Future of Spectrum

- This inlcudes a number of slides Slides from Anton O' Gara -

spectrum allocation

- Radio spectrum is a finite public resource
- Regulated using a command and control structure

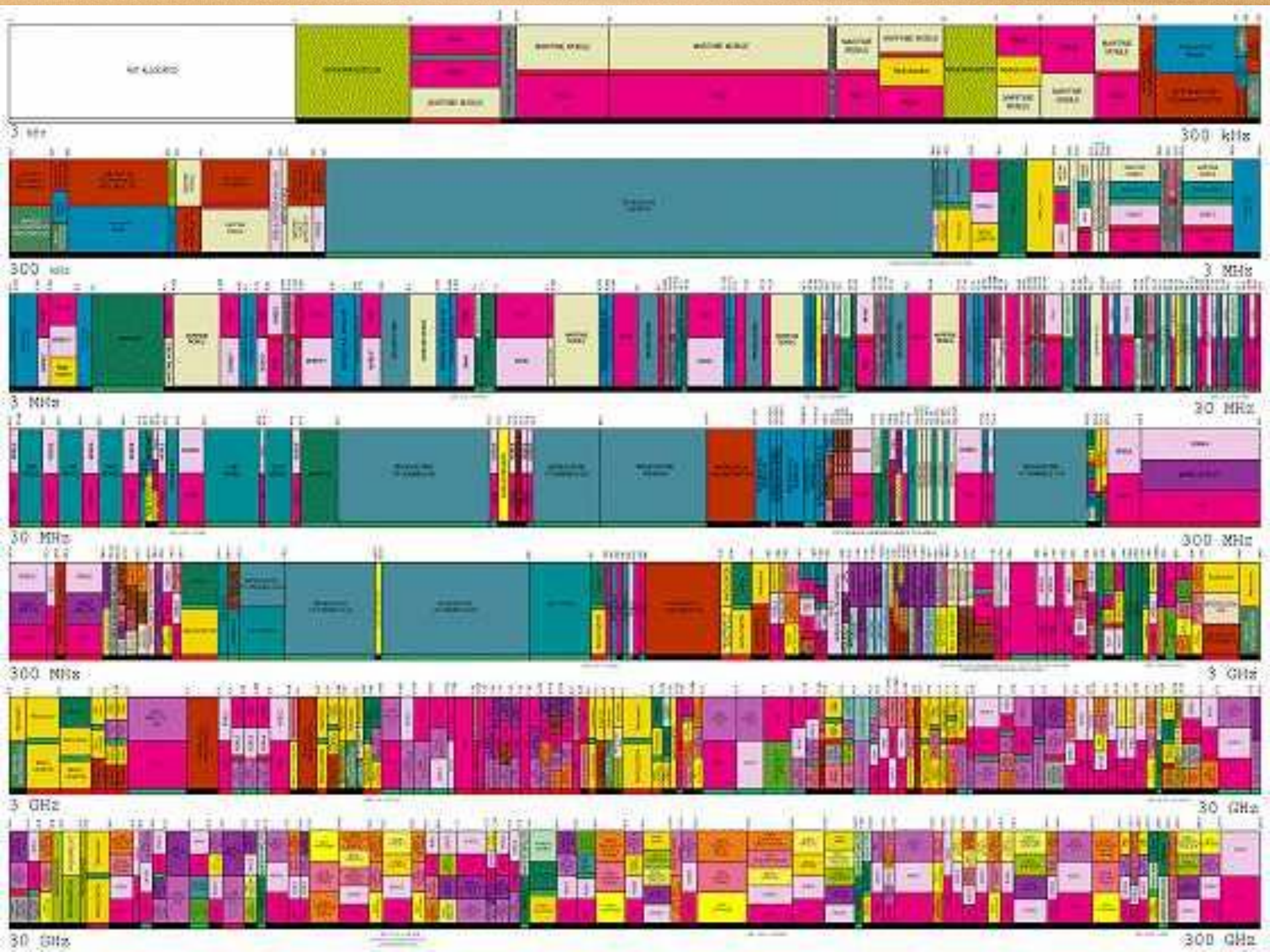
- Traditionally when you get spectrum you keep it forever.
  - 3G licenses (of course in some of these cases you can't get rid of it fast enough)
  - TV broadcasters etc.

wireless everywhere ..

an enormous growth in wireless communications over the past two decades and we now live in a world where there are ever-increasing numbers of wireless communication devices in operation. => an increase in demand for spectrum.

