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Spectrum Agile Radio: Detecting Spectrum Opportunities

Kiran Challapali, Stefan Mangold and Zhun Zhong

Philips Research – USA

kiran.challapali@philips.com

stefan.mangold@philips.com

Spectrum Agile Radio: Outline

- Spectrum Agile Radio
  - Motivation
  - Introduction
- Radio resource measurements
  - IEEE 802.11 Task Group h and k
- Spectrum opportunity identification
  - Preliminary approaches
- Evaluation of concepts
- Summary

Philips Research team: Background

- Active participant in IEEE WLAN standardization
  - More than 100 submissions
  - To shape standards to Consumer Electronics and Medical application needs
- Protocols for Spectrum management
  - Significant contributors to radio resource management
    - IEEE 802.11 TG h, TG k and TG e
  - Contributor to Spectrum etiquette/Co-existence discussion in Wi-Fi
- A major proposal to UWB-MAC development
  - Distributed MAC architecture with Peer-to-peer communication
  - Supports Mesh networking

Spectrum Agile Radio: Motivation

- Use of unlicensed spectrum for commercial applications has been a tremendous success
  - Has resulted in many new applications
  - Medical, Consumer Electronics, Telecommunications, etc.
- Overall, spectrum underutilized
  - Preliminary utilization studies confirm this
  - Current (time) static allocation of spectrum has resulted in this inefficiency
- Fundamental rethinking of spectrum allocation
  - FCC's SPTF recommends dynamic allocations
  - Presidential Spectrum Policy Initiative (PSPI)

Spectrum Agile Radio: Motivation (II)

- This means rules for radios as opposed to rules for services/applications
  - radio regulators will continue to decide policy that specify behaviors of these radios
- We call such a radio a spectrum agile radio, that
  - makes opportunistic use of spectrum
  - based on available radio resources
  - while accommodating behaviors of primaries

Cognitive Radio: what makes them smart?

- IEEE-USA Position on "Improving Spectrum Usage Through Cognitive Radio Technology"
  - CRs [Cognitive Radios] are "smart" in that they can "learn" about current use of spectrum in their operating area, make intelligent decisions on that basis, and react to immediate changes in the use of spectrum by other authorized or CR users
  - http://www.ieeeusa.org/forum/POSITIONS/cognitiveradio.html
- FCC NPRM and order on Cognitive Radio
  - The ability of cognitive radio technologies to adapt a radio's use of spectrum to the real-time conditions of its operating environment offers regulators, licensees, and the public the potential for more flexible, efficient, and comprehensive use of available spectrum while reducing the risk of harmful interference.

Spectrum Agile Radio: Salient features

- Spectrum sharing by Interference management and Coordination between users, based on
  - Radio environment awareness
    - Real-time measurements, Dissemination and Opportunity identification
    - Awareness of primary and secondary usage
  - Radio behaviors influenced by evolving policies
    - Policies set by regulators
    - Policies for wireless network management
    - Examples:
      - For U-NII bands, using Etiquette as discussed in Wi-Fi
      - For hospitals
- We favor simple approaches
  - Being a manufacturer and provider of consumer/medical solutions

