# New Trends in Spectrum Management Technology: Big Data and Spectrum Sharing

State Radio Monitoring Center of China
Radio Monitoring Department

# Dynamic Spectrum Allocation Background and Introductions

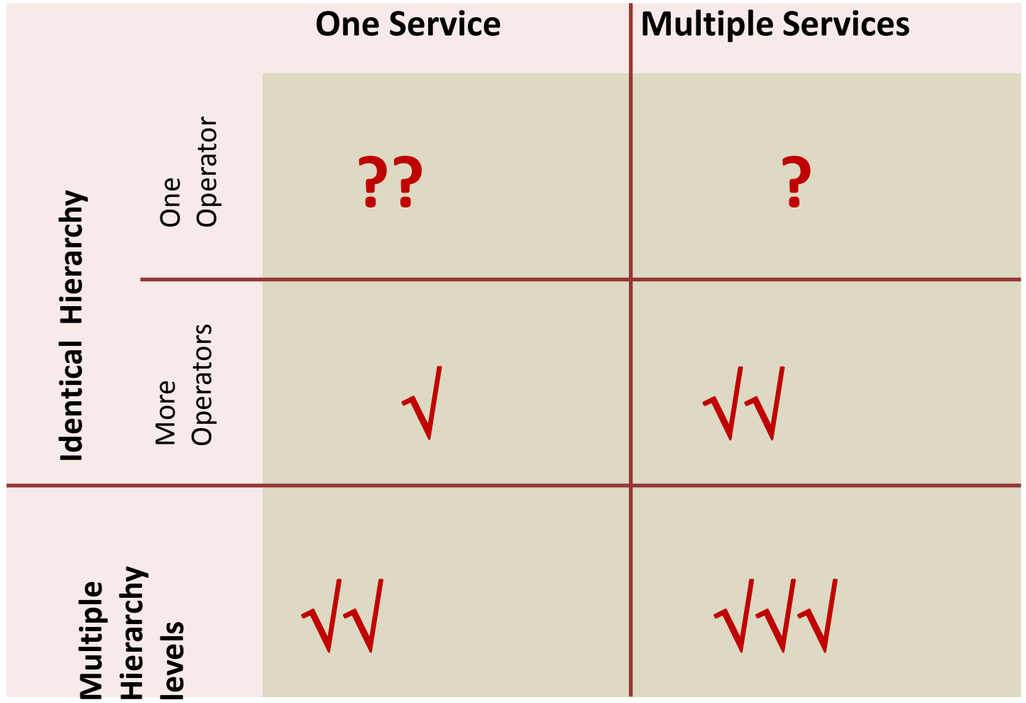
State Radio Monitoring Center of China
Radio Monitoring Department

# What is DSA?

- A mechanism to utilise underused spectrum in a temporal or geo-locational varied way.
- Allocations can be a short as seconds to as long as …..
- The future of spectrum management as an additional allocation tool
- Requires complex negotiations with all stakeholders, and management of primary users concerns.
- Very suitable for many military bands and other underutilised but important bands.

# Dynamic Spectrum Access: Motivation

- Better usage of “residual” Spectrum
- Easy reclaim and re-farming of Spectrum
- Instant reaction possibility on emergency incidents
- Making Spectrum available which cannot be freed otherwise like military bands




**Many entities would be open for band sharing if they could definitely reclaim their frequencies within one hour**

# What spectrum is suitable for DSA?

- Low utilisation with slow change of use
- Geographically dispersed use in a nationally allocated set of bands
- Suitable commercial user or network infrastructure or at least desire to support this new band
- A secondary user who is able to absorb the risks of spectrum allocation: Not all channels are available all the time!
- A licensing or regulatory control regime that the primary user is willing to accept.

# What are the problems with DSA?

Problem 1: There are already users on the frequencies

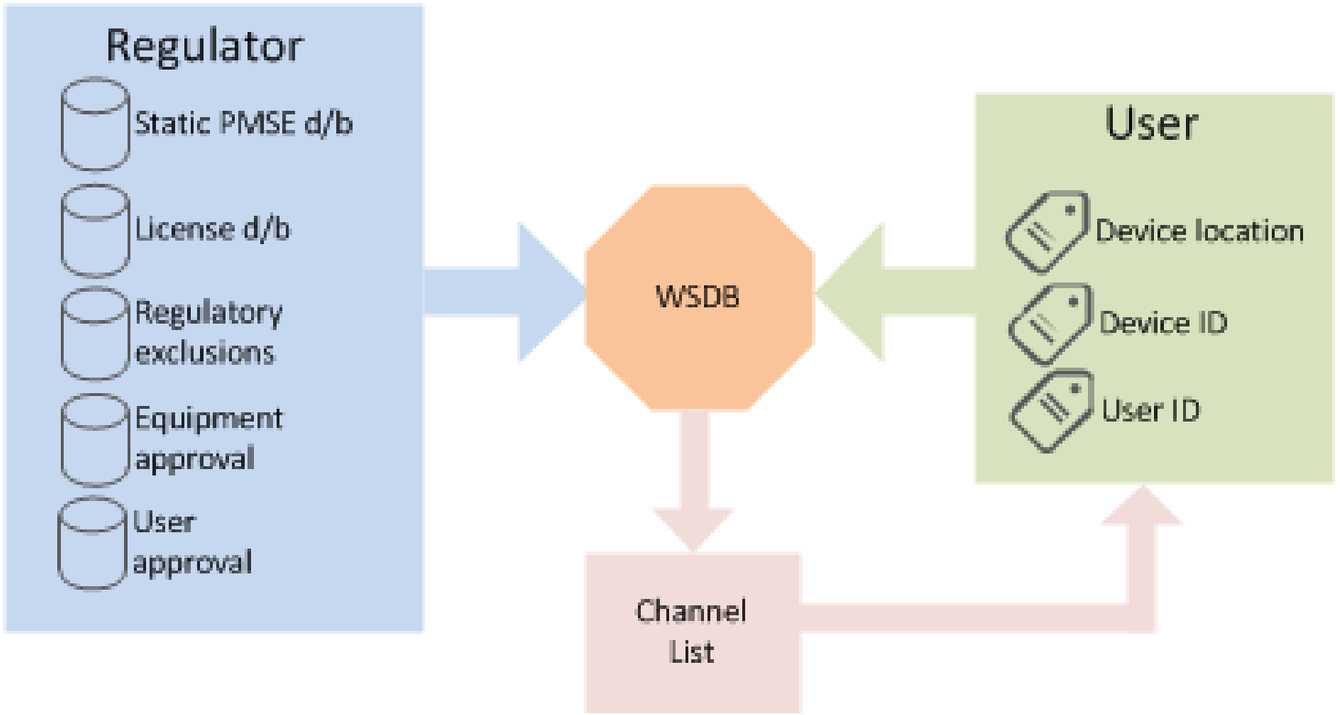
Problem 2: The available channels vary by location (and time sometimes)

Problem 3: The possibility of interference is high

Problem 4: The potential number of devices is huge

Problem 5: Cross border co-ordination

# How does the database get its information?




- The database is a rules based algorithm
- The regulator maintains full control of the licensing  inputs to the database to keep control

# What does this mean to traditional Spectrum Management?

- Originating data from DSA comes from the spectrum management system
  - Must be accurate
  - Detailed
  - Have interfaces to DSA databases

- Primary user data and interference management systems within traditional Spectrum management

# Can DSA and traditional licensing co-exist?

Of course and will do!

- DSA will not be “mainstream” for 5 to 10 years
- Certainty of access will always remain in traditional systems
- “When” or “if” the spectrum crunch has financial impact DSA will become more relevant.
- Some countries may opt for no DSA but have more flexible traditional licensing.

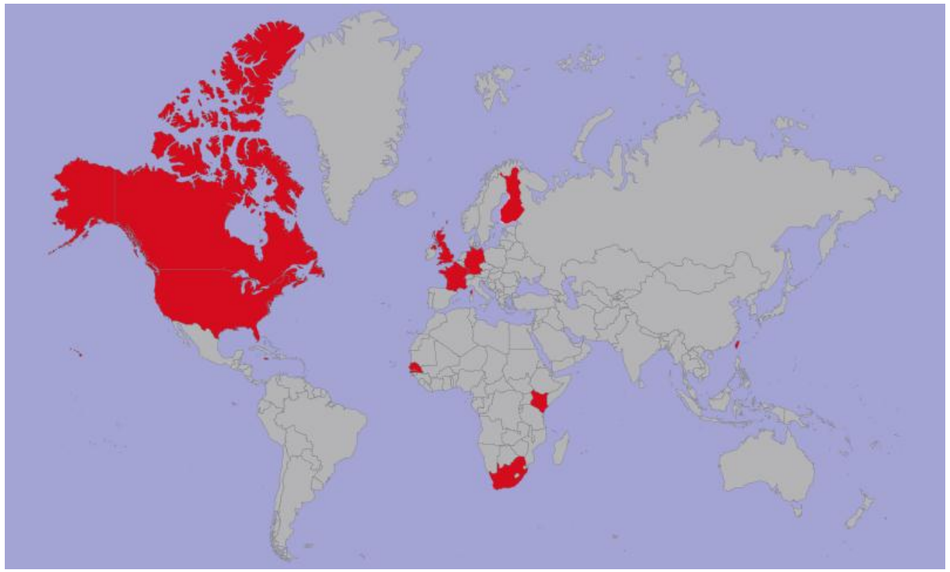
# Future of DSA and Spectrum Management

- In traditional Spectrum management future developments are more about e-service / self service to licensees.

- In DSA more opportunities open up:
  - Automated “auctioning” of spectrum
  - Spot market for spectrum demands
  - Any band any type allocations
  - Short term spectrum demand management
  - And many more…….

# International footprint

- Operational DSA policy and operations (trial or commercial)
  - USA, Canada, Jamaica
  - UK, Finland, Germany, France
  - Singapore, Taiwan
  - Malawi, South Africa, Senegal,
  - Kenya



- Mainly TVWS although several countries are now moving to release of other bands (primarily Military spectrum)
  - Netherlands, France, USA

# Regulatory Techniques (Sharing, LSA, DSA)

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# Sharing

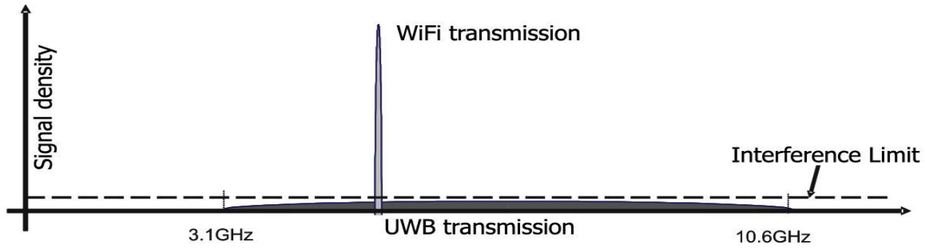
- An ‘age old’ technique
  - Sharing is at the heart of the ITU radio regulations

| Allocation to services | | |
|---|---|---|
| **Region 1** | **Region 2** | **Region 3** |
| **2 400-2 450**<br>FIXED<br>MOBILE 5.384A<br>Amateur<br>Radiolocation<br>5.150 5.282 5.395 | **2 400-2 450**<br>FIXED<br>MOBILE 5.384A<br>RADIOLOCATION<br>Amateur<br>5.150 5.282 5.393 5.394 5.396 | |
| **2 450-2 483.5**<br>FIXED<br>MOBILE<br>Radiolocation<br>5.150 5.397 | **2 450-2 483.5**<br>FIXED<br>MOBILE<br>RADIOLOCATION<br>5.150 | |

- Sharing often handled by separating services
  - By geography (e.g. distance)
  - By directionality (e.g. fixed versus satellite, WiMAX versus satellite)
  - By ‘spectral density’ (e.g. UWB)

# Ultra Wide Band (UWB)

- A technology which was described in the early 1960‘s as 'carrier-free', 'baseband' or 'impulse' technology
- Transmit (and receive) a burst from one to only a few cycles of a radio frequency (RF) carrier wave
  - effectively an impulse of RF with *infinite* bandwidth
  - spreads the transmission so ‘thinly’ that on any given frequency there is virtually no signal
- Operates invisibly ‘beneath’ other transmissions
  - an ‘underlay’ network

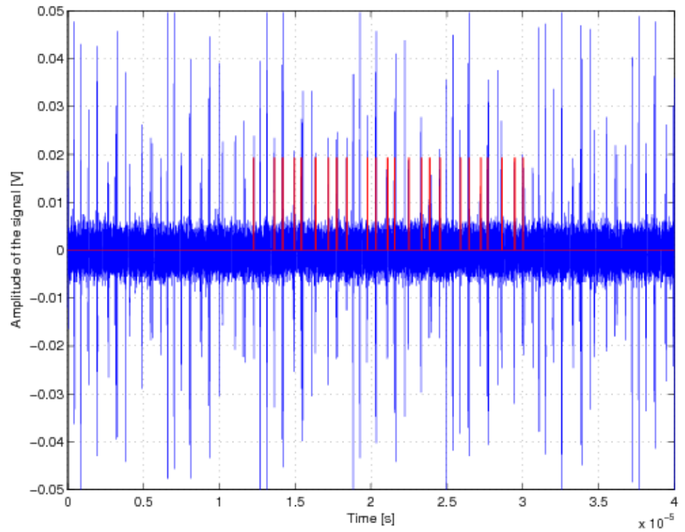


# Why is UWB Special?

- UWB was proposed to offer
  - Extremely high bandwidth data links (over very short ranges)
    - e.g. as a replacement for USB, HDMI
  - Precision measurement and location identification
    - in radar applications
    - and for ‘radio tags’
  - Collision avoidance systems
  - Low complexity and therefore (in theory) low cost
- UWB is mainly used for
  - Radio imaging
    - Emergency services
    - Medical (alternative to MRI)

# What's the Fuss with UWB?

- A single device should not cause interference to other radio users
- But what happens when there are thousands, or even millions of devices in a given area?
  - overall increase in background noise levels
  - deterioration of performance of other networks
  - harmful interference to protected services
- No-one knows for certain…
  - …hence the caution with which it has been treated by regulators
- UWB… failed because of regulatory restrictions?



# DARPA spectrum challenge

- The DARPA Spectrum Challenge was a competition to demonstrate a radio protocol that can best use a given communication channel in the presence of other dynamic users and interfering signals. The Challenge was not focused on developing new radio hardware, but instead was targeted at finding strategies for guaranteeing successful communication in the presence of other radios that may have conflicting co-existence objectives.
- The Spectrum Challenge entailed head-to-head competitions between each team's radio protocol and an opponent's in a structured testbed environment. The Challenge awarded first place teams in the preliminary event, and first and second place teams in the final event with cash prizes totaling $200,000.
- 17 teams
- Winner was Tennessee Tech University who used software defined radios!