The Radio Spectrum

- As technology has progressed, the range of usable bands has increased
- However, the range of applications and number of users has increased at a much higher rate
- This has led to an artificial scarcity of spectrum


3 kHz
300 kHz
300 kHz
3 MHz
3 MHz
30 MHz
30 MHz
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3 GHz
3 GHz
30 GHz
30 GHz
300 GHz

The Radio Spectrum

"…there have been four core assumptions underlying spectrum policy:

1. unregulated radio interference will lead to chaos;
2. spectrum is scarce;
3. government command and control of the scarce spectrum resource is the only way chaos can be avoided; and
4. the public interest centers on government choosing the highest and best use of the spectrum.

Todays environment has strained these assumptions to the breaking point."

- FCC Chairman, Michael Powell, 2002

The Radio Spectrum

- The main driving force behind research into spectrum management is the alleviation of the man made spectrum scarcity.

  - Most of the spectrum has been allocated.
  - Even in the licensed bands that are busy, the level of activity often varies wildly with time and location.
  - Large amounts of spectrum allocated to emergency services.

Good Example - Unlicensed Activity

- Licenced bands stagnate quickly, when the spectrum is awarded people are secure and have no incentive to change.
- In the few unlicensed bands, necessity has driven **groundbreaking research**.
- Lower cost of entry into the unlicensed bands **encourages research**.
- New technologies are **breaking the 'rules'**

so we can see that ..

- static allocation does not help
- looking at other technologies all innovation in the ISM bands (license free band)
- ideas stunted / experimentation limited

so therefore …..

the traditional ideas of network infrastructure and ownership and the centralist model of a public carrier network and licensed spectrum must be challenged in an attempt to go beyond present systems and to design for the future in an innovative manner

we need to think differently about spectrum allocation

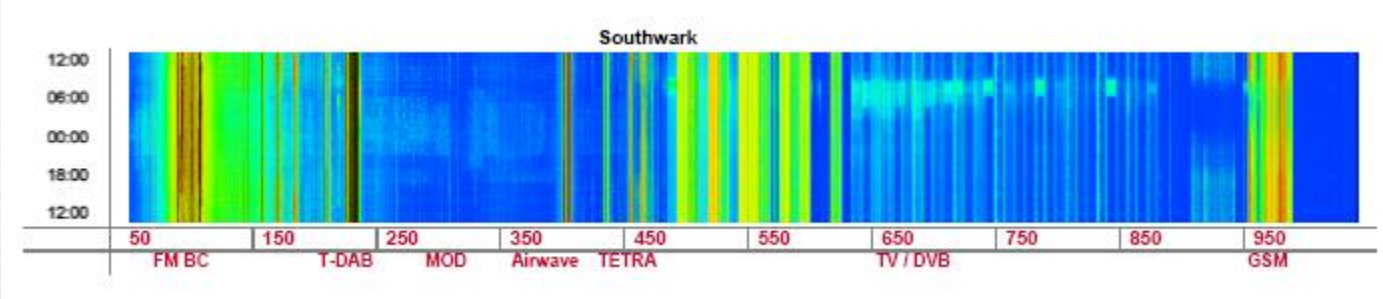
note: Regulations in most countries have changed little since the 1930's.

It is possible to allocate spectrum on a range of other bases, on a non-permanent footing with a result in increased capacity. For example dynamic allocation on a spatial basis would allow organizations in different regions to use the same frequencies. In time, the granularity of space could be reduced and in the extreme examples users would be permitted to use the same frequencies within much smaller vicinities (e.g. on different floors of a building). Allocation on a temporal basis would allow users access to underutilized spectrum, effectively filling the unused gaps of available spectrum time.

Transmit power, although partly regulated today, could be made a more effective means of allocation and would go hand in hand with regulation by space. In summary it is clear that there are many options for dynamic allocation of spectrum that greatly improve on the static and permanent allocation of frequency bands that exists at present.