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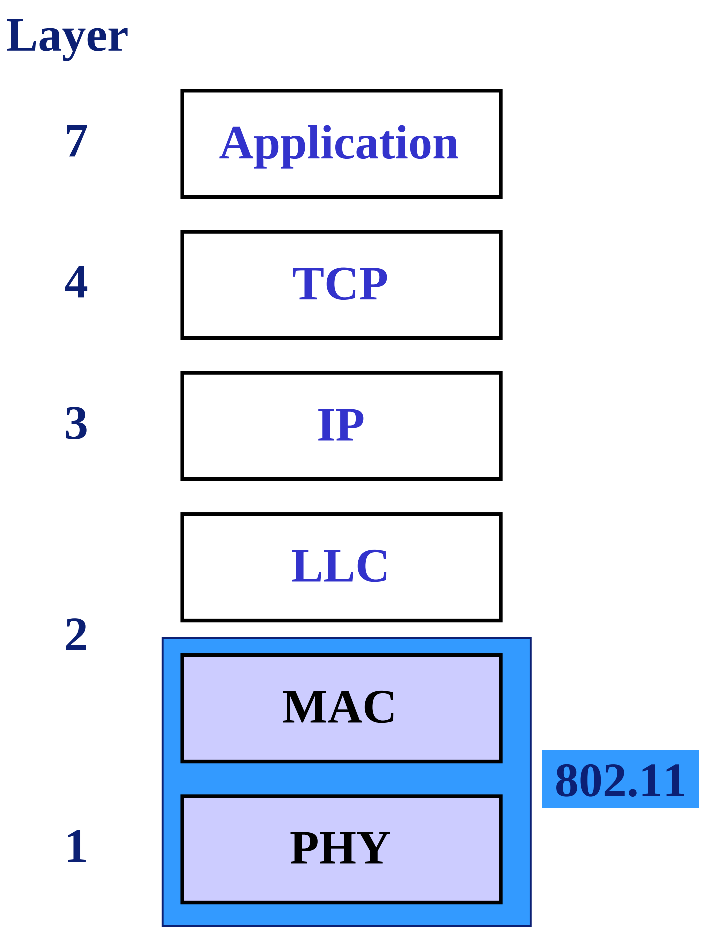
IEEE 802.11: Introduction

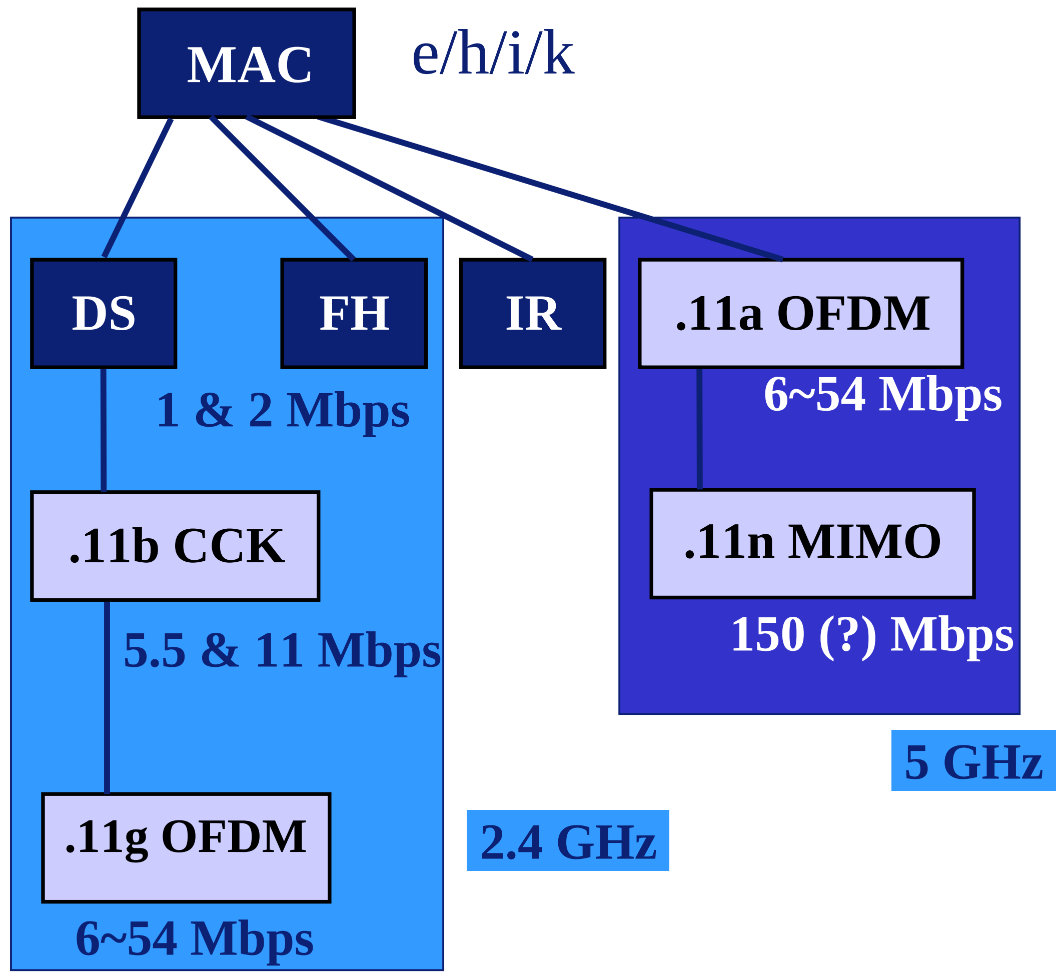
- A successful WLAN standard, that is cost effective, easy to install, and notably *still evolving*
- Originally developed as "wireless Ethernet"
- New applications require additional support:
  - Quality-of-service
  - Spectrum Management
  - Hand-off and Roaming
  - Enhanced security
  - Higher rates
- IEEE 802 standards body has formed Task Groups (TGs) to develop extensions to the standard
- Compliance to the standard certified by Wi-Fi