# Sharing summary

- Sharing is a “high level” method of allowing more than one set of users into a piece of spectrum
- It happens every day, all the time
- It generally operates at a macro level
  - International
  - Intranational

# Licensed Shared Access – RSPG Definition

- “A regulatory approach aiming to facilitate the introduction of radio communication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the LSA approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum , thereby allowing all authorised users, including incumbents, to provide a certain Quality of Service (QoS)”

# Implementation of LSA

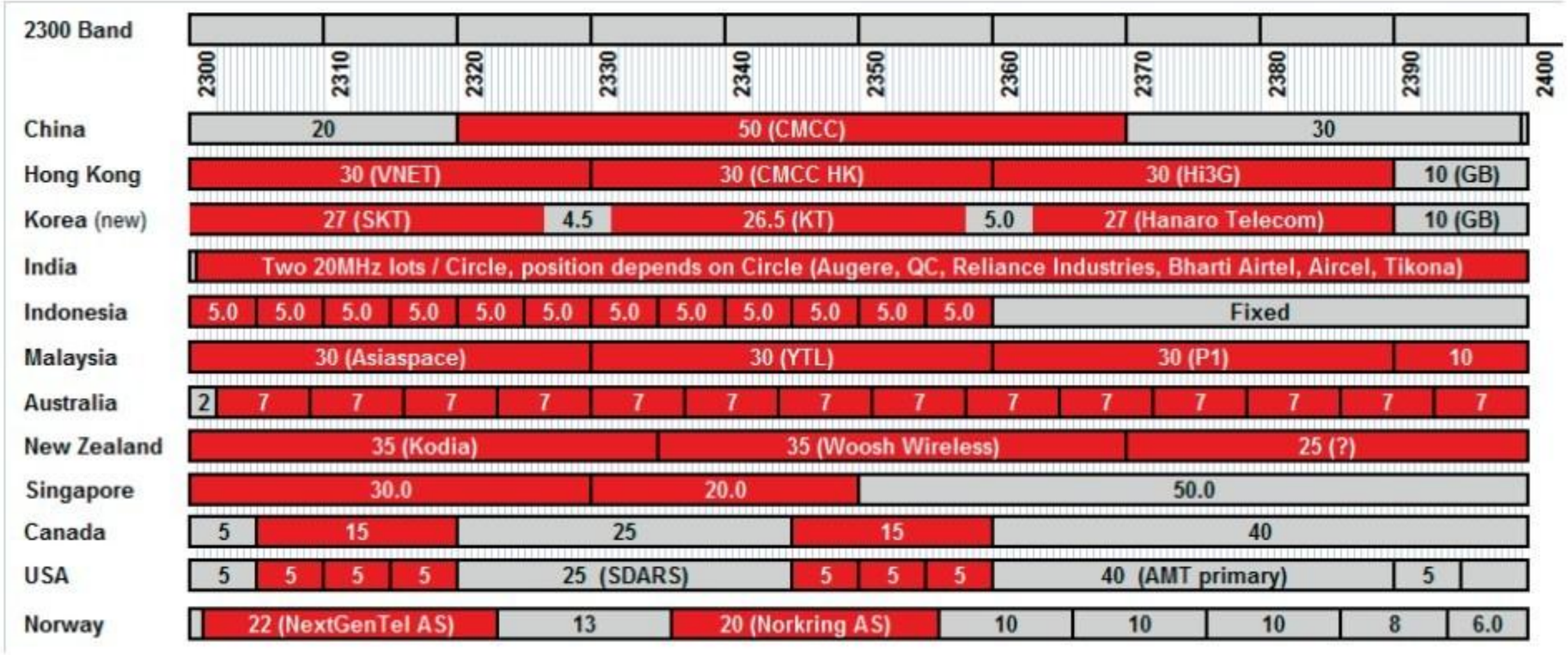
- LSA of primary use where the incumbent spectrum user:
  - Is not able to trade their spectrum or has no way to ‘sell’ it
  - Has fragmented availability (e.g. different pieces of spectrum in different areas)
  - Does not want to make all of a band available
  - Is slowly clearing a band to be fully released at a later date
  - May want to change their usage over the medium-term
  - May want to impose different technical or other criteria
- In general, some or all of the above apply mainly to:
  - Military spectrum
  - Government spectrum
  - Broadcast spectrum
  - Satellite spectrum

# Spectrum considered for DSA

- 470 – 790 MHz
  - UHF television broadcasting band
  - LSA seen as a way of providing better ‘cognitive’ access or for PMSE
- 2300 – 2400 MHz band
  - Often military or governmental
  - Existing IMT band
- 3400 – 4200 MHz band
  - Satellite ‘C-Band’
  - Existing IMT band in 85 countries in Region 1
  - Not generally used for direct-to-home reception thus limited geographic requirements

# 2300 – 2400 MHz

- ECC Report 205
- ECC Decision ECC/DEC/(14)02
- CEPT Report 55
- RSPG Opinion (RSPG13-538)




*Global Magnitude of 2300MHz Band Assignments.*

# LSA in action…?

- LSA is just a ‘cheaper’ way of getting access to spectrum for mobile services
  - Less certainty than normal licensing regimes and thus lower value
  - Less desirable spectrum due to sharing characteristics?
- LSA is a way of trying to force users (e.g. government) to release mobile spectrum
  - Assumes government spectrum use is not universal/dense
  - Heavy handed tactics to shame users into action?

# Dynamic Spectrum Assignment

- Extension of cognitive radio concept
- Devices are aware of their location (e.g. using GPS)
- A central database stores information on frequency usage
- Devices send their location to the database
- The database responds with a list of frequencies available at that location
  - With other restrictions (e.g. time/power)
- Devices use the available frequencies
- Opportunity to charge for frequencies
- Opportunity to register frequency use
- Provides a proper regulatory environment

# Pros and cons of DSA

| | Pros | Cons |
|---|---|---|
| **Incumbent User** | ▪Dictate usage and protect services<br>▪Stop usage (e.g. by day/hour) if needed<br>▪Possibility of charging for use | ▪Need to properly document spectrum use<br>▪Need to manage data for database<br>▪Feeling of pressure to share |
| **White-Space Device** | ▪Guarantee that a frequency can be used<br>▪Usage should not cause interference<br>▪Incumbents may be more willing (compared to pure cognitive access)<br>▪Possibility of registering use (to protect service) | ▪Incumbent user dictates usage (could be too restrictive)<br>▪Need to know location<br>▪Need to interface with database<br>▪May have to pay for use of spectrum |

# Questions about DSA remain

- Who should operate the database?
  - Regulator, incumbent spectrum user, third party
- Who should pay for the database?
  - Should or could the database be commercial?
- Who is responsible for the accuracy of the database?
- How many databases should their be?
- What is in the database?
  - User supplied exclusion zones
  - Transmitter information for database to calculate available spectrum
- Should there be a common interface standard?
- How should white-space devices connect to the database?
- What information is supplied to the white-space devices?
  - List of frequencies
  - Just 1 frequency (selected optimally)
  - Information on other WSD

# Conclusions

- Spectrum has been shared between users for many years
- Licensed Shared Access may be a response to frustration by some users (e.g. the mobile community) with the restriction of incumbent users to release apparently unused bands
- Dynamic spectrum assignment provides a method of permitting cognitive radio that is a ‘win-win’ for spectrum owners and cognitive devices
- But the same problems likely to apply as spectrum usage densifies

# Software Defined Radio and Cognitive Radio

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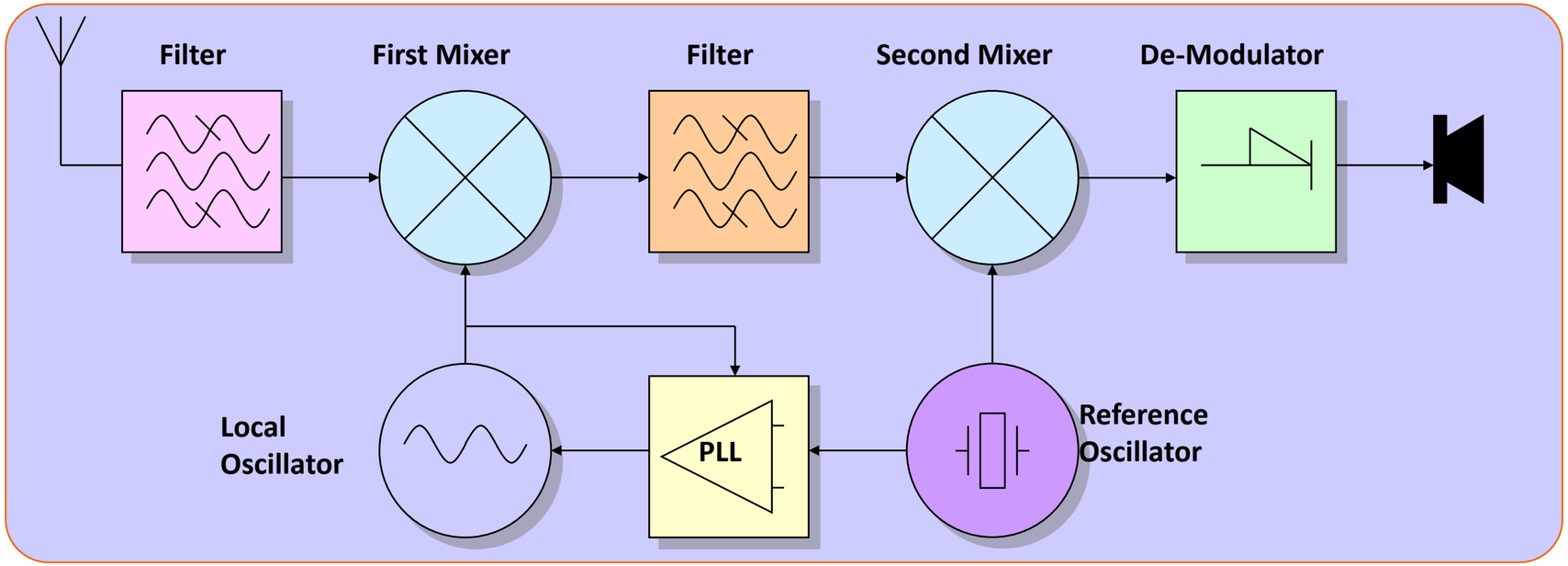
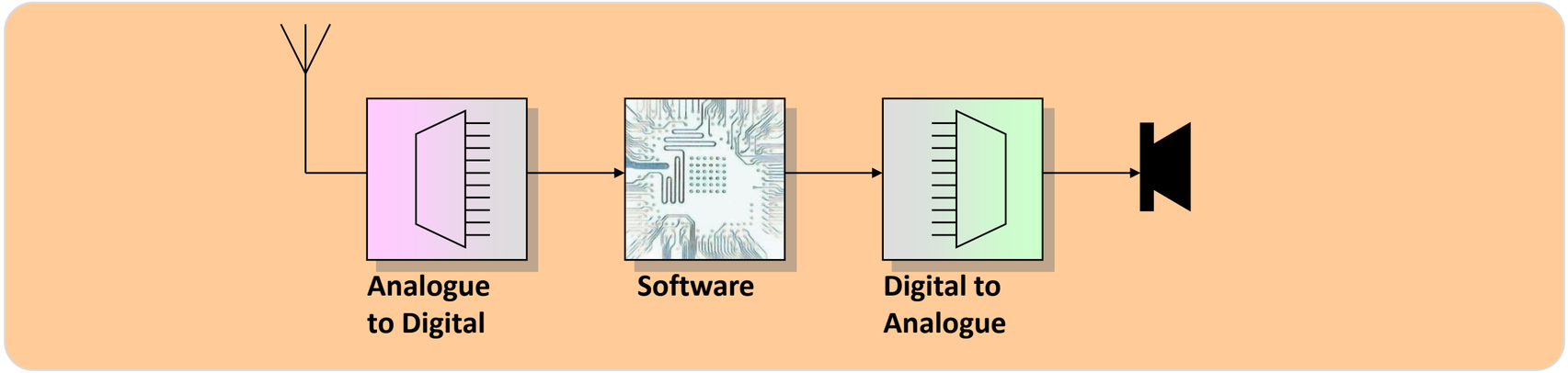
# SDR is the Martini of Radios

- Most radios are restricted to:
  - A specific frequency of set of frequencies
  - A particular modulation scheme
  - A particular receive bandwidth
- In essence – a particular technology
- Software Defined Radios (SDR) do away with all these restrictions
  - Any time, any place, anywhere!

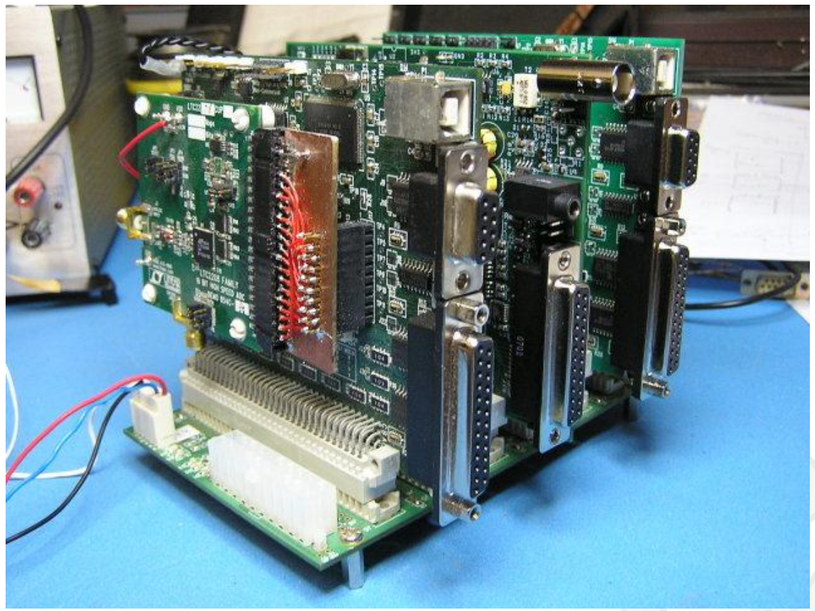
# Traditional versus Software Defined Radio Architectures



# Software Defined Radio

- Radios have historically been based on discrete components designed to undertake specific tasks
  - only one band or one modulation scheme at a time
- Digital Signal Processing (DSP) chips can undertake these tasks
  - and can be re-programmed to do a different task
- The ultimate SDR would be able to:
  - receive (and transmit) on any frequency
  - using any modulation scheme
- Technology limitations still prevent the ‘ultimate’ SDR being produced
  - frequency limitations are the greatest
  - restricted to a band of neighbouring frequencies