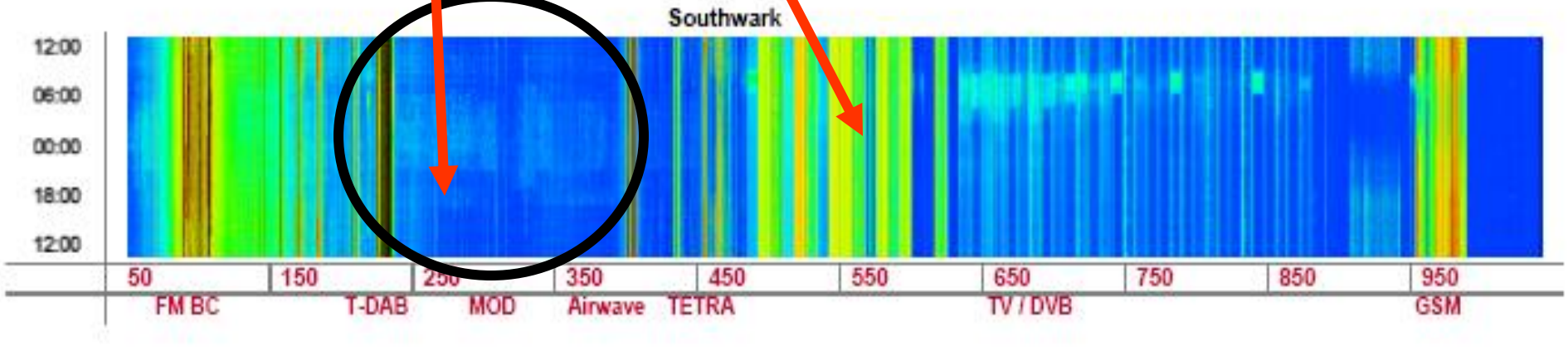
Spectrum Usage

This is the measurement taken over a 24 hour period in central London, July 2004. The solid blue represents no activity, while red represents heavy activity.



operator 1

operator 2



time

Spectrum Management Today

Spectrum Management

- The aim of spectrum management is to ensure the optimal use of the radio spectrum in civic and economic terms and to ensure reasonable and fair access to those who require it.

- Regulatory bodies recognise the need for change

Spectrum Management

- **The Ofcom Spectrum Vision**

1. Spectrum should be free of technology and usage constraints as far as possible. Policy constraints should only be used where they can be justified;
2. It should be simple and transparent for licence holders to change the ownership and use of spectrum; and
3. Rights of spectrum users should be clearly defined and users should feel comfortable that they will not be changed without good cause.

Spectrum Management

- Ofcom describe the key mechanisms in spectrum optimisation as follows:
  - Trading of spectrum
  - Liberalisation of spectrum use

Aims & Advantages

- The introduction of spectrum trading offers the following advantages:
  - Improved spectral efficiency
  - Greater control and responsibility for the market
  - Improved ease of access to the spectrum
  - A more ‘natural’ pricing mechanism
  - Increased capacity and rewards for innovation

Aims & Advantages

- The degree to which these advantages can be exploited will vary
- Regulators are keen to modernise the systems
- Wary of over-liberalisation

Issues

- Defining the set of rules to govern this trading market is a hugely complex issue
  - Standard trading unit
  - Spectrum division mechanism
  - Spectrum recall
  - Usage measurement
  - Licensee freedom
  - Dissaggregation

Proposals for Spectrum Trading

- In an attempt at creating a technology neutral regulation system, Ofcom have proposed a two tier rights system – specific and restrictive
- The specific rights may vary across different users of the spectrum
- License holders abide by their specific usage rights unless they change the use of the spectrum
- When a change of use occurs they must abide by the restrictive usage rights until they generate a new set of specific rights with the agreement of their neighbouring spectrum users
- The restrictive licences should be such that whatever the original and new uses are, the neighbours to the spectrum being traded should not suffer any additional interference.