IEEE 802.11: Network Hierarchy

Layers 1 and 2



One MAC and multiple PHYs



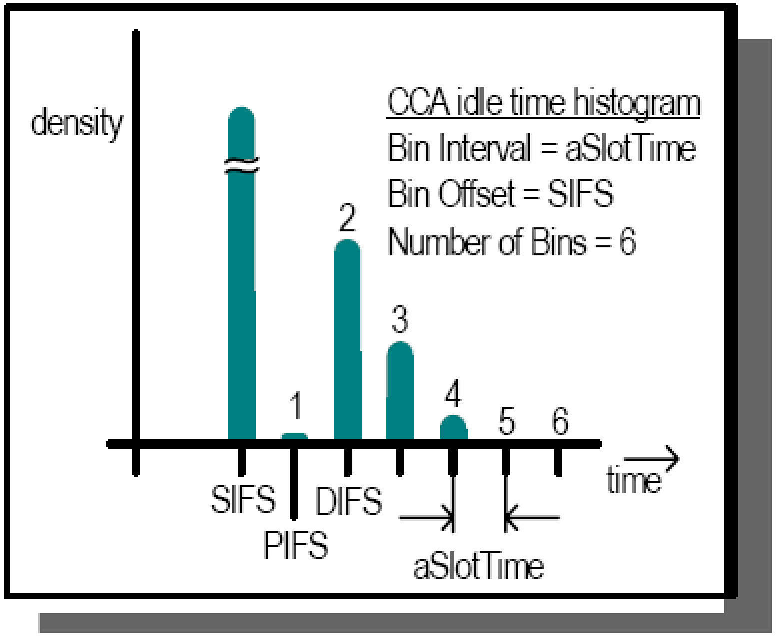
SARA: IEEE 802.11 TG h (DFS/TPC)

- Philips laid the foundation for DFS in 802.11
  - Together with a partner company
  - Philips recognized as a major contributor
- Mechanisms in 802.11h
  - DFS: Dynamic frequency selection
  - TPC: Transmit power control
- Originally, for sharing U-NII band between radars/WLANs
  - If primary detected, use DFS and TPC to avoid interference
  - Can be used for other applications
- Can request simple measurements
  - Link Margin, CCA busy fraction
- For Infrastructure (BSS) and Ad-hoc (IBSS) modes

SARA: IEEE 802.11 TG k (RRM)

- Provides mechanisms to make and share more elaborate measurements
- Medium sensing measurement requests and reports
  - For collecting spectrum usage patterns
  - Reported as time histogram
  - Using indicators such as Received Power Indicator (RPI), CCA or NAV coverage
- Provides information about other radio systems on a channel
  - Could be non-802.11 radiators such as a microwave
  - Can derive parameters of operation of 802.11 stations
- Philips recognized as a major contributor (draft standard)

Medium sensing measurement



Reported densities are indicators [0..255] for probability *p* of occurrence:

$$p(bin) \approx \frac{Density(bin)}{255}, \quad bin = 1 \ldots 6$$

$$\sum_{bin} p(bin) \approx 1$$

Density Vector (m=var.)