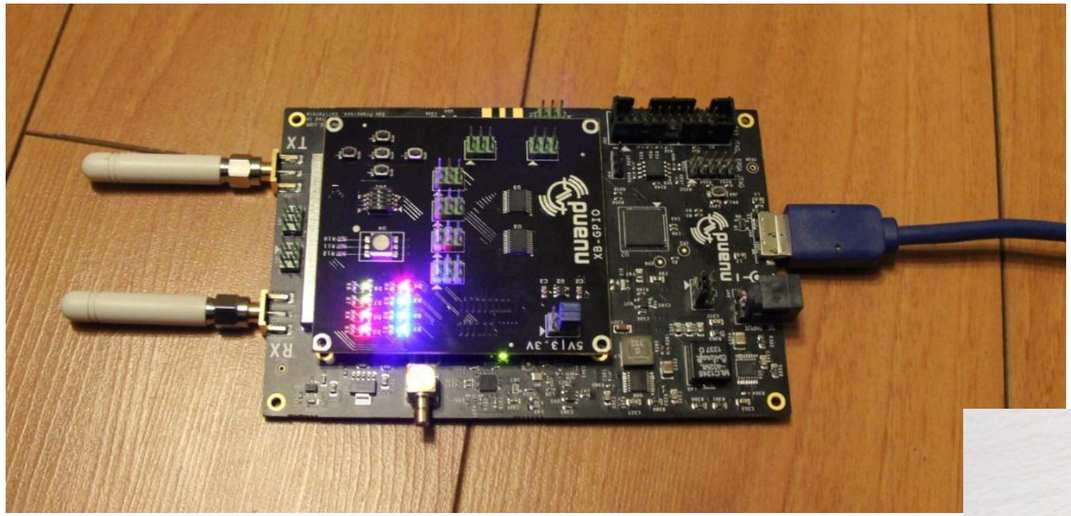
# Disadvantages of SDR

- Problems with licensing (normally frequency / technology specific)
- Gaining type approval
- Opportunities for hackers to re-programme devices
  - Move all subscribers from one network to another
  - Cause purposeful interference
- Very open to malicious use if not carefully controlled

# Examples of ‘off-the-shelf’ SRD equipment

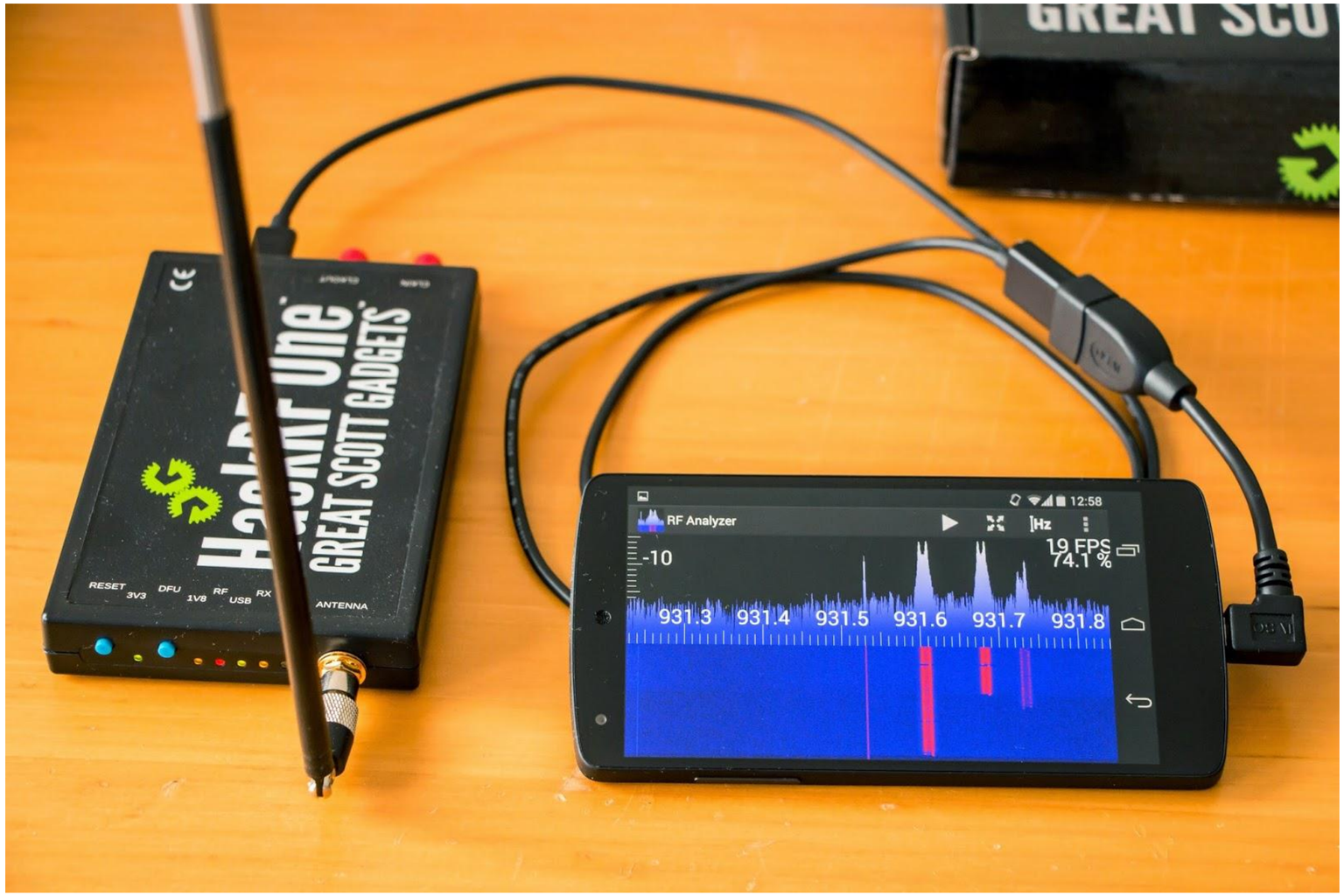
| Name | Frequency Range | Resolution (Bits) | Bandwidth (MHz) | Transmit | Price (US$) |
|---|---|---|---|---|---|
| TV Dongle | 24 - 1750 MHz | 8 | 3 | No | 10 |
| FunCube+ | 0.1 - 2000 MHz | 16 | 0.2 | No | 200 |
| AirSpy | 25 - 1750 MHz | 12 | 10 | No | 200 |
| SDR Play | 0.1 - 2000 MHz | 12 | 8 | No | 150 |
| HackRF | 0.1 - 6000 MHz | 8 | 20 | Yes | 300 |
| MyriadRF | 0.3 - 3800 MHz | 12 | 28 | Yes | 300 |
| BladeRF | 0.3 - 3800 MHz | 12 | 28 | Yes | 500 |
| USRP | 0.07 - 6000 MHz | 12 | 56 | Yes | 675 |
| SignalHound | 0.01 - 6000 MHz | 14 | 27 | Yes | 3000 |

# SDR Examples




Blade RF


# SDR used for spectrum analysis



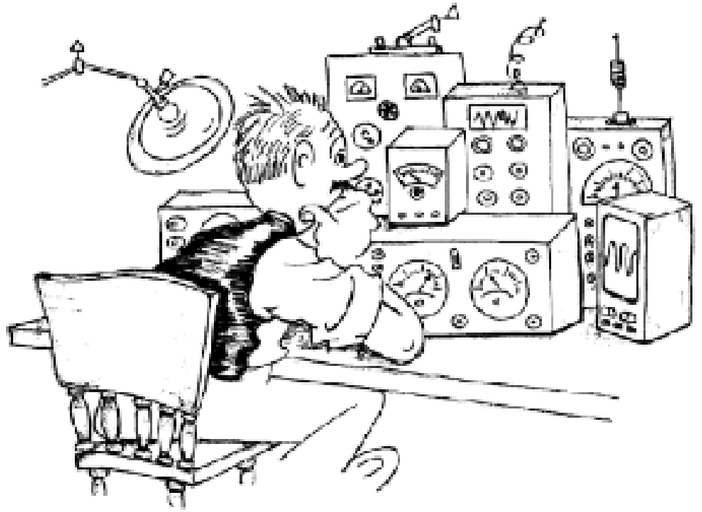
# Cognitive Radio

- Two devices listen to the radio spectrum and identify ‘unused’ frequencies
- Share each other’s list of unused frequencies
- Select optimum frequency and bandwidth for the required connection
- Maintain listening watch on frequencies to avoid causing interference

**Cognitive** /kógnitiv/ *adj.* Awareness with perception, reasoning and judgement, intuition, and memory

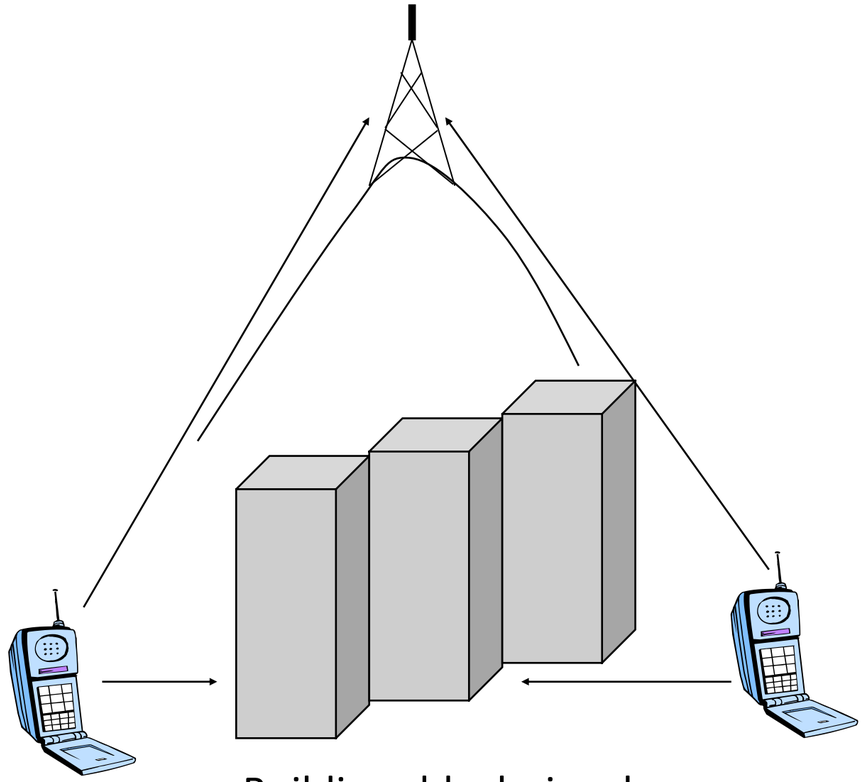
# Ham Radio = Cognitive Radio?

- Listen for unused frequency
- Transmit short message, “Is anyone using this frequency?”
- If a reply is received, go and find a different frequency
- If no reply is received, use the identified frequency
- In addition, similar uses are corralled together so that they can better find each other
  - And so that users know what to listen out forc



# The Hidden Node Problem

Receiver cannot hear any use of a particular frequency, but would cause interference if it transmitted

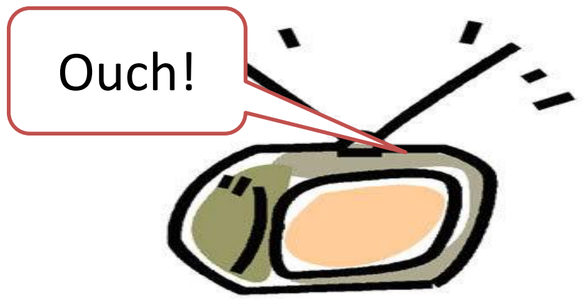


The frequency is in use for communication to a base station on a high point

Buildings block signal and stop stations hearing each other

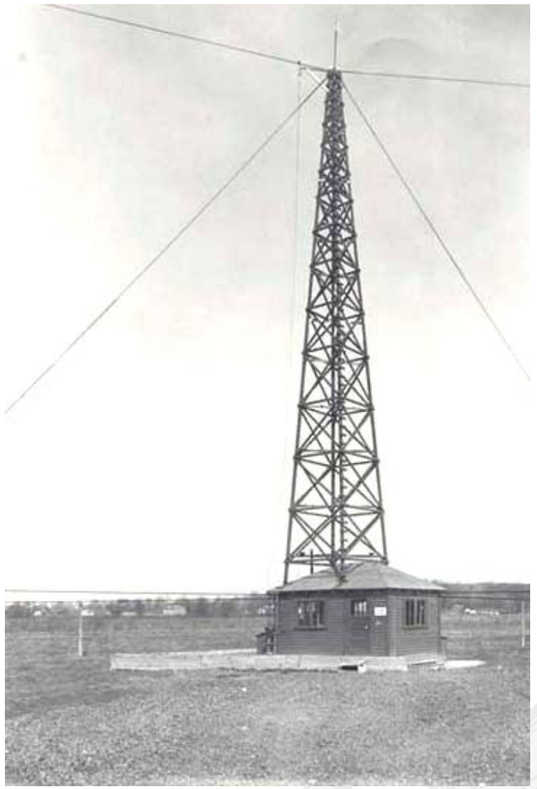
# The ‘Ham Radio’ model also fails

- If the frequency is in use, even a short ‘is this frequency clear’ transmission could cause interference
- Many devices that could suffer interference have no way of replying (e.g. a television receiver)
- The transmitter would have to identify itself so that any device suffering interference could tell it to switch off
  - This may not be possible if the frequency is already heavily interfered
  - What if it is the combination of several transmitters that tips the balance?



