WIRELESS TECHNOLOGY
PROSPECTS AND POLICY OPTIONS

David Liddle

Computer Science and Telecommunications Board
National Research Council

cstb.org

Committee on Wireless Technology Prospects and Policy Options

DAVID E. LIDDLE, U.S. Venture Partners, *Chair*
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DAVID BORTH, Motorola Labs (ret.)
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DAVID P. REED, Massachusetts Institute of Technology
GREGORY ROSSTON, Stanford University
DAVID SKELLERN, National ICT Australia

JON EISENBERG, staff director

Current Wireless Policy Framework

- Will not be able to satisfy the increasing and broadening demand for a mobile, wireless broadband Internet.
- Continues to rely on centrally managed allocation and assignment despite growing agreement that this is inefficient and insufficiently flexible.
- Relies on service-specific allocations and assignments primarily by frequency band and geographic location.
- Does not fully exploit available and emerging technology.
- Designed for a world of few, huge transmitters and many mute receivers, now long gone.

Goals of a New Policy Perspective

- Make the *effective* supply of spectrum plentiful, making it cheaper and easier to innovate and introduce new or enhanced services.
- Reduce the total cost—including licenses and equipment for both end users and networks—of introducing or enhancing services.
- Fairly evaluate and debate cost of adverse impacts on existing users and services in advance of regulatory changes.

Key Technology Considerations

- Technological advances in radios
- Interference as a property of radios and radio systems, not radio signals
- Low-cost, portable radios at frequencies of 60 GHz and above
- Enduring technical challenges
- Non-uniform timescales for technology replacement
- Spectrum use is much lower than allocations and assignments suggest, especially at higher frequencies

Technological advances in radios

- Digital signal processing and radio implementation in CMOS
- Digital modulation and coding
- Low cost and modularity
- New radio system architectures
- Dynamic exploitation of all degrees of freedom
- Flexibility and adaptability

Digital signal processing and radio implementation in CMOS

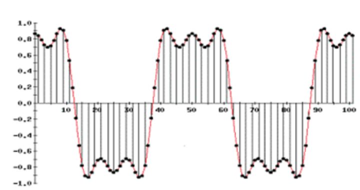
• Increasing use of complementary metal oxide semiconductor (CMOS) integrated circuits in place of discrete components;

• The application of dense, low-cost digital logic (spawned primarily by the computer and data networking revolutions) for signal processing;

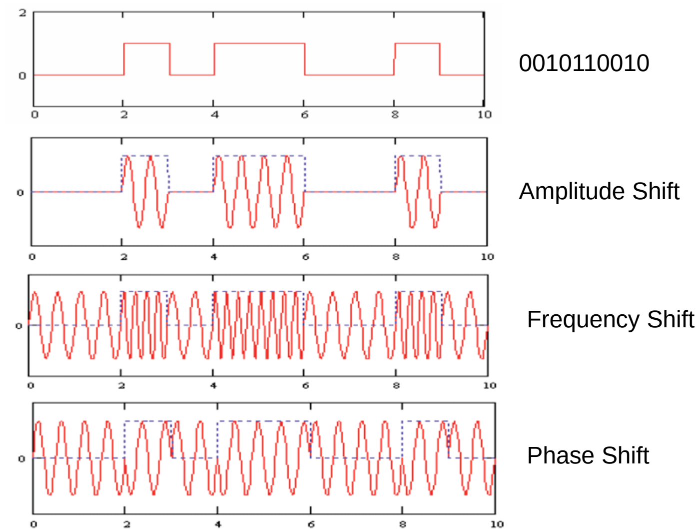
• New algorithms for signal processing;

• Advances in practical implementation of signal processing for antenna arrays; and

• Novel RF filter methods



Basic Digital Modulation



Advanced Modulation Techniques

- They rely on the separation of intentionally combined signals to carry more information in the same bandwidth.
- Multiple phases (QPSK), multiple amplitudes (QAM), or even a large constellation of many frequencies or “tones” (OFDM).

Interference !?!

- In 1912, 1927 and 1934 when the rules of spectrum allocation were established, the principal barrier to communication was atmospheric and component noise.
- As a result, any interference was considered intolerable, and frequencies were allocated to only one service in a given geography.
- Analog radio components of the time were noisy and very non-linear.
- There were few, large transmitters and many silent, cheap receivers, and regulation was designed to suit this model.

Maxwell's Equations may be resolved into two Partial Differential Equations of Second Order

- Maxwell's Equations

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

- Resulting Wave Equations

$$\nabla^2 \mathbf{E} = \frac{1}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\nabla^2 \mathbf{B} = \frac{1}{c^2} \frac{\partial^2 \mathbf{B}}{\partial t^2}$$

They are LINEAR equations, and so superposition holds for multiple waves, which add linearly at any point.

Time for a Change in Perspective

- So, signals by themselves don't interfere with each other; they add or subtract linearly, and can be separated.
- "Interference" is actually a result of the limitations of the receivers we build; a property of radio systems, not of radio signals.
- We need to build radios that tolerate interference by separating coincident signals!
- "Interference" is easily avoided in most cases, and has become an excuse for making spectrum scarce and thus restraining competition.

Low Cost Radios at 60 GHz and above

- The increasing demand for HDTV in the home, and Cruise Control Radar in automobiles, has driven the development of low-cost CMOS devices at millimeter wavelengths.
- These devices are attractive both because of their high data rate and extremely short range which makes interference nearly impossible.
- This part of the spectrum is fully allocated but is virtually unused today.
- Much of this spectrum could be reallocated as open, subject only to protocol controls rather than specific allocation of bands.

Enduring Technical Challenges

- Power consumption
- Nonlinearity
- Nomadic operation and mobility
- Heterogeneity of capabilities

Enablers of a More Nimble Policy Framework

- Abandon the extremes in the “property rights” versus “commons” debate
- Leverage standards processes but understand their limitations and political weaknesses
- Collect much more data on spectrum use
- Ensure that regulators have access to technology expertise needed to address highly technical issues
- Sustain talent and technology base for future radio technology

Forward-looking policy options (1)

- Consider “open” as the default policy regime at a frequency range of approximately 20 to 100 ghz
- Use new approaches to tolerate interference and a wider set of parameters in making assignments
- Introduce technological capabilities that enable more adaptive spectrum management
- Trade near-absolute outcomes for statistically acceptable outcomes, as is done in the Internet
- “Design for light” as well as “design for darkness,” assuming sharing rather than a silent, dedicated frequency.

Forward-looking policy options (2)

- Consider regulation of quality of receivers and networks of transceivers, rather than transmitters
- Exploit programmability so that radio behavior can be modified to comply with operating rule changes
- Use adaptive and environment-sensing capabilities to reduce the need for centralized management
- Establish enhanced mechanisms for dealing with and eventually retiring legacy systems

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