Density:	21	89	62	31	03	02
Bin:	1	2	3	4	5	6

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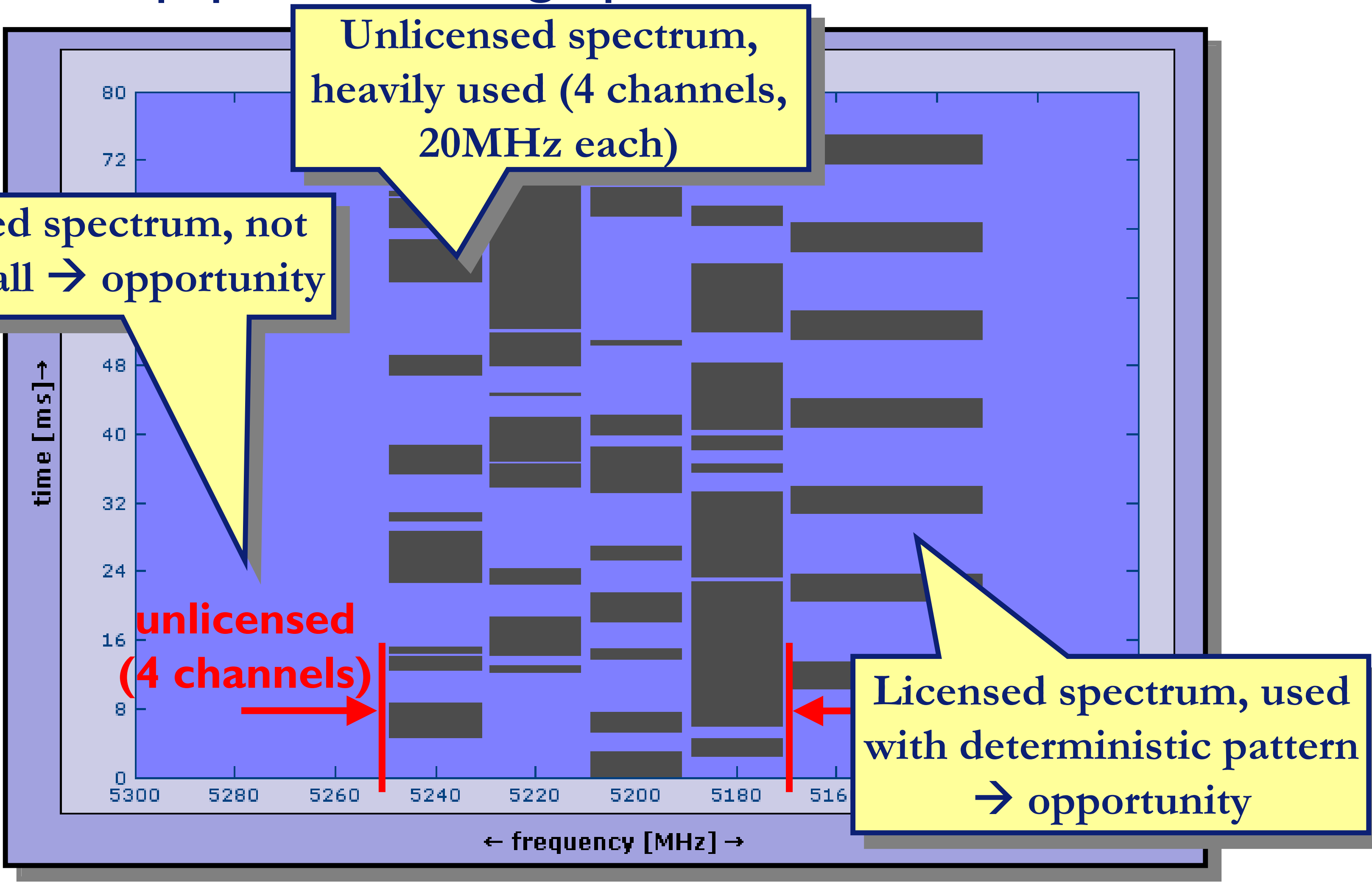
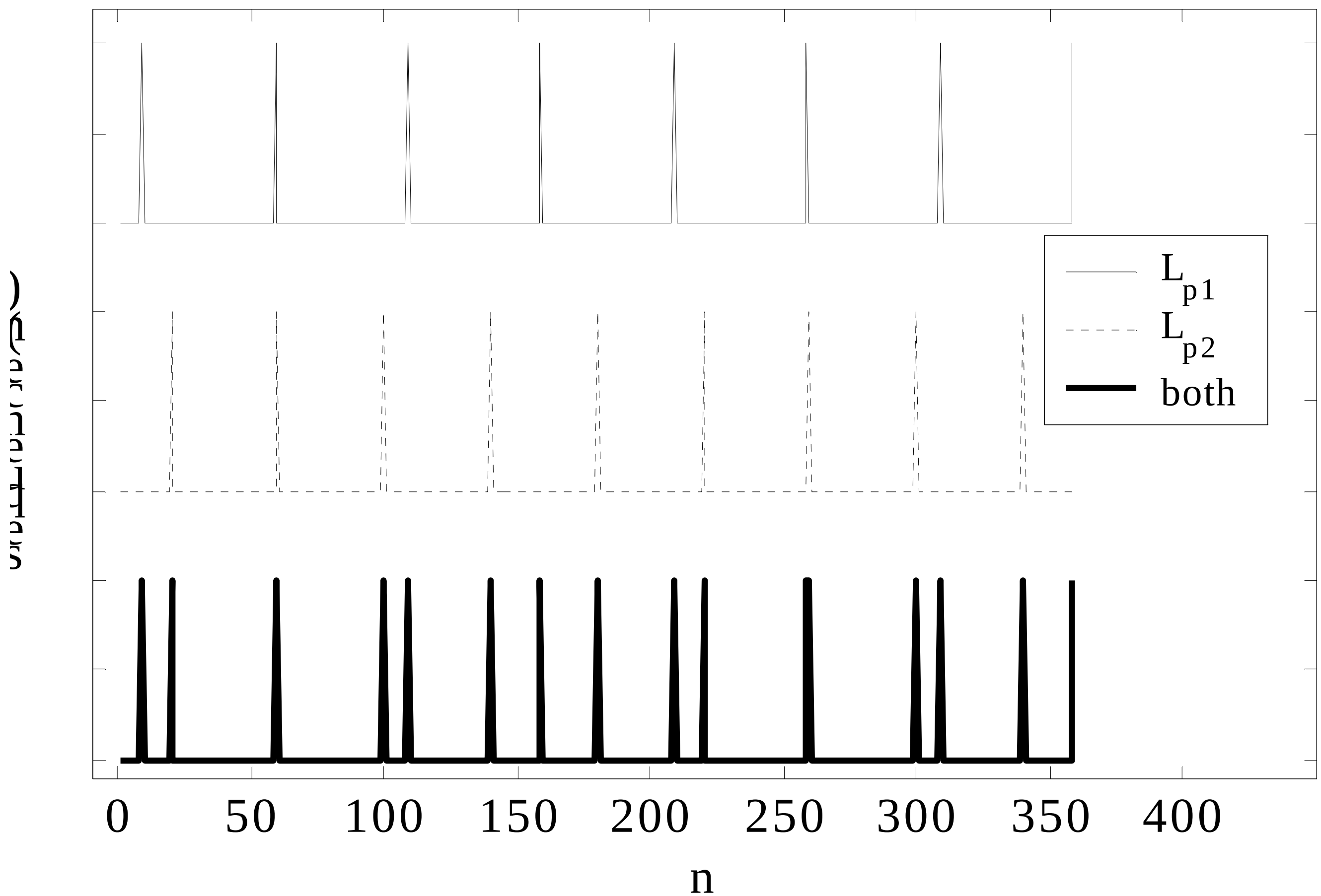
Spectrum Opportunities