# Cognitive beacon principle

- Receiver stations to scan the area to see which frequencies are (and are not) in use and send this information to local users
- Relay information about ‘unused’ frequencies
- Use of high sites so a wider field of view to detect frequency use
- Could also be used to register local cognitive devices



# Cognitive beacon difficulties

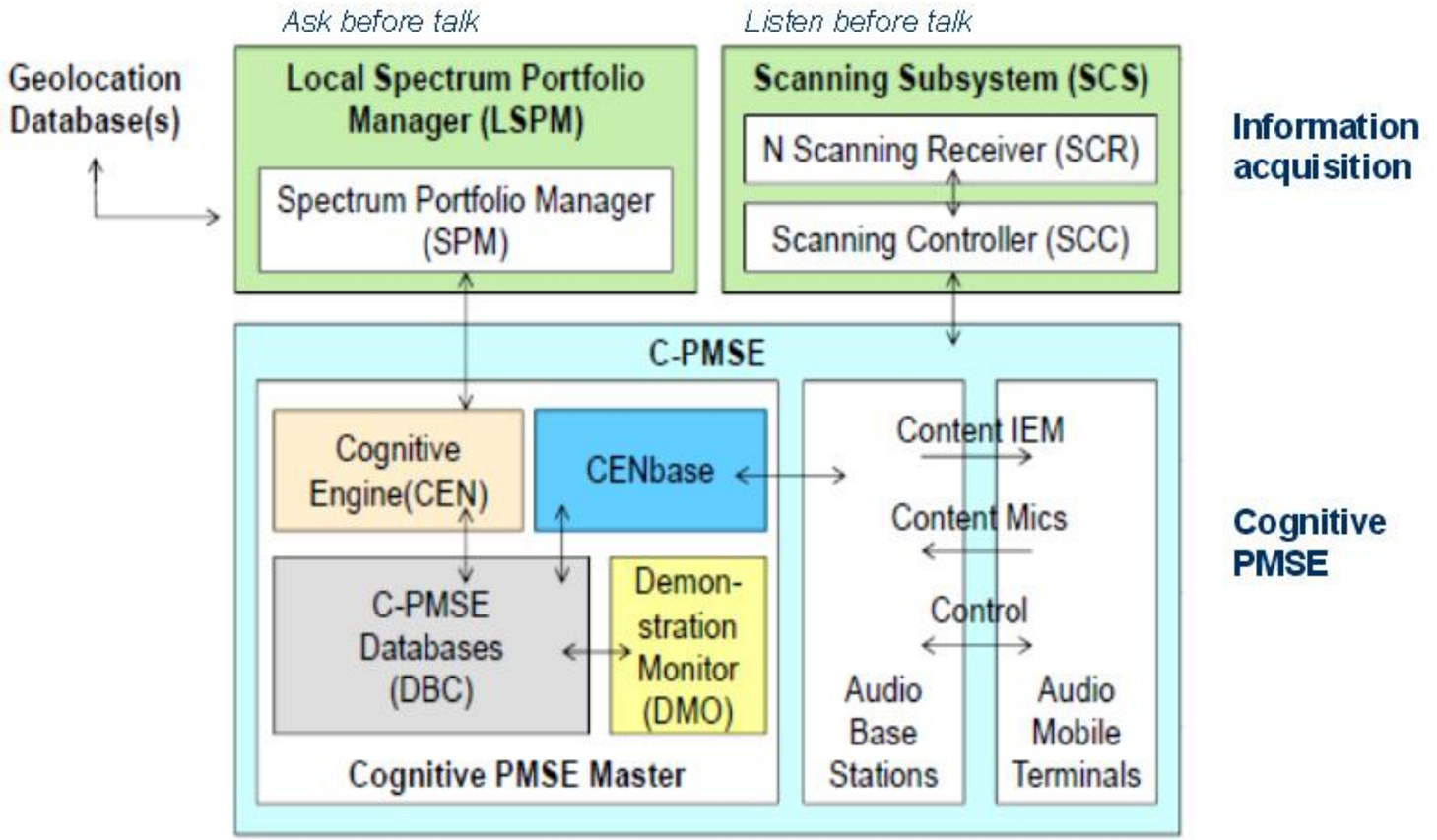
- No ‘cast iron’ guarantee that the receiver will detect all local radio usage
  - Hidden node problem may not be fixed
- Who should operate the beacon?
  - The spectrum owner?
  - The regulator?
- How is the beacon paid for?
  - A subscription by the end user?
- How is the information from the beacon communicated to the cognitive devices?

# Cognitive receiver network

- Multiple distributed receivers scattered around the area of interest (or the whole country)
  - If cheap enough (e.g. SDR)
- Central management node co-ordinates and analyses data from the receiver network
  - Calculates available white-space for each location
- Results from central node would still need to be distributed to cognitive devices
- More expensive than the beacon concept?

# Cognitive PMSE (C-PMSE)

- Standardised at ETSI (TR 102 800)
- Uses a network of receivers to detect frequency use
- Adjusts power and frequency of microphones to avoid interference



# C-PMSE progress

- Concept demonstrated at Berlin Messe (April 2013)
- 17 receivers monitored UHF spectrum across 3 exhibition halls
  - Frequency band analysed every 0.7 seconds
- A central processor assessed the level of interference and signal
- A single microphone roamed the venue changing power and frequency as necessary

C-PMSE

# No further developments…

- Insufficient guarantee of quality?
- Potential to interfere with non cognitive PMSE
  - If other PMSE use not detected
- Too costly?
- Too complex?
- Existing solutions (e.g. co-ordinated usage) are just as effective

# C-SomethingElse?

- Cognitive approaches for military systems
  - Arrive in theatre
  - Monitor spectrum activity
  - Select ‘unused’ frequency
    - **No need for prior co-ordination**
  - Communicate
  - Continue to monitor frequencies
  - If interference detected (deliberate or accidental) change to alternative frequencies
- Such concepts, using Artificial Intelligence to manage frequency usage, are beginning to be considered
- Could free lots of public sector spectrum for commercial use

# Cognitive Radio Situation

- Significant interest in using cognitive radio applications in the television whitespace
  - The gaps between television transmissions left by nearby transmitters
  - But other bands are under consideration (public sector)
- A number of trial radios were tested by the FCC to examine their sensitivity to such transmissions
  - Some were able to meet the restrictions required
- Big name companies see opportunities for cognitive radio
  - Google, Microsoft, Motorola and more believe it could be the next ‘free public Internet’
- Various trials now underway
  - Both civil and military!

# Cognitive Radio Regulation

- Can not assign a specific frequency
  - relies on being able to select from a wide range
  - the wider the range, the better
- Must specify
  - operating frequency range
  - signal detection threshold
  - transmitter power levels?
  - transmitter bandwidth?
  - sense and avoid mechanisms?

# Conclusions

- Software Defined Radios remove the restrictions on frequency or modulation scheme that traditional radios suffered from
  - SDR beginning to be incorporated into mobile infrastructure and handsets
- Cognitive techniques enable ‘unused’ spectrum to be used in an intelligent way
  - Difficulties with ensuring that devices operate in a way that is guaranteed not to cause interference
  - Problems with setting parameters for regulation
  - Too expensive or costly in light of possible alternative methods to access the same spectrum

# TV Whitespaces
# DSA in TV Bands

State Radio Monitoring Center of China
Radio Monitoring Department

# What is a white space?

# What are the problems with Whitespace?

Problem 1: There are already users on the frequencies

(TV stations! Wireless Microphones and PMSE / LPAUX)

Problem 2: The available channels vary by location (and time sometimes)

(Some places have none some have plenty, some vary due to use of wireless microphones)

Problem 3: The possibility of interference is high

(TV's have often receivers, but this is improving, wireless microphones are part of high profile broadcasts and similar, other services are adjacent)

Problem 4: The potential number of devices is huge….

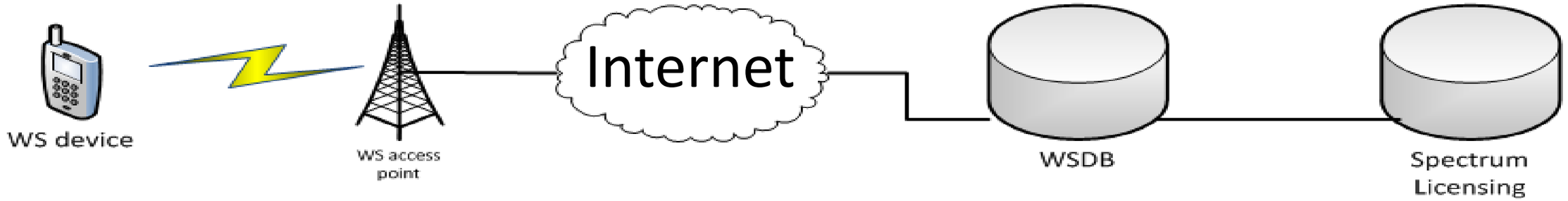
(think WiFi base stations IF this technology is popular)

Problem 5: Channels are not reserved with reliability

(There is no right to a channel, and no right to keep it)

# So how do you make use of the white space then?

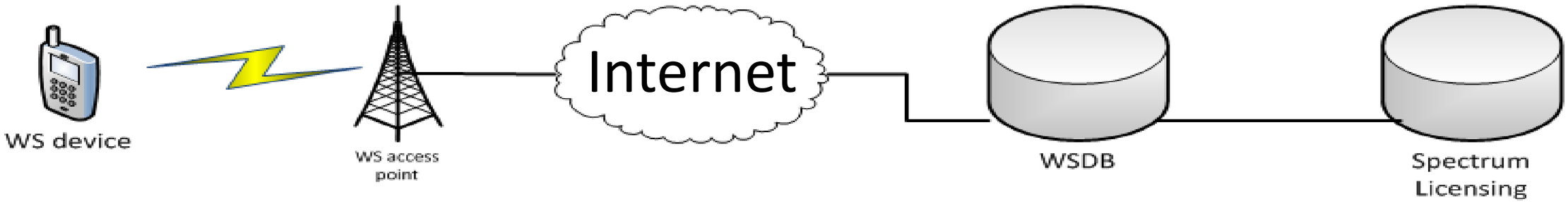
## Use a Database to manage spectrum allocation




| User access | Infrastructure | Interconnectivity | Whitespace database | Spectrum Licensing data |
|---|---|---|---|---|
| Consumer access device | Consumer access point Network provider infrastructure | Network transport mechanism probably internet based | Whitespaces spectrum assignment, registration, authorisation | Incumbent users, temporary protected users and regulatory controls |
| Large number of devices | Large number of access nodes | Multiple paths | One database OR multiple administrators | One source of prime data |

Sensing is an additional option and not a solution to managing whitespaces

# What does the database do?




Request available WS channels

Periodic updates and control messages

Authorise and provide available channel list

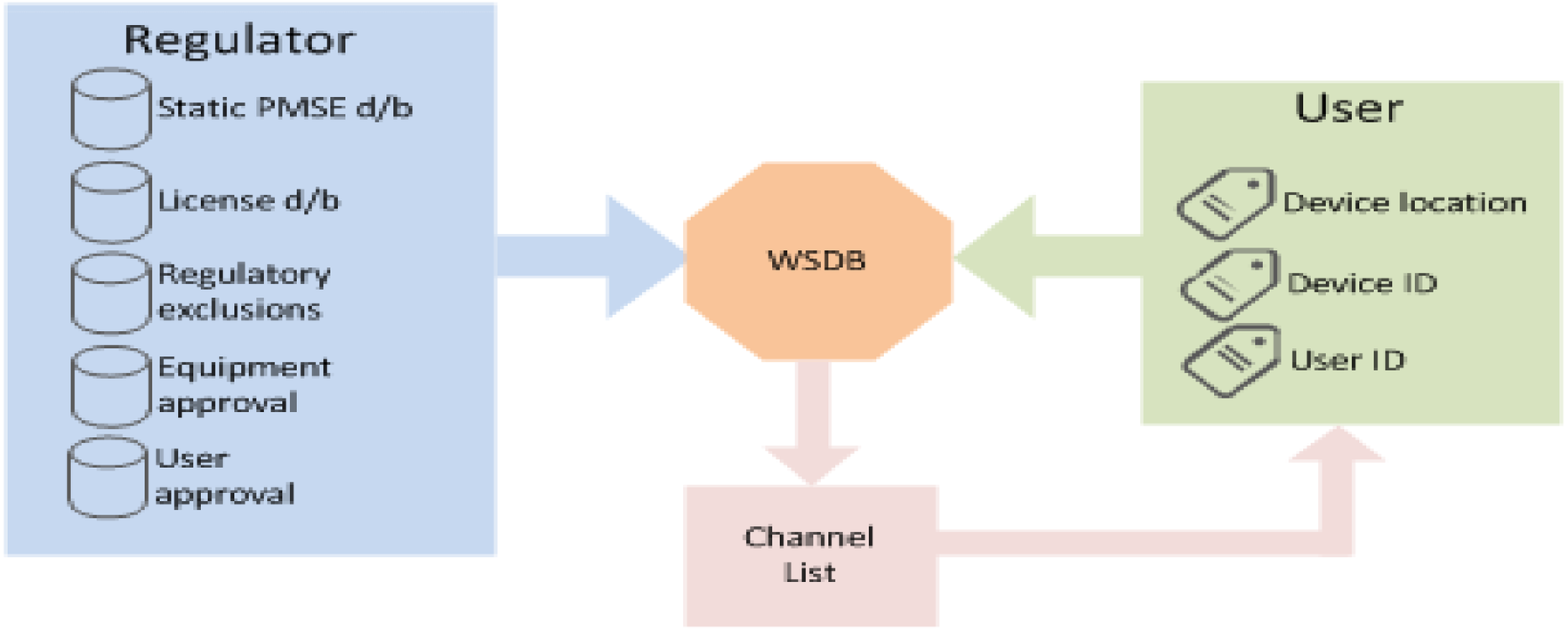
Beacon availability

Request access

Authorise and provide access

Some countries require notification of which channel selected

# Where does the database get its information?




- The database is a rules based algorithm
- The regulator maintains full control of the licensing  inputs to the database to keep control

# Motivation: Still there is something to gain!

**Seattle**


High dense urban
1 channel

**Anchorage, Alaska**

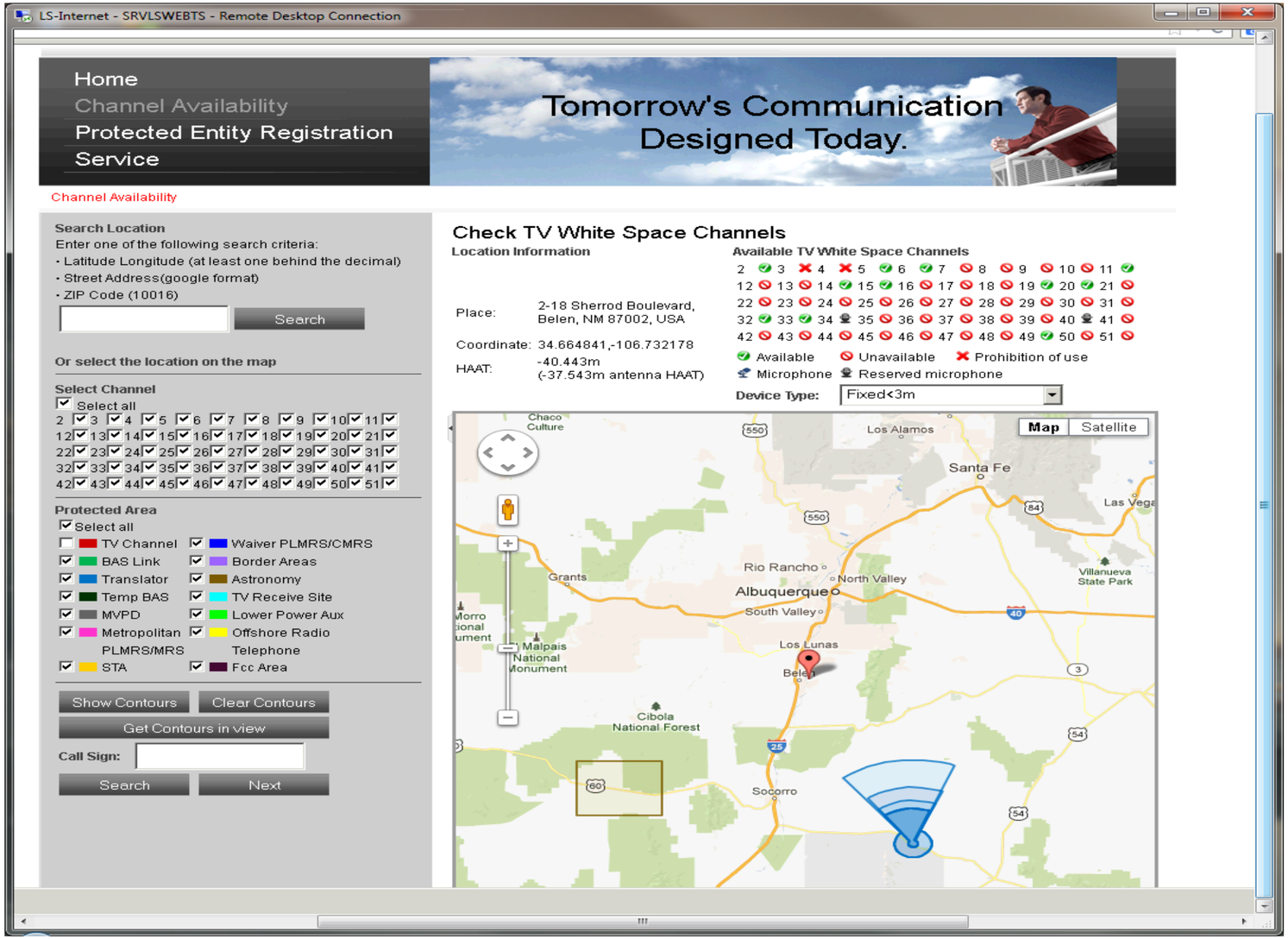

Dense urban
10 channels

**Toccoa, Georgia**


Rural
16 channels

**But: There are many places, where more bandwidth would be welcomed!**

# Whitespace Databases: An example




www.whitespaceforus.com

# What are the benefits of this?

## Consumer*

- Lower frequency allocations (c/f WiFi) means greater coverage per node
- More wireless internet opportunity
- Rural access at higher speed
- Remote meter reading
- Lower cost
- Higher speed and more coverage in the home
- Enables the “internet of everything”
- Innovation springboard