Worked Example

- Broadcaster A indicates to a 3G operator that they would be willing to trade part of their spectrum. Were this to happen, the 3G operator would only be able to use the restrictive spectrum usage rights. These would be too restrictive to allow the 3G operator to provide a viable service;
- Before entering into detailed negotiation with the seller, the 3G operator consults with the owners of the neighbouring channels, who are broadcasters. The 3G operator reaches an agreement in principle with them that were it to buy broadcaster A's spectrum it would abide by certain restrictions on siting base stations and make compensatory payments of an agreed amount to the other broadcasters. In return, the other broadcasters would agree on a new specific property right which would be close to the 3GPP specification;
- The 3G operator builds a business case based on the new specific spectrum usage rights and compensation payments and decides on the maximum it will pay broadcaster A for its spectrum. It then re-enters negotiation with broadcaster A; and
- If the business case is viable, the trade proceeds.

Motivation towards Spectrum Trading

- Worth €9bn annually in the EU
- Gives firms a strong incentive to respond to market signals and put resources to their best possible use.
- Frees the airwaves

Proposed Further Liberalisation

- Amount of spectrum available for license exempt use be expanded

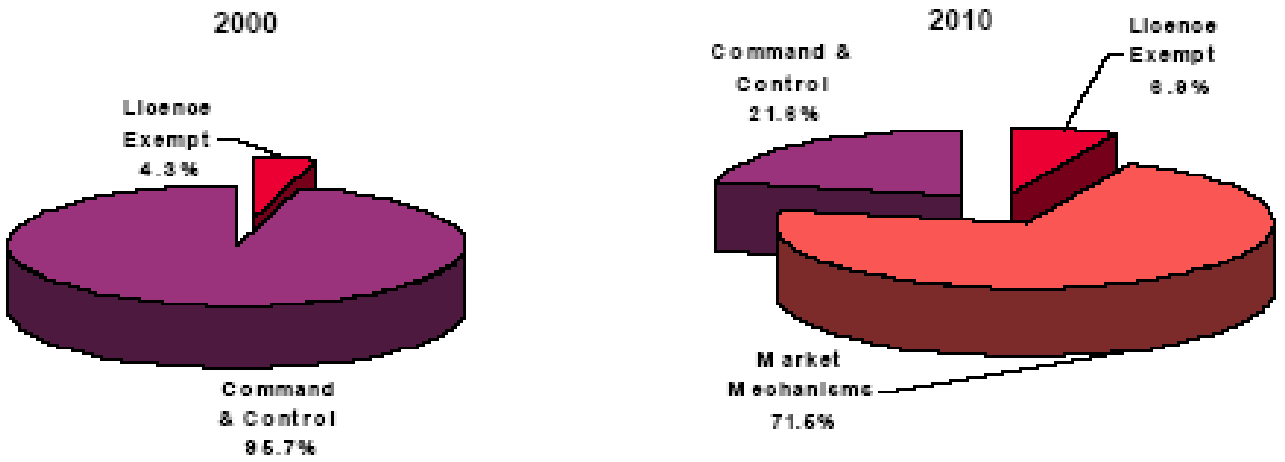
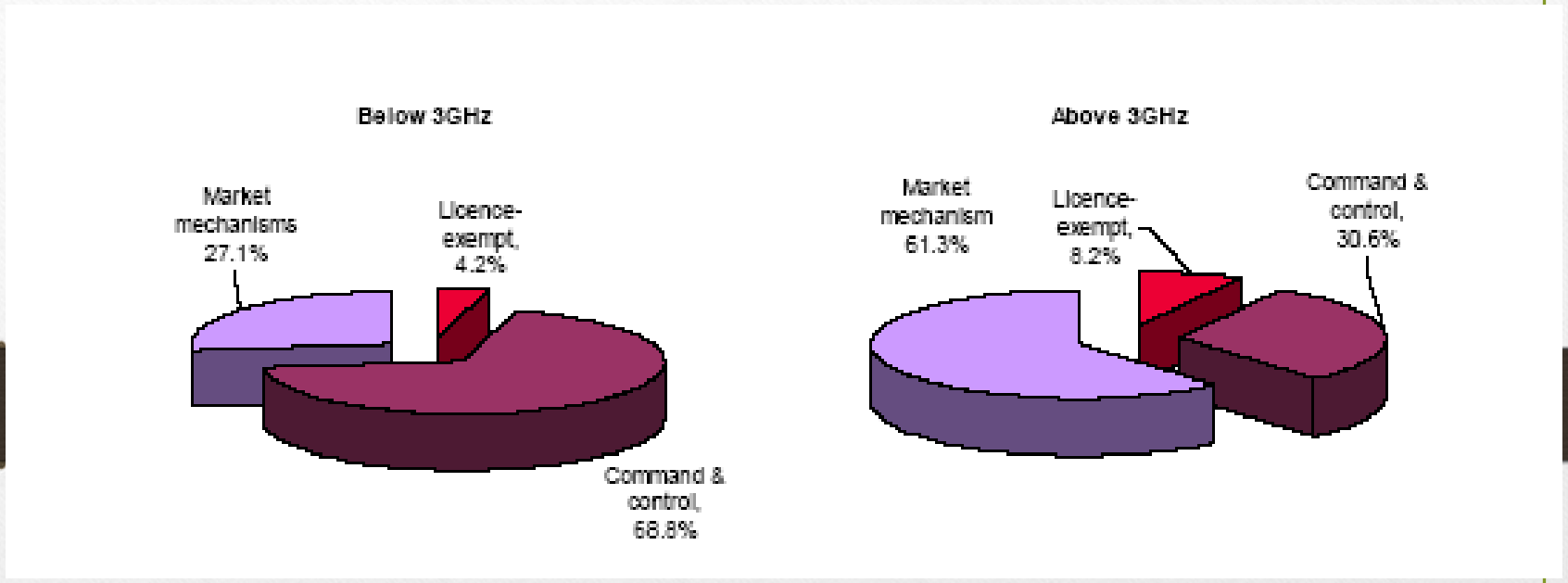