- Time/freq spectrum usage pattern:



Sequence obtained from CCA busy measurements



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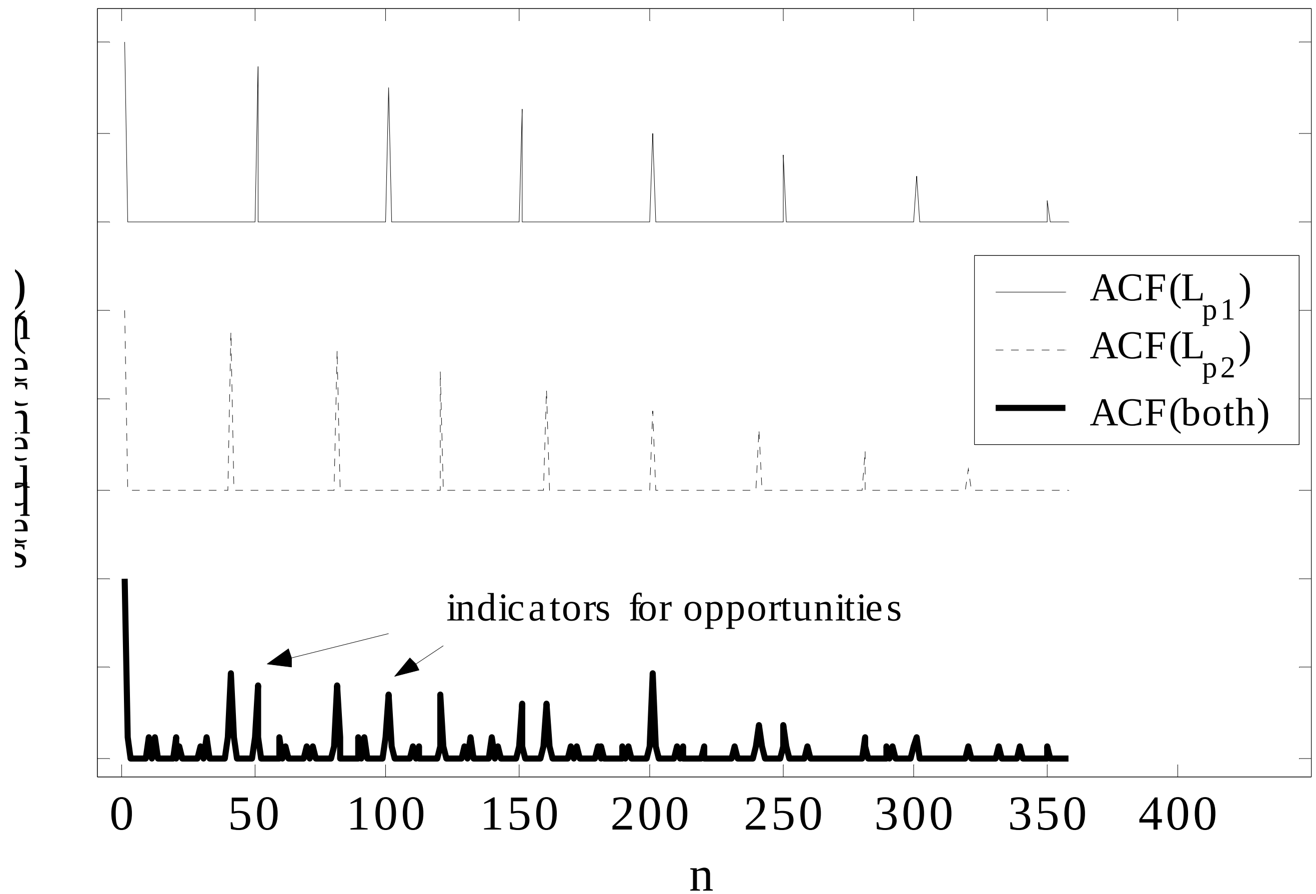
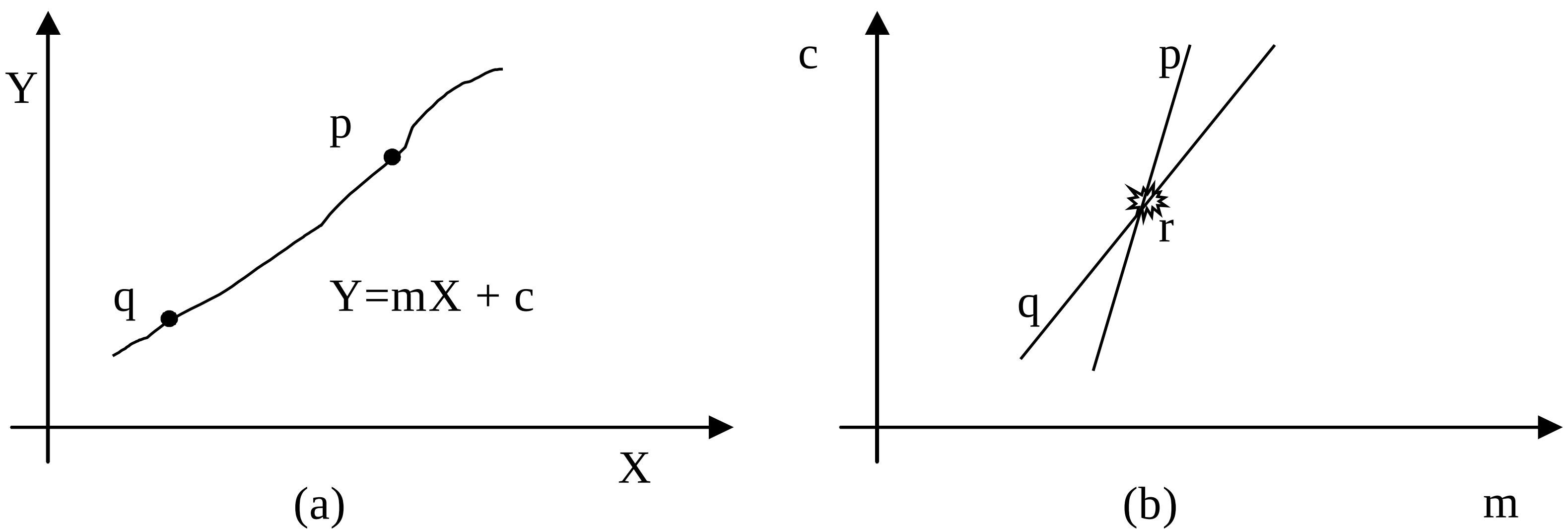
Identifying opportunities, method 1: Using autocorrelation

