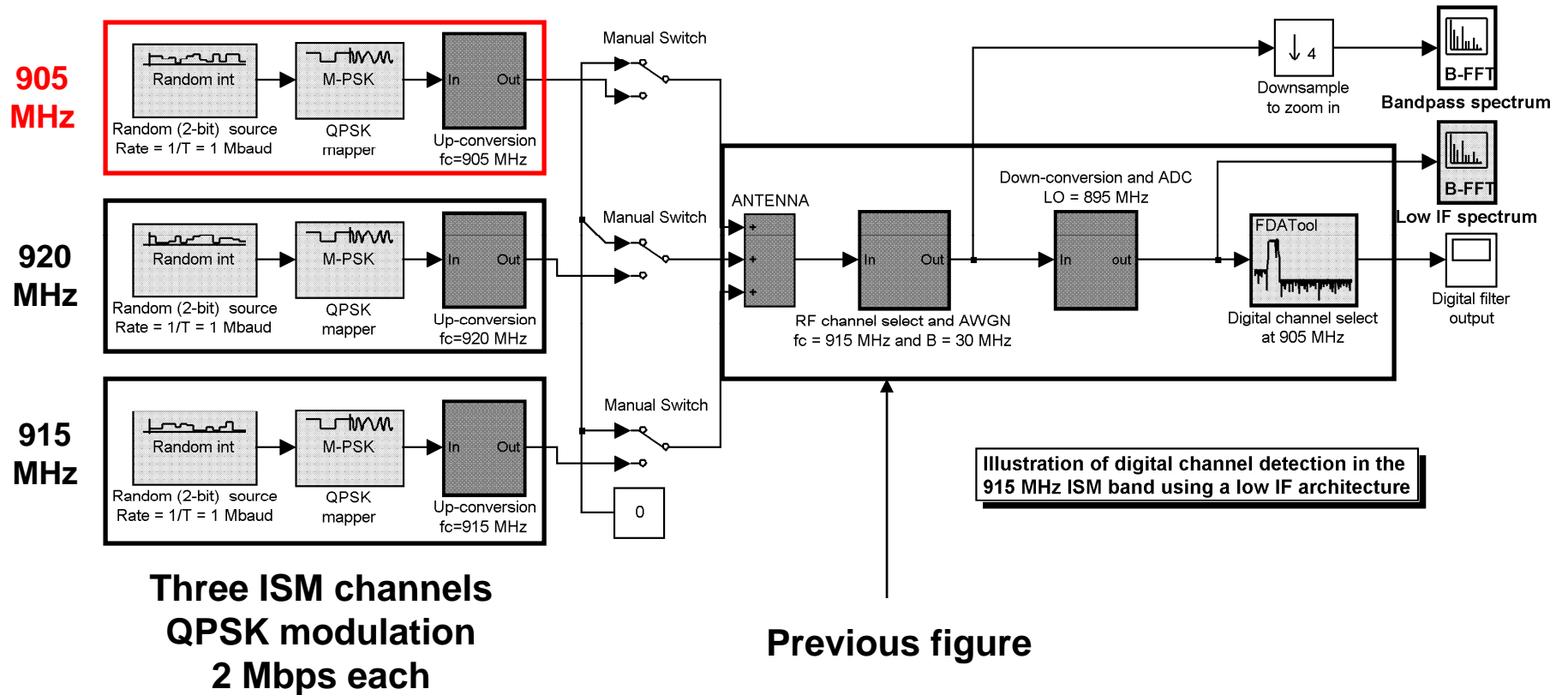
802.22 WRAN (regional) [6]

- Adaptive modulation: Typical spectrum capacity is 3 bits/sec*Hz (e.g., 64-QAM with $\frac{3}{4}$ code rate)
- OFDM type modulation to counter increased multipath due to less directional antennas at VHF and low UHF (e.g., 1000 carriers to cover a range of 0.16 μ sec to up to 33 μ sec) (8000 carriers if on-channel repeaters are needed?)
- OFDMA on return link allows scaling of the user terminal transmit power to the transmitted data rate

4. Digital channel detection in the 915 MHz ISM band (demo)



Matlab demo ...



5. Opportunities

- With cognitive radio technology, the “best” hardware does not necessarily win
- Functionality and flexibility are premium
- Do your wireless communications coursework
- Small companies can compete
- In principle, any format of signal is valid, as long as interference power levels are respected
- ...

Technical challenges

- Programmable multirate baseband architectures
- Wide, multiple and flexible RF front-ends
- High-performance and flexible ADC/DAC
- Dynamic signal processing
 - Spectrum sensing, channel estimation, MIMO, modulation and coding, spectrum shaping, transmit power control, interference avoidance
- Cognitive wireless network etiquette
 - Sense, discover, negotiate, transfer, ...

References

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- [5] M.J. Markus, "Unlicensed Cognitive Sharing of TV Spectrum," *IEEE Comm. Magazine*, vol. 43, no. 5, pp. 24-25, May 2005
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- [8] S. Geirhofer, L. Tong and B.M. Sadler, "Dynamic Spectrum Access in the Time Domain: Modeling and Exploiting White Space," *IEEE Comm. Magazine*, vol. 45, no. 5, pp. 66-72, May 2007