Science, Engineering and Regulation – Support for Future Radiocommunications