## Regulator

- Makes maximum use of sweet spot spectrum
- “cost free” spectrum release
- Increases consumer choice
- No real additional administrative burden
- Politically fits with the socio-economic agenda of most governments
- Technology development enabler with low cost of entry
- Control and Flexibility

** Consumer in this instance means Manufacturer, Network operator, Developer, Operator through to user*.

# What's in the future of Whitespaces?

Whitespaces is not a technology its just a spectrum allocation policy in the TV bands (which is why dynamic spectrum access is a better phrase)

- Dynamic spectrum access mechanisms for other bands?
- Possible reduction in revenue per Hz for the regulator but increase in revenue per user for network operators.
- Significant technology development opportunities, stimulating industry
- Shift of spectrum manager from Regulator to commercial organisations

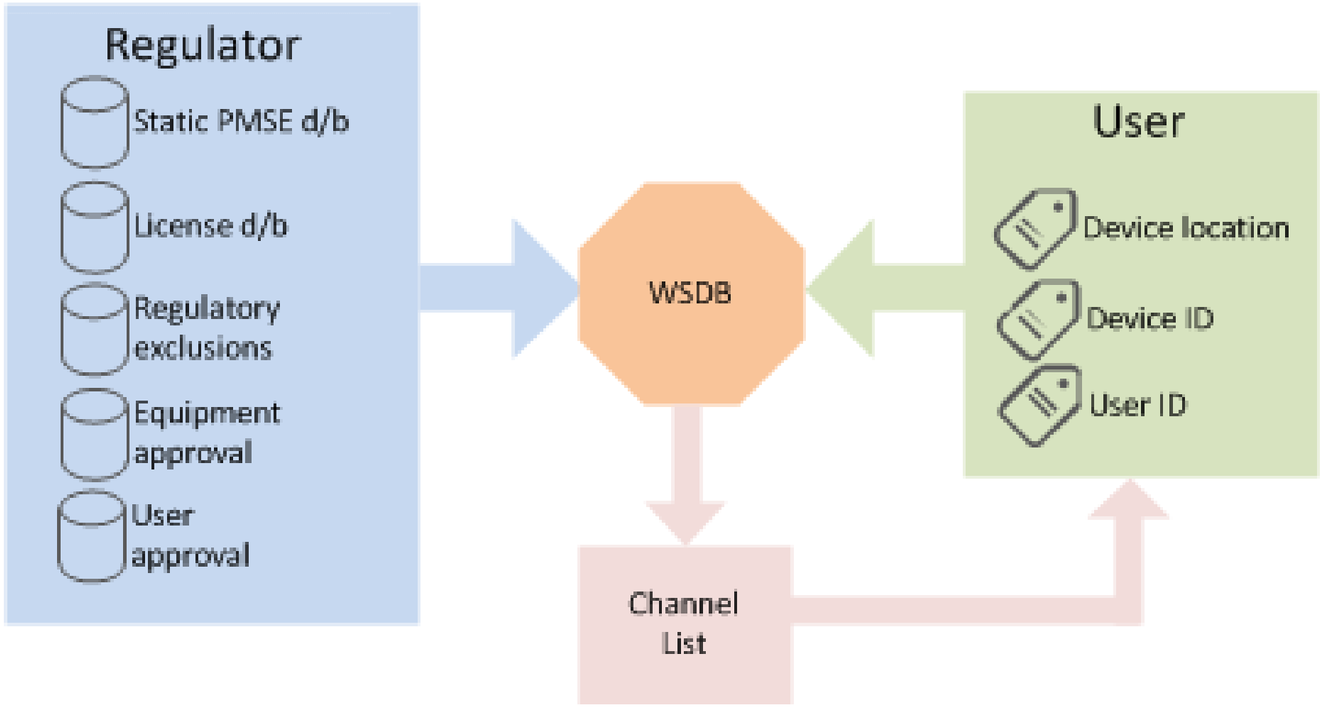
# The risks of dynamic spectrum access

- The database operator becomes a defector spectrum manager
  - How to you trust a spectrum manager with purely commercial objectives?
  - If you have multiple db operators how do you arbitrate between access disputes?
  - How do you protect the consumer from a defaulting db operator?
- The system is only as good as the originating data
  - How does the regulator assure the quality of originating data?
  - How does the regulator assure, permanently, the db is serving the correct allocations?
  - How dynamic can the regulator update and manage the originating data?
- What about data privacy, national security, disaster recovery?

# Implementing a whitespace database

State Radio Monitoring Center of China
Radio Monitoring Department

# Where does the database get its information?




- The database is a rules based algorithm
- The regulator maintains full control of the licensing inputs to the database to keep control
- The regulator needs accurate and up to date license information at all times

# Issues with database provision

- Who provides and manages the database?
  - The regulator?  A third-party?
  - Could there be multiple databases from different spectrum owners?
- How do devices connect with the database?
- How long should ‘assignments’ last?
- How often should devices check in?
- Should the database push control messages?
  - This determines how quickly spectrum owners could take it back if they need it…

# Database approach

- The FCC, Ofcom, Industry Canada, IDA Singapore, FICORA and others have either fully operational  policies or trials for database approaches to TVWS.
- It works well!
- LS telcom is an FCC authorised TVWS database supplier in the USA
- https://www.whitespacefor us.com
- The FCC took a multiple commercial provider approach.

# The two (main) TVWS database approaches

## FCC

- Regulator supplies;
  - License data for incumbents
  - Regulatory rules
- Regulator Demands;
  - Certification before operation
  - Access to allocations for validation
  - Provision of LP-Aux protection portal

## Ofcom

- Regulator supplies;
  - “maps” of available TVWS availability based on pixels
  - Data for protection of PMSE
  - Regulatory rules
- Regulator Demands
  - Commercial contract before operation
  - Access to database for enforcement

# Database approaches cont……

## FCC

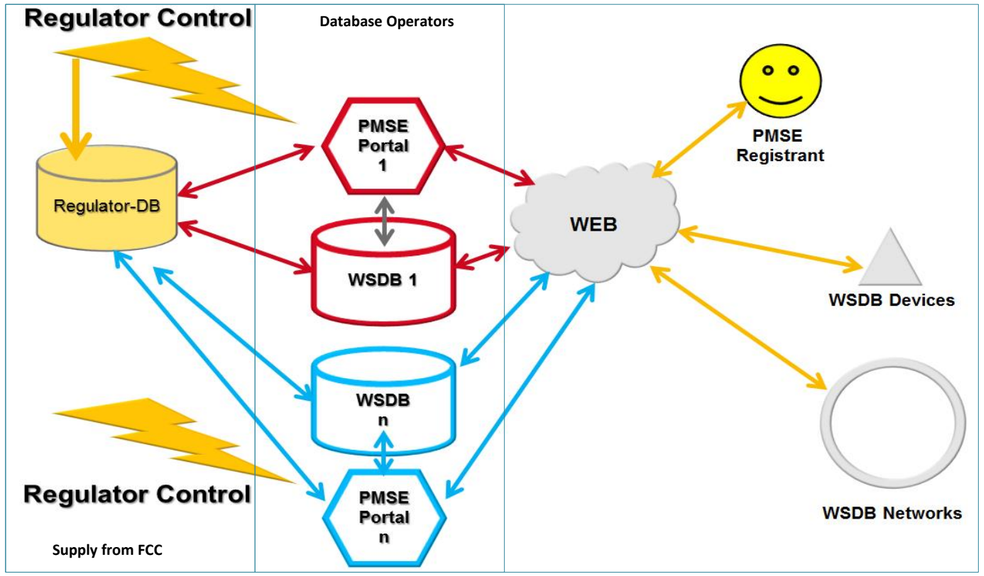
- For the operator;
  - Multiple database operators
  - More could join or leave at anytime
  - Calculates available TVWS on the fly
  - Must register protected LP-Aux
  - Must share data between databases

## Ofcom

- For the operator;
  - Multiple database operators
  - Can only join at specific Ofcom approved times
  - Calculation is a logic engine of data provided by Ofcom
  - Must provide a specific enforcement portal for Ofcom

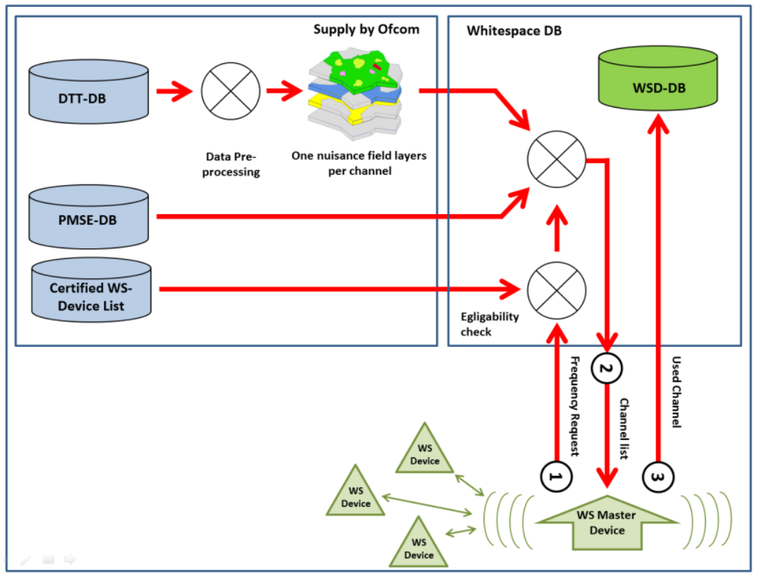
# DSA (Whitespace) Mechanics: FCC vs. Ofcom

## FCC: is easier to implement




- Multiple database operators
- More could join or leave at anytime
- Calculates available TVWS on the fly
- Must register protected LP-Aux
- Must share data between databases

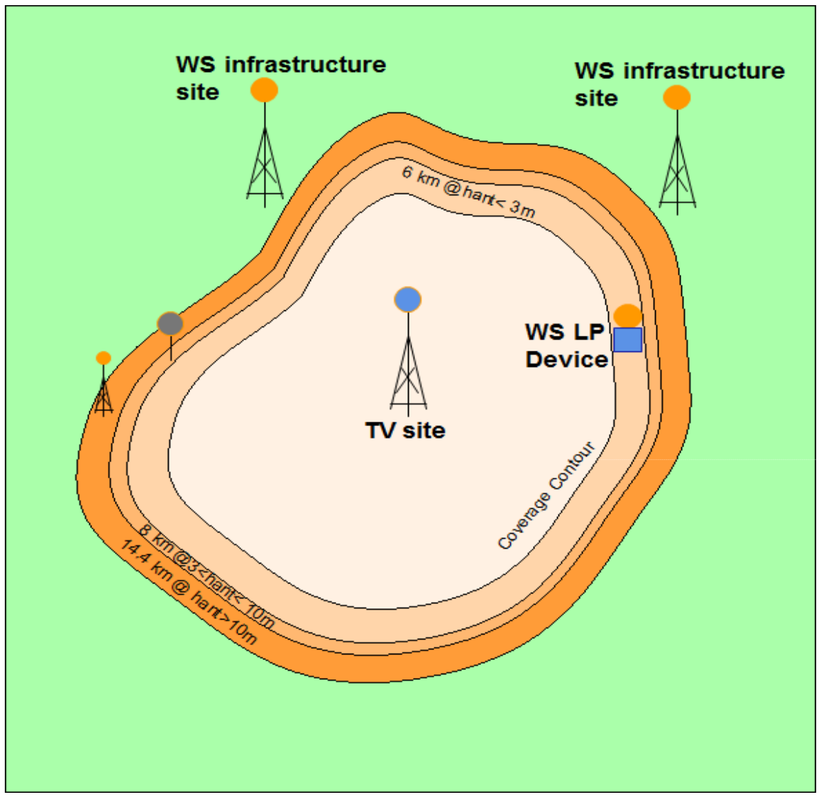
## OFCOM: more controlled and risk averse



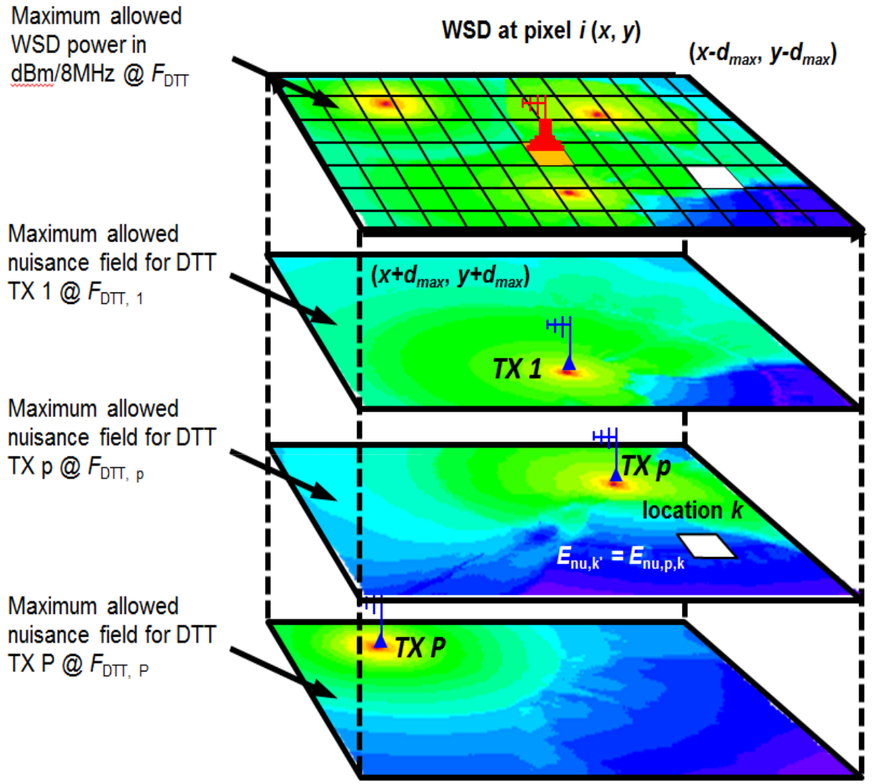

- Multiple database operators
- Can only join at specific approved times
- Calculation is a logic engine of data
- Must provide a specific enforcement portal

# DSA (Whitespace) Physics:FCC vs. Ofcom

## FCC: a contour based approach




## OFCOM: pixel based



# Implementing DSA

- There are choices and decision to be made in moving forwards into DSA as a spectrum allocation policy;
  - Is there enough commercial interest in the band?
  - Is industry interested and wanting to develop devices in the band?
  - How are you going to manage confidentiality and National Security concerns?
  - Who is going to provide the database, operate and maintain it?
  - What policies are going to be developed to support DSA and associated interference management.