- Intuitive approach
- Conceptually simple



Identifying opportunities, method 2: Using Hough Transform



- A robust approach to detect straight lines
- Transformation to parametric space

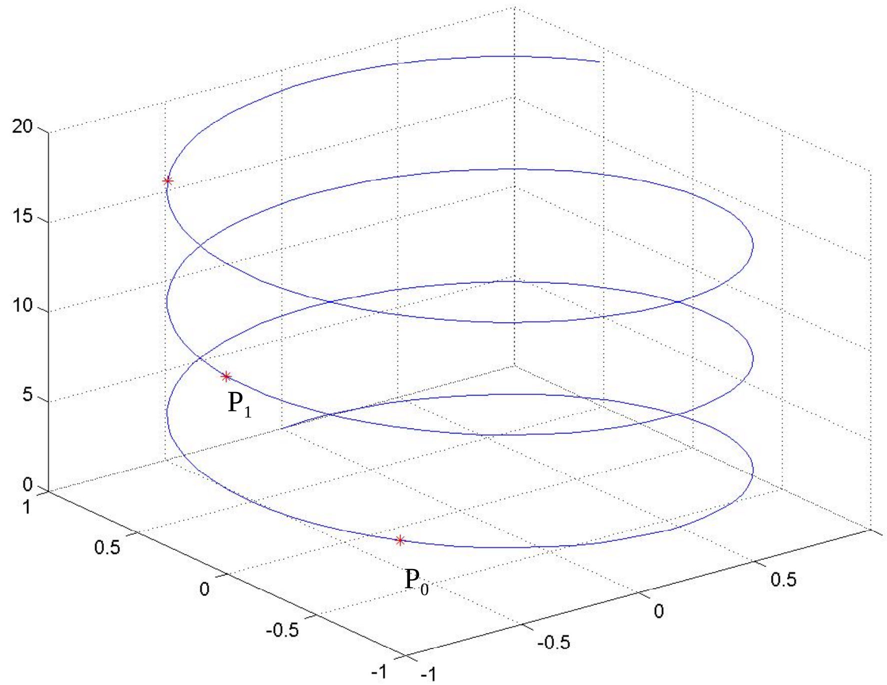
Identifying opportunities, method 2: Using Hough Transform (II)