Figure 1.1: Current and future balance of spectrum use

Proposed Further Liberalisation



	Below 3GHz	Above 3GHz
Market mechanisms:	27.1%	61.3%
Licence exempt:	4.2%	8.2%
Command & Control:	68.6%	30.6%

Proposed Further Liberalisation

- As well as increasing the amount of spectrum dedicated to license exempt use, it is proposed that licensees be allowed to sell underlay access to it's allocation
- This is where the licensee can grant a third party permission to transmit on its block of spectrum, as long as the power of the transmission remains so low as to be indistinguishable from noise to the licensee.

Spectrum Trading In Practice

- Spectrum trading has been introduced to varying degrees in several countries including New Zealand, Australia, Guatemala, the U.S.A. and the U.K.

Spectrum Trading In Practice

- U.S.A. –
  - The U.S.A. has a two tier leasing system in place, allowing licensees to lease out some or all of their spectrum for a portion of the term of their license
  - Spectrum manager leasing allows the licensee to lease spectrum without consulting the FCC, but they retain responsibility to ensure the license conditions are met
  - De Facto transfer leasing transfers requires FCC approval, but transfers most of the responsibilities of compliance to the lessee

Spectrum Trading In Practice

- Australia –
  - Australia chose to divide spectrum into blocks of frequency and area called STUs
  - STUs can be combined vertically (increased bandwidth) or horizontally (increased coverage)
  - The country was divided by a spectrum map grid, where the cell size varied depending on location and population level with larger cells in rural areas.

Spectrum Trading In Practice

- New Zealand –
  - New Zealand employs a 3 tier rights system
  - Management rights grant the exclusive right to manage a nationwide band of frequencies for a fixed term up to 20 years
  - License right are then bestowed by these band managers allowing licensees access to these frequencies. The licenses are specific in terms of use and location and the manager can grant licenses to itself if it chooses.
  - Apparatus licenses exist in the blocks of spectrum where management rights have not been created.