# Database design considerations

- Who operates the database
  - How do they get access to the licensing data? Is it dynamic?
    - Direct access
    - Occasional manual exchange
  - Do they need to share between databases if there's more than one?
    - Is there any PMSE / LP-Aux use at all in the band? If so who colelcts the data?
  - What are the security issues
    - Are there national standards?
  - What availability standard is specified?
  - Where is the licensing and regulatory data coming from?
    - Is it accurate?
    - Is it maintained?

# Enforcement issues

- Protection against harmful interference is the purpose of enforcement in spectrum management.
- The regulator needs to assure that only validated and certified databases are utilised.
- Access to the database is available to the regulator to query allocations and validate data
- A policy is in place to terminate service upon enforcement issues

# Sensor Based Networks and DSA

State Radio Monitoring Center of China
Radio Monitoring Department

# What's Missing?

- Some (usually Military users) don’t want or maintain actual usage.
  - Large areas can be excluded as a result
  - Large amounts of temporal opportunities can be lost

- Not all spectrum databases are accurate
  - Over protection of areas
  - Under protection of areas
  - Mis-licensed and illegal use not known

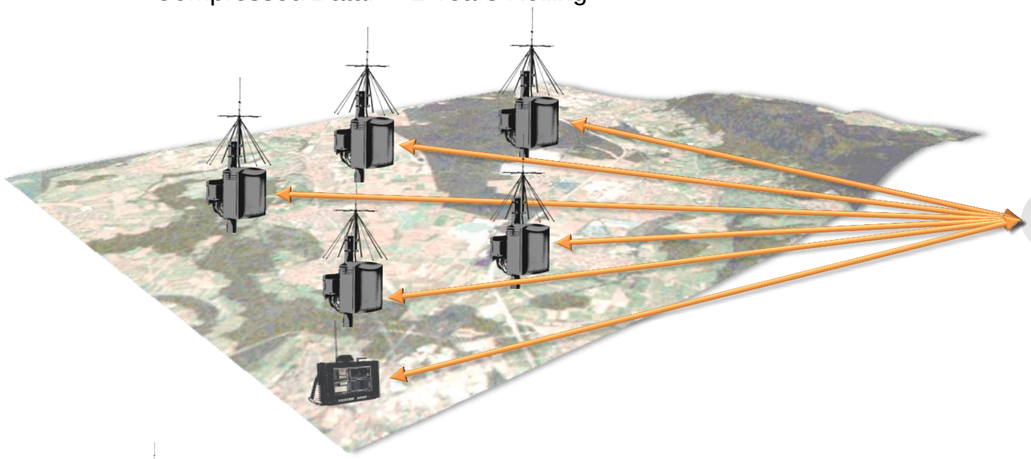
- Equipment parameters not known
  - Over protection of area
  - Potential interference (conservative allocation or opposite)

# Sensor system overview

## Remote Monitoring Network

Local Processing

- RAW Data: 30 Days Rolling
- Compressed Data: 2 Years Rolling



**F**ixed **M**onitoring **U**nit

**P**ortable **M**onitoring **U**nit

## Central Management Unit

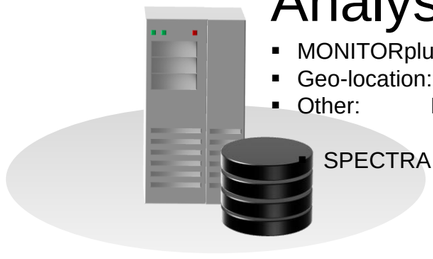
- Network Management
- Access Control
- Profile Management
- Storage of Previous Data Requests (can be Back up of RMU)

Local or
Remote Access

Optional

Optional

## Analysis Servers and Tools



- MONITORplus: Spectrum Analysis, Reporting and Display
- Geo-location: TDoA / PDoA Geo-location and GIS
- Other: EMC Analysis Server/Base Station Data Server

SPECTRA License Database and Spectrum Management

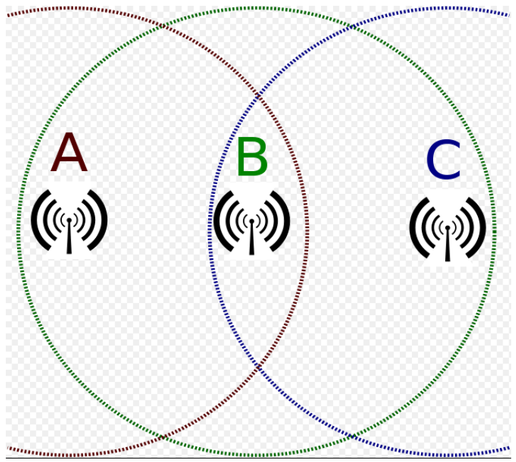
## Client

- Spectrum Analysis Display

# What can this add?

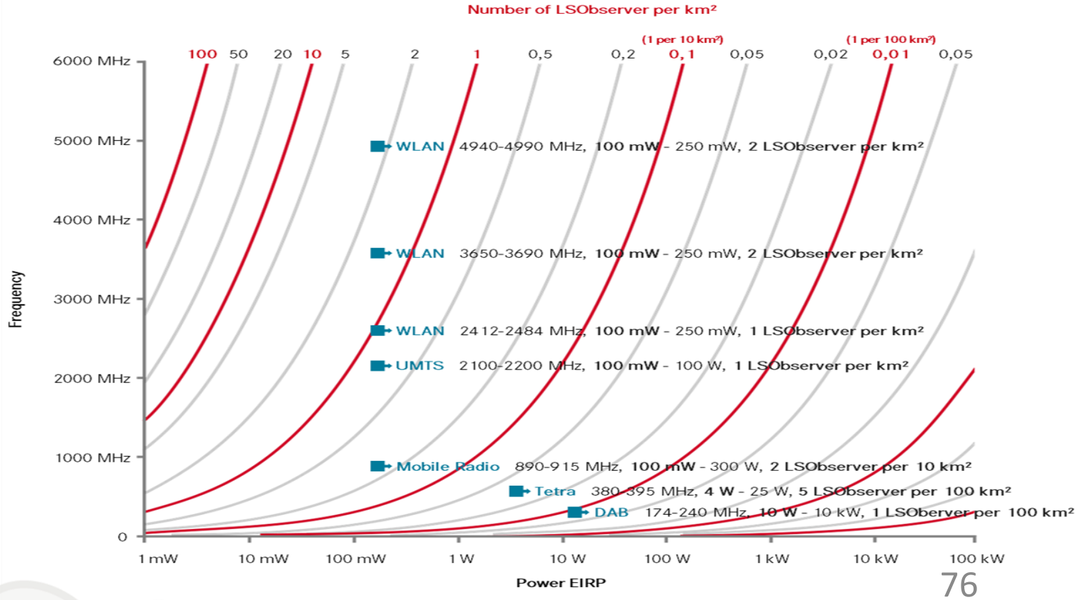
- Refinement of use detail
- Real world data to support dynamic allocations
- Much more aggressive re-use of spectrum
- Protection of incumbents
- Easier interference resolution

# What are the problems?




Hidden node problem:

A can monitor B but
does not know about C.




Quantity of nodes to cover an area with reliability of monitoring.

# Spectrum Map Introduction

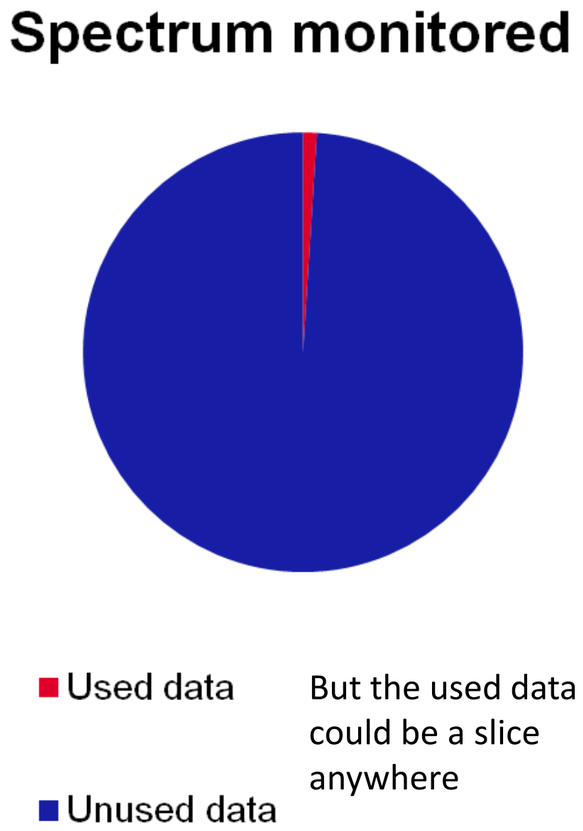
State Radio Monitoring Center of China
Radio Monitoring Department

# Modern Operational Spectrum Monitoring Requirements

- A distributed monitoring system that covers everything, everywhere.
- Flexible design, packaging, performance so devices can be matched to operational environment / requirement.
- Rich storage of spectrum data so historical picture can be built up.
- Small monitoring devices that can be placed anywhere, both antennas and receivers etc.
- Able to use equipment remotely, “other side of the world” as if we were directly connected to it.
- Purchase and running costs of monitoring system kept low.

# The problems of data overloading in the sensor approaches.

- High speed sensors produce vast data volume.
- 20MHz to 6 GHz = ± 12TB of data per 30 days
  - What use is it if we can not analyze it
  - Human analysis is pointless – too much data
  - Why record everything if you don't know what you want?
    - But I don't know what I need in the future!
  - How do I store / archive all this data?
  - How do I network this volume of data together?
- Is it worth collecting all this data?
- Is there value in the business case?

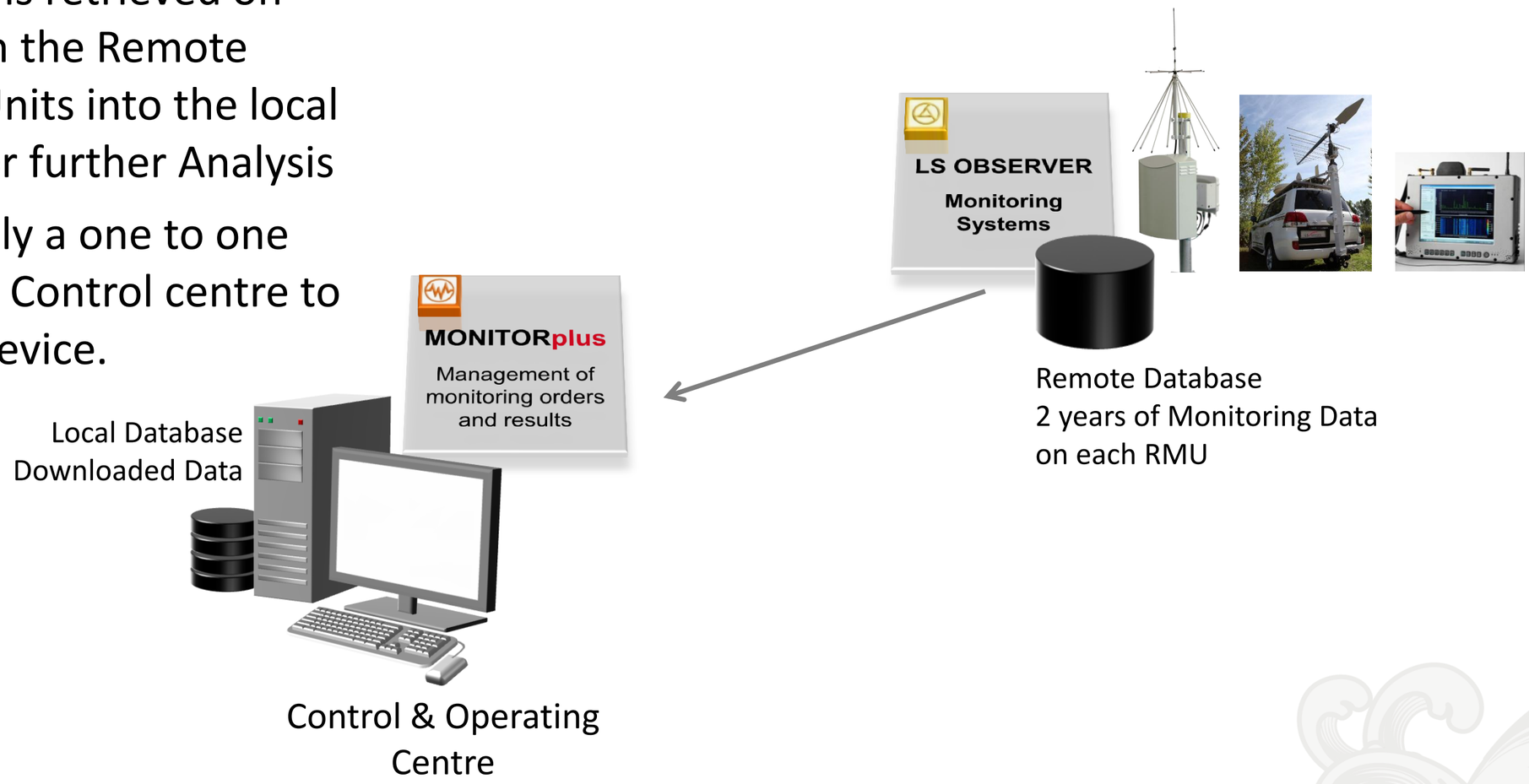


# Existing approaches to sensors / monitoring analysis and use

- Many organisations are moving from large scale monitoring sites to multiple sensors / portable or drive test approaches.
- There are mixtures of equipment types, makes and models.
- Software is often tied to an individual manufacturer and so several programs are required to make use of these mixed systems
- Although remote control is quite normal, its often a one to one relationship that is one control station accesses one device at a time to make measurements or analysis having to access devices sequentially.
- Software is installed onto individual machines meaning either limited people having access or high costs / complexity of licensing.