$$X(t) = \sin(\omega t)$$

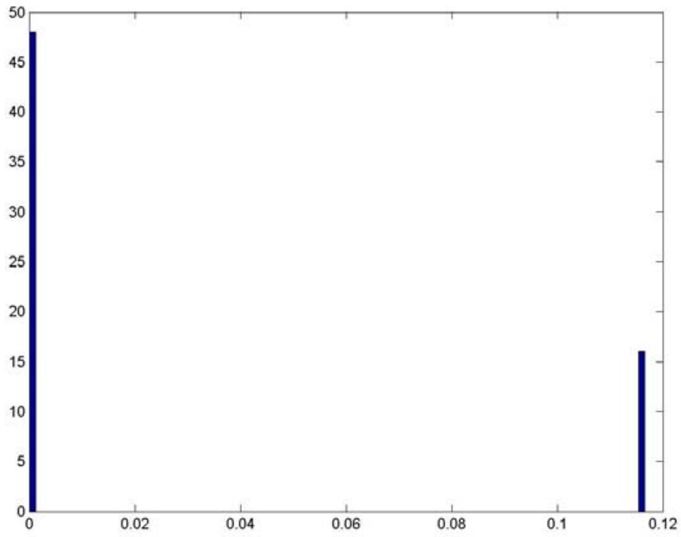
$$Y(t) = \cos(\omega t)$$

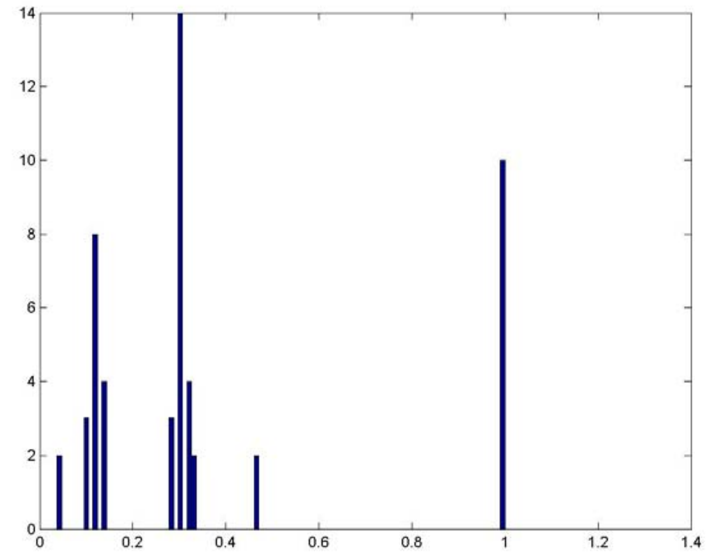
$$Z(t) = t$$

$$\omega = \frac{a\tan\left(\frac{y_1}{x_1}\right) - a\tan\left(\frac{y_0}{x_0}\right)}{z_1 - z_0}$$



Identifying opportunities, method 2: Using Hough Transform (III)





- Bin aggregation with only one pulse train
- Bin aggregation with a mixture of 2 pulse trains

Summary

- Spectrum Agile Radio, an emerging area of Research
- Key features of Spectrum Agile Radio:
  - Radio Measurements and
  - Opportunity identification

Contact information:

kiran.challapali@philips.com