Spectrum Trading In Practice

- Guatemala –
  - Spectrum rights in Guatemala are granted in fully transferable and fragmentable frequency usage titles
  - Technical limitations to protect against interference but which have no service limitations
  - All spectrum that is not assigned can be requested

research issues galore

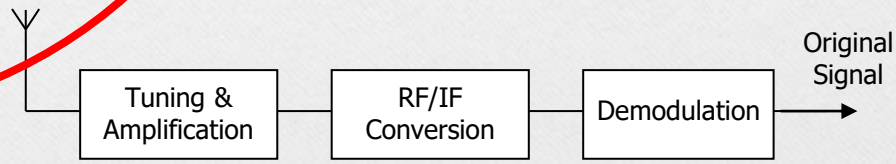
- how do we divide up spectrum?
- what bandwidth granularity?
- what time period granularity?
- how do we manage the allocation / pooling?
- who gets to be broker?
- what allocation algorithms do we use?
- how do we pay for it?
- how do we measure what is available?
- how do we monitor what is going on?
- how do we design technology to be useful at wider ranges of frequencies?
- transmitters / receivers??

Enabling Technologies

Software Radio / Cognitive Radio

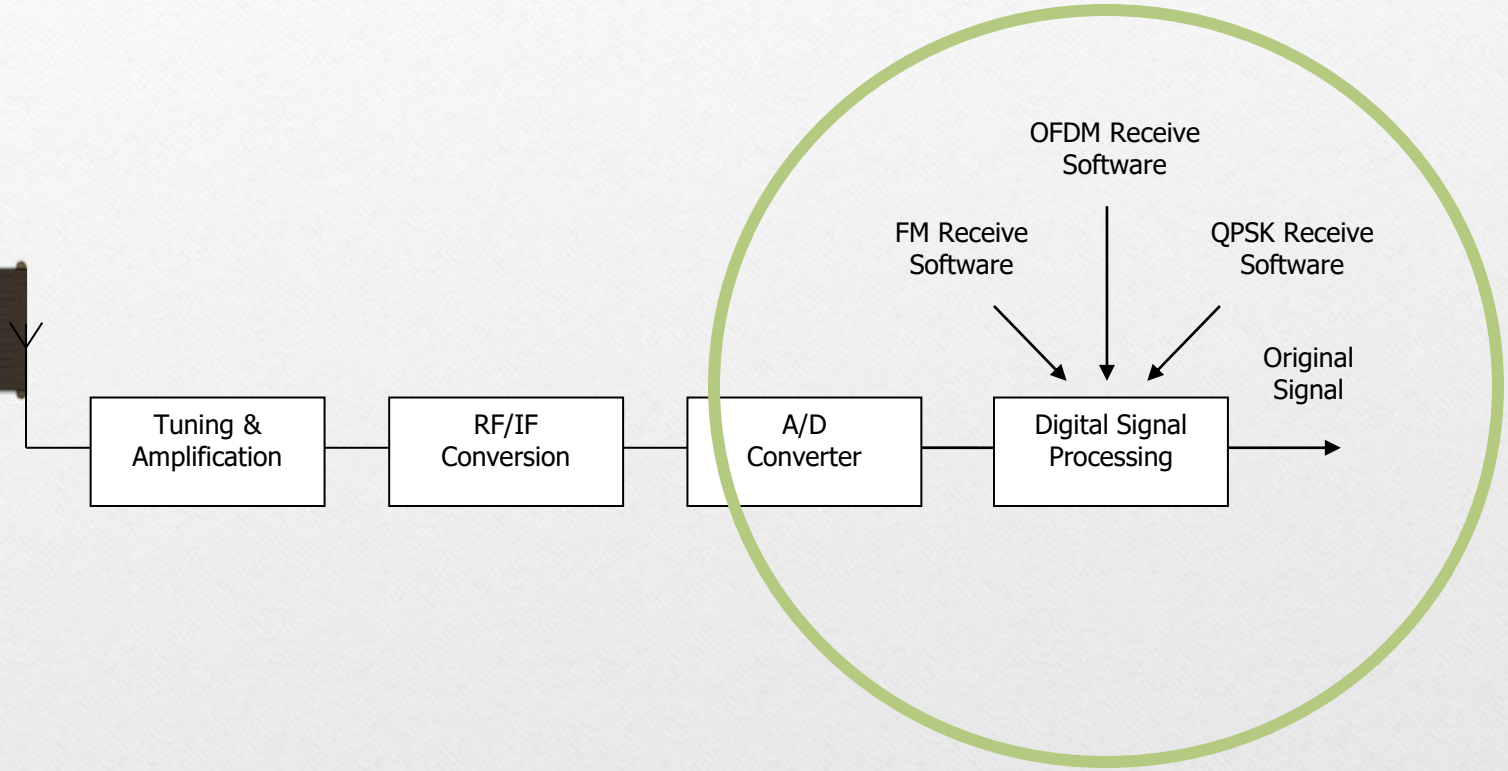
software radio

a software defined radio is a radio that includes a transmitter in which the operating parameters of the transmitter, including the frequency range, modulation type or maximum radiated or conducted output power can be altered by **making a change in software** without making any hardware changes.



different hardware for phone, WLAN, bluetooth, spectrum analyser etc.

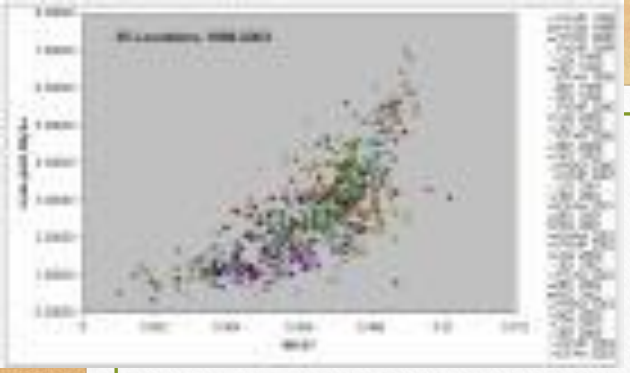