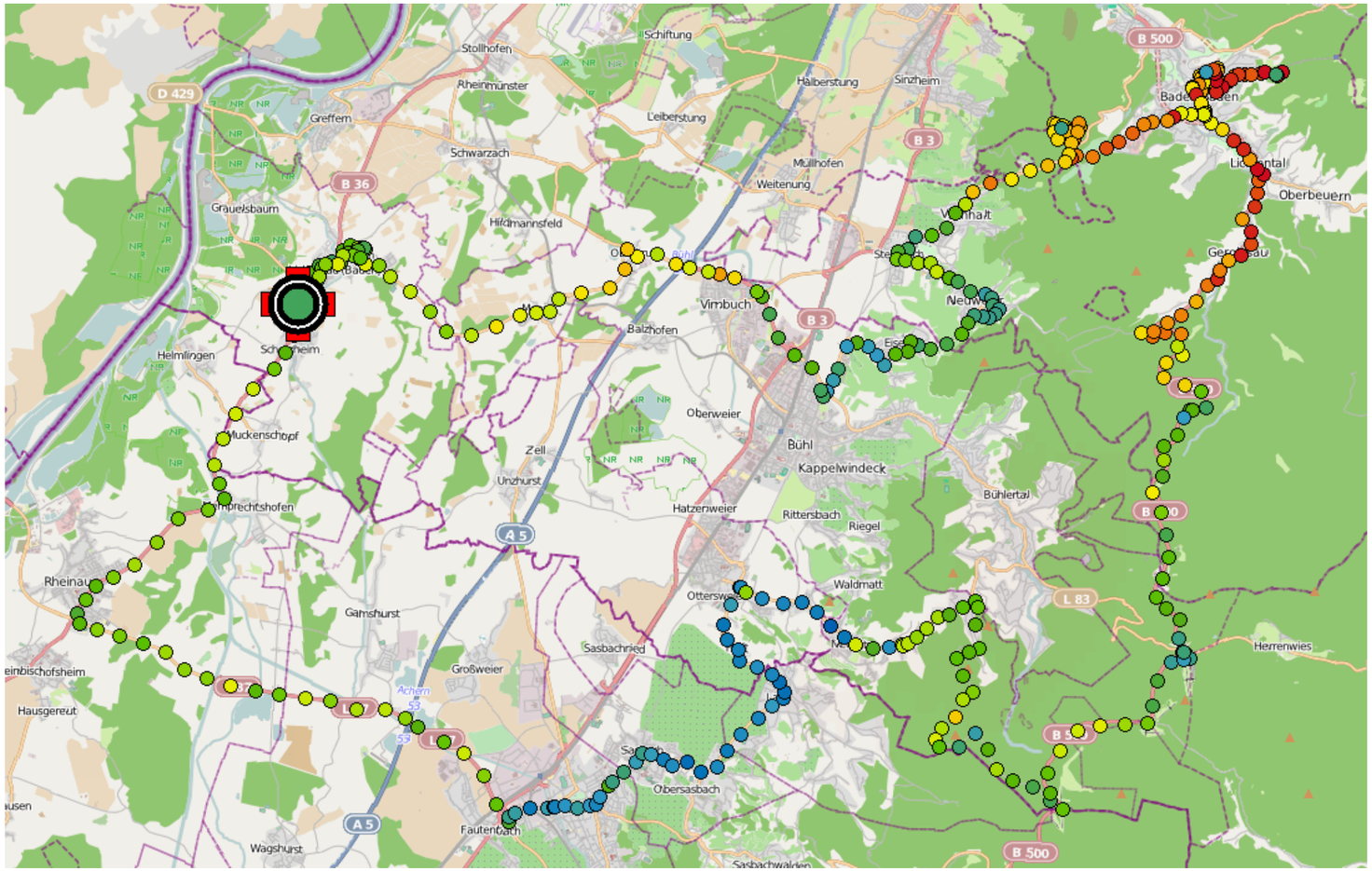
# Downloading Remote Data for Analysis

- Needed data is retrieved on-demand from the Remote Monitoring Units into the local computers for further Analysis
- This is typically a one to one relationship.. Control centre to monitoring device.



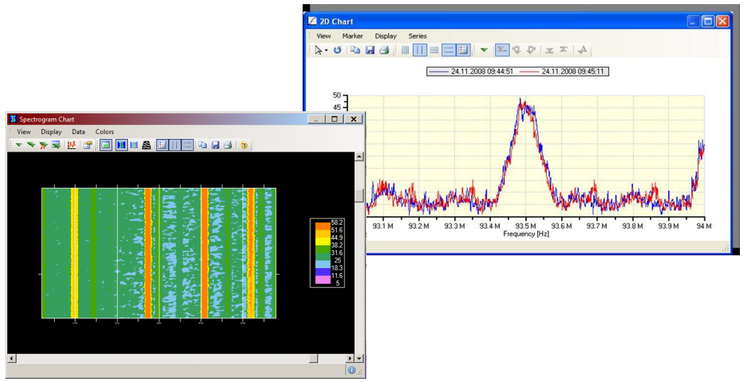
# Measurement drive

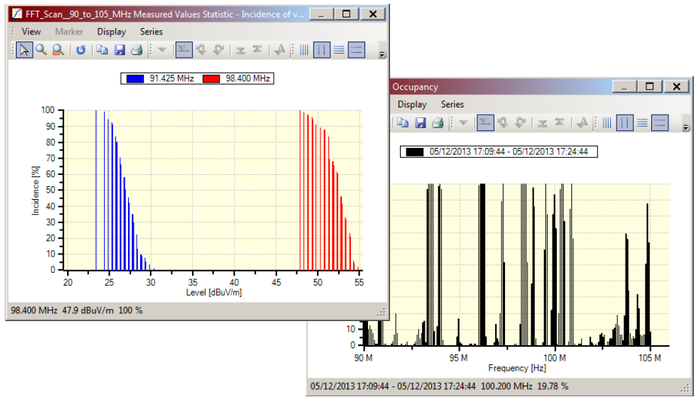
- Trace on Map for drive tests.. Typical display of measurement points of one drive test.



# What can we do with MONITORplus?

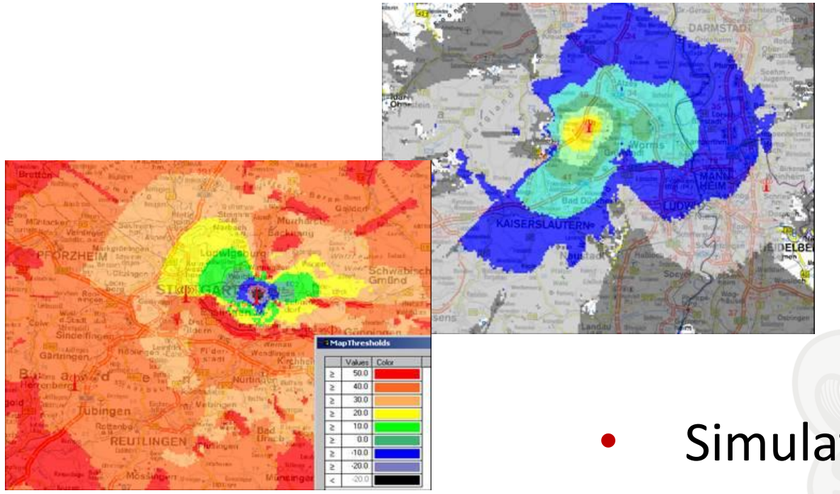
- Visualisation of Raw Data




- Analysis of Data / Technical Calculations

- Control Monitoring Systems
- Control Monitoring Devices
- Again a one to one relationship




- Simulations

# What If….

- You've a sensor network of hundreds of devices
- You don't care what the device is you just want to analyse the spectrum
- You have multiple vendors multiple types and a mis-fit network of fixed, transportable, mobile, portable sensors
- You want a big data approach of merging different sources of data
- You want to quickly model, adapt and analyse the data based on differing requirements (location / time / frequency / coverage / interference)

AND YOU WANT THIS NOW

# Spectrum Map
# Cloud Computing Platform
# for visualisation of Spectrum Data

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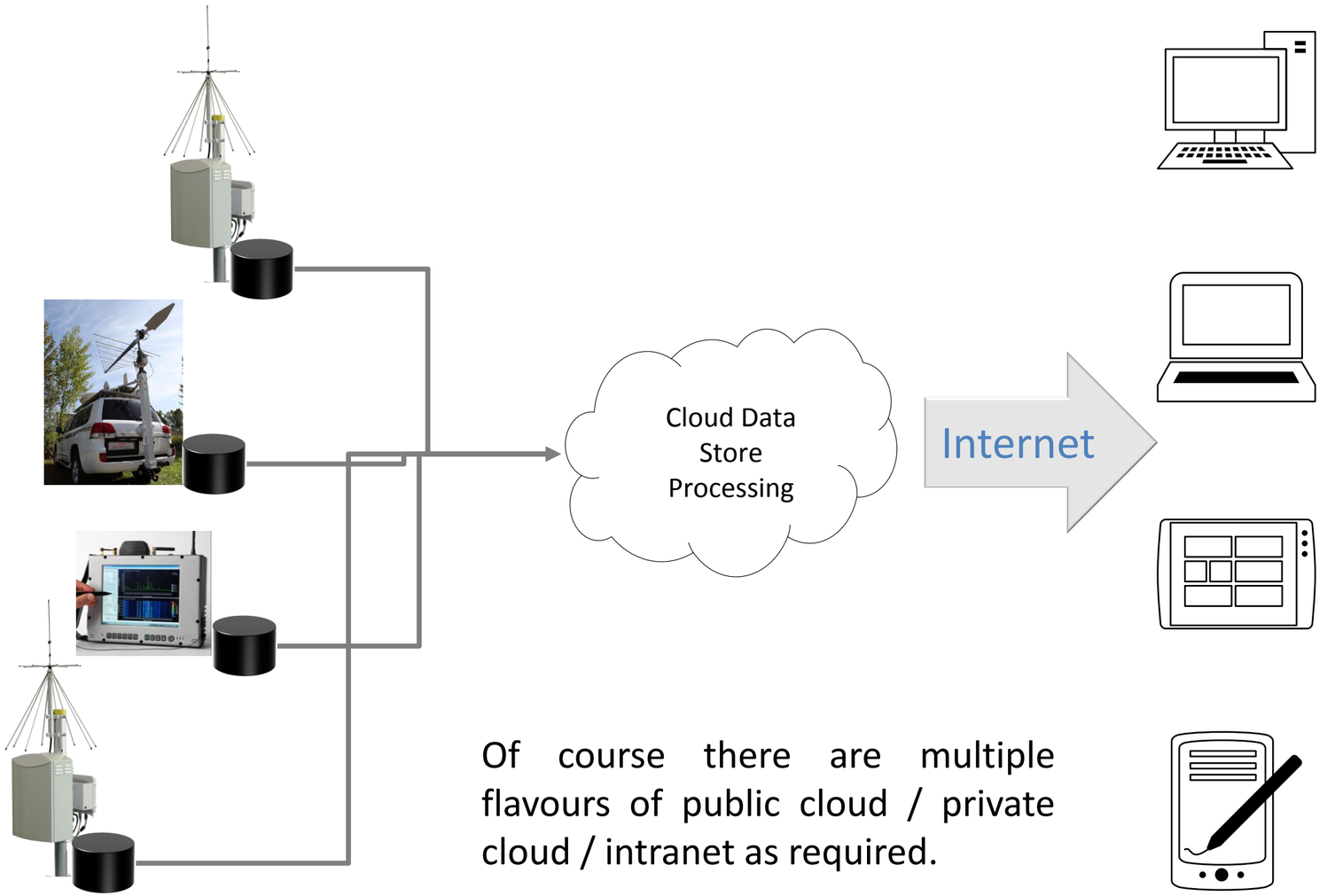
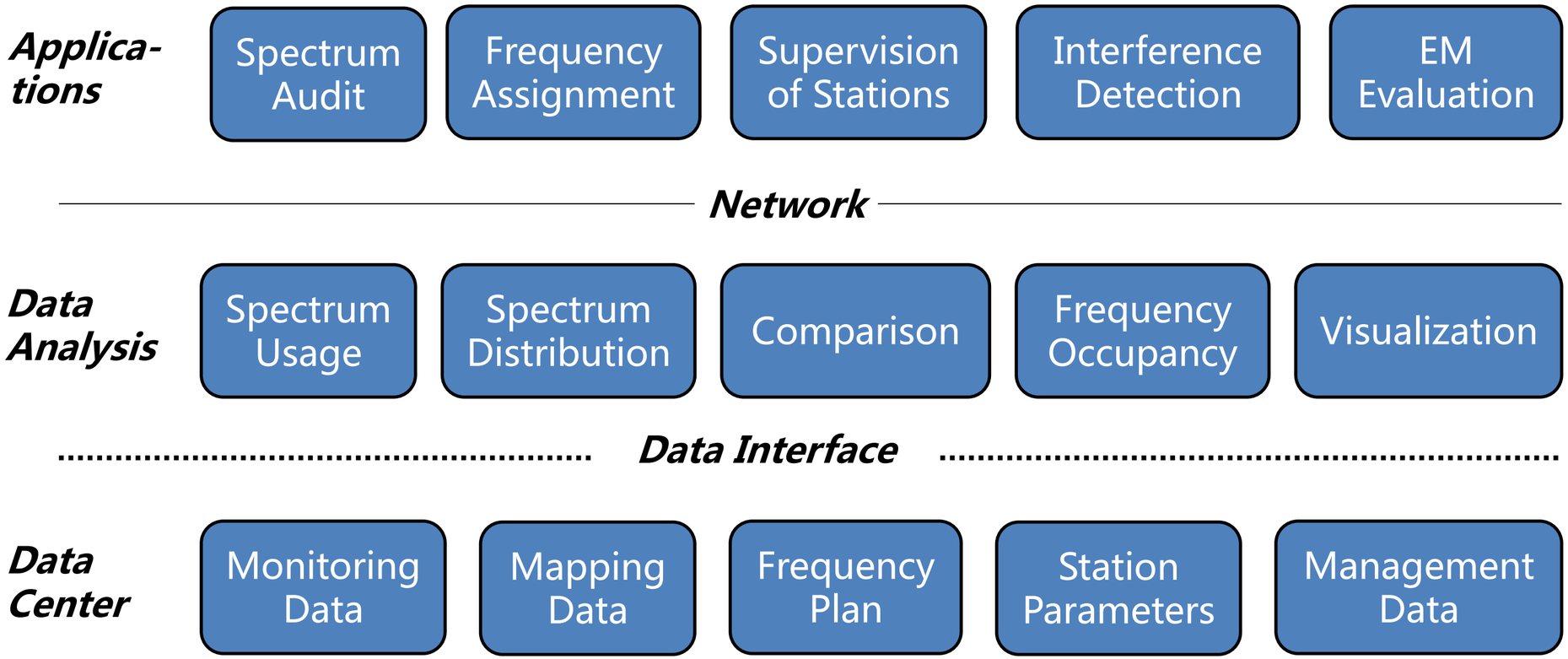
Radio Monitoring Department

# Spectrum Map Architecture




Of course there are multiple flavours of public cloud / private cloud / intranet as required.

# Spectrum Map Software Platform



# Spectrum Map Process

**RF Data Collection**

- Fixed Stations
- Grid Monitoring nodes
- Vehicle/UAV Measurement
- Other RF Sensors

**Data Mining / Fusion**

- Data Processing
- Fusion on Location
- Fusion on Time
- Fusion on Frequency

**Data Rendering / Visualization**

- 2D/3D Display
- Dynamic Display
- Comparison on Time/Frequency Domain

# Spectrum Map Server

Data Processing Algorithms：

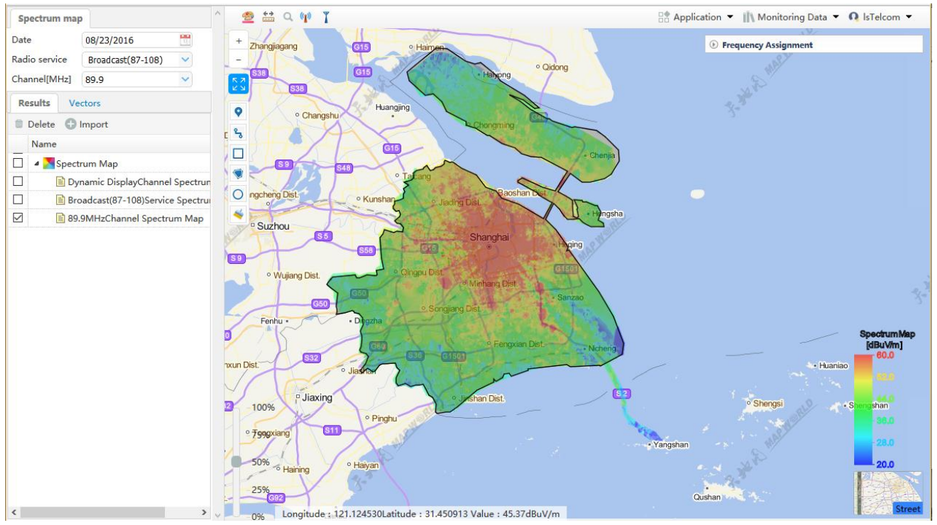
- Automated data pre-processing: data filtering, data correction, ……
- Adaptive interpolation algorithm
- Data correlation, data mining, ……
- Data fusion based on location/time/frequency
- Parallelization

# Spectrum Map Apps

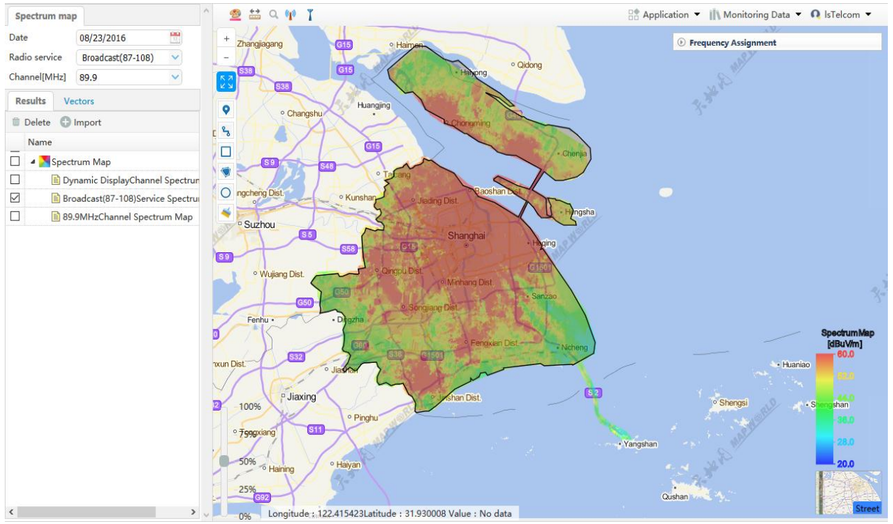
Data from multiple sources can be aggregated seamlessly.

Vehicle Measurement Data
Aggregating all drive tests

# Spectrum Map Apps




Field Strength of a Single Frequency (89.9MHz)



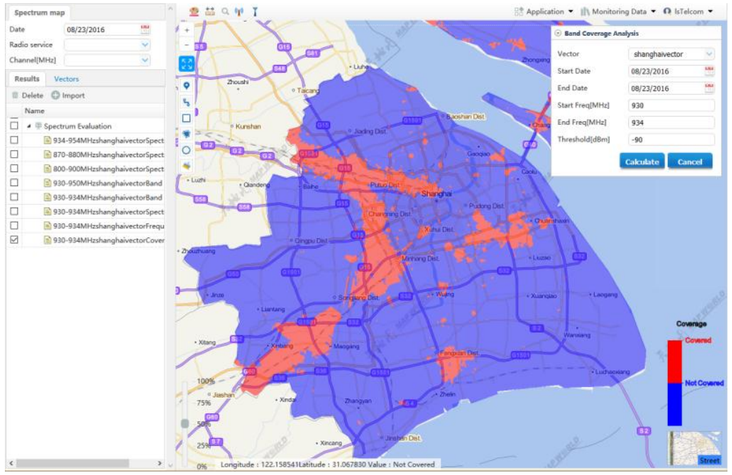

Field Strength of a Frequency Band (Broadcast)

# Spectrum Map

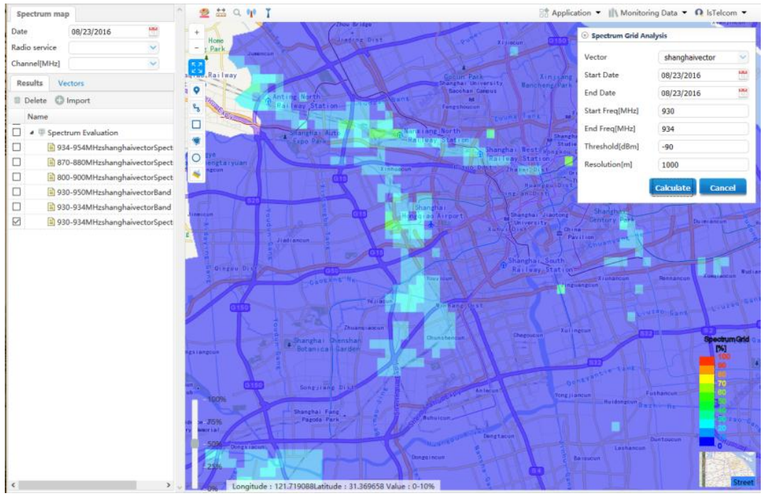
State Radio Monitoring Center of China
Radio Monitoring Department

国家无线电监测中心
The State Radio Monitoring Center

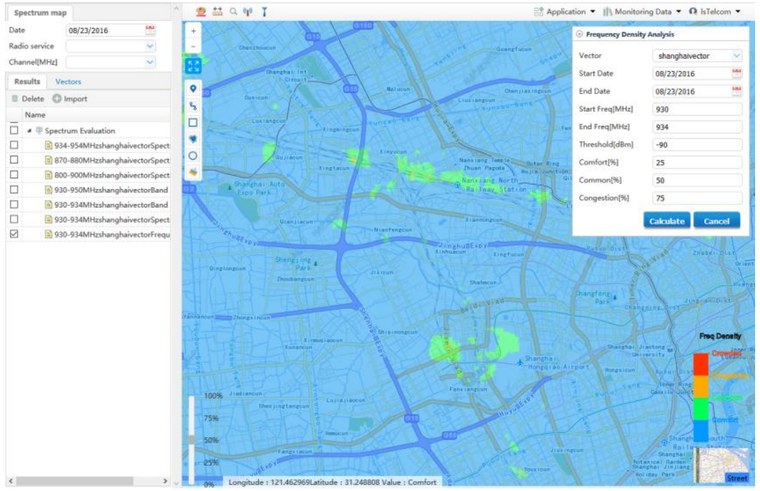
## Spectrum Map Apps



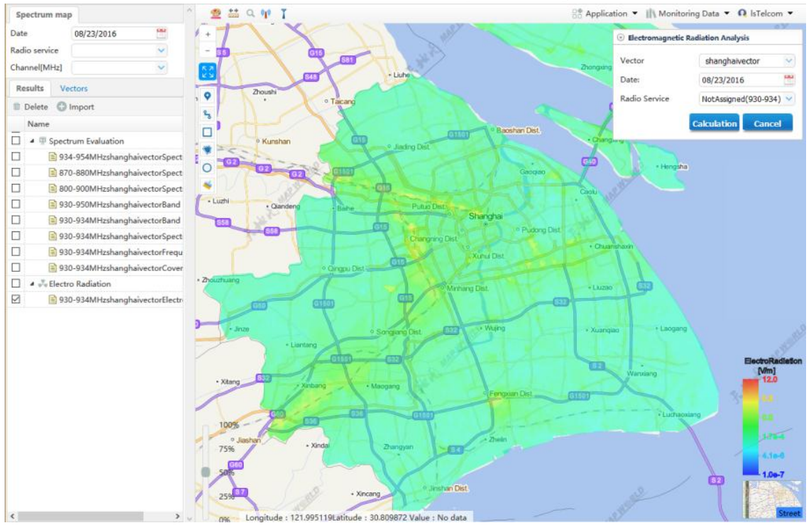

Coverage of a Frequency Band




Band occupancy

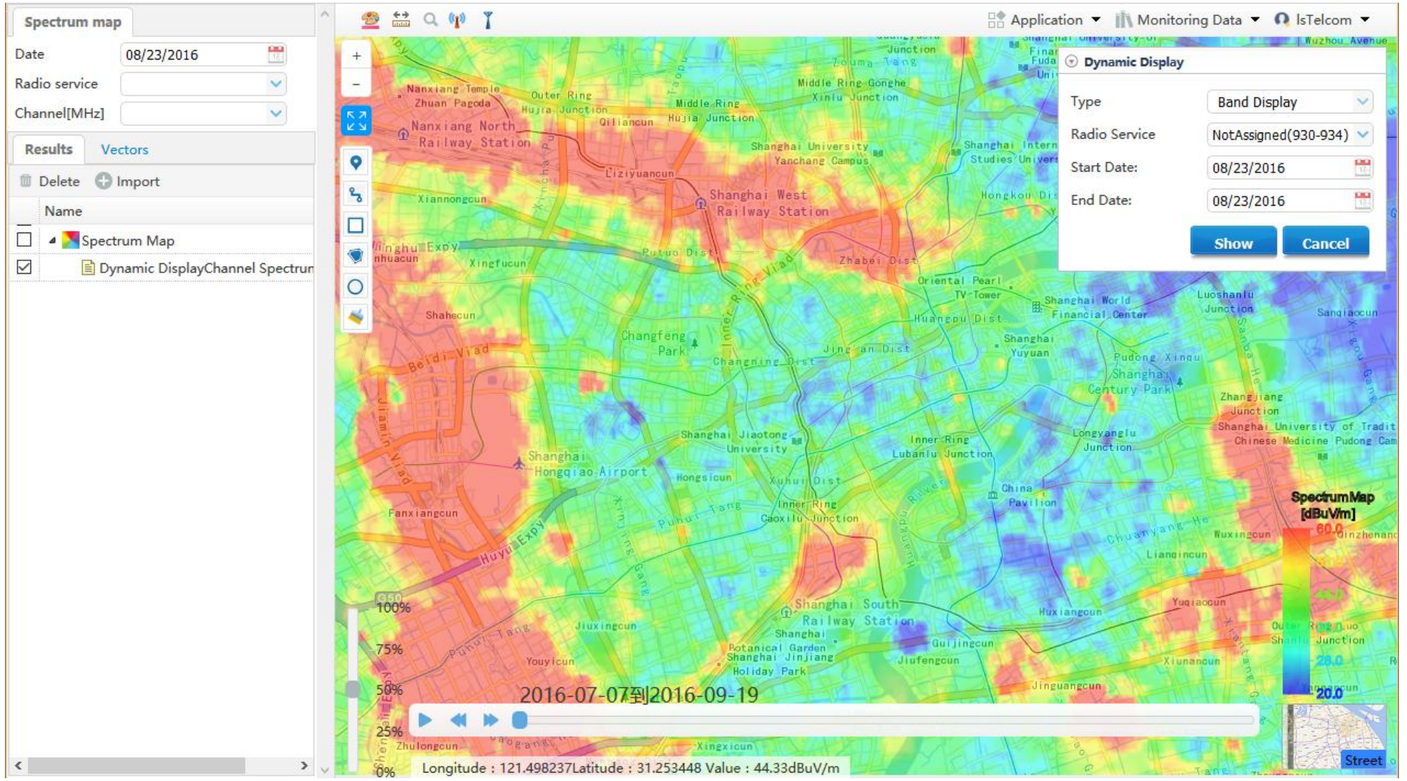



Spectrum Utilisation




Radiation hazard

# Spectrum Map Example




Dynamic Display (930MHz to 934MHz, Step: 100kHz)

Dynamic display allows you to “step” through a band at desired increments

# Spectrum Map

- The apps make **full use of all data from all sensors. This is not a propagation prediction**
- **Visualization of radio spectrum** as web GIS.
- Display the field strength distribution and spectrum usage on the **energy/time/ frequency/spatial** domains.
- It makes **full use of monitoring data** and integrates existing equipment incl. fixed stations, grid monitoring nodes and sensors.
- **Powerful data analysis capabilities** to generate spectrum maps from a huge amount of data.
- **Fast data processing capabilities** benefiting from cloud computing.
- **A variety of applications** can be implemented based on the spectrum map.
- **In use** by a customer for a major sensor / drive test network for over 6 months

# Thanks