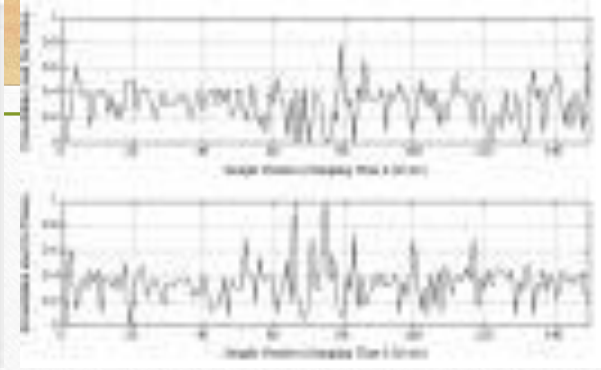
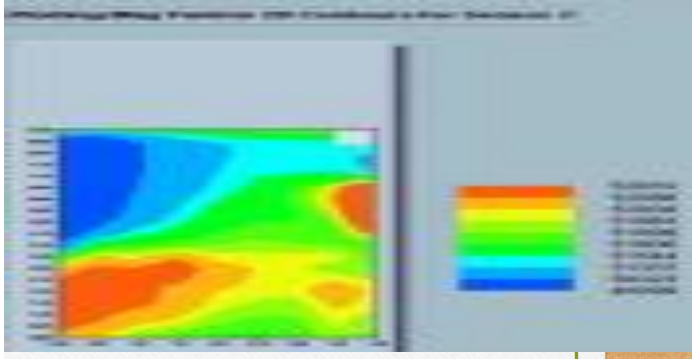
software radio, one hardware platform does it all ……



it all happens in the digital domain ….
in the signal processing / software

cognitive radio … more still

the term ‘cognitive radio’ was coined by Mitola [Mitola1999] in 1999 to describe a reconfigurable radio capable of choosing a course of action based on observations of not only the wireless channel environment, but also based on the device user's present, past and anticipated actions.

- a cognitive radio may include several sensors which continuously monitor many aspects of the local environment.

- examples of such conditions include the location of the device, spectrum-usage restrictions in the current location, current power reserves, anticipated user actions and other environmental factors including the time of day, current light level and local temperature.

- the concept of this cognitive radio system also includes the ability to conform to spectrum etiquette.

- this means that the radio could conceivably vary its transmitted power output level if it detects that interference is being caused to other legitimate users, or if local spectrum regulations that may be in service dictate a maximum output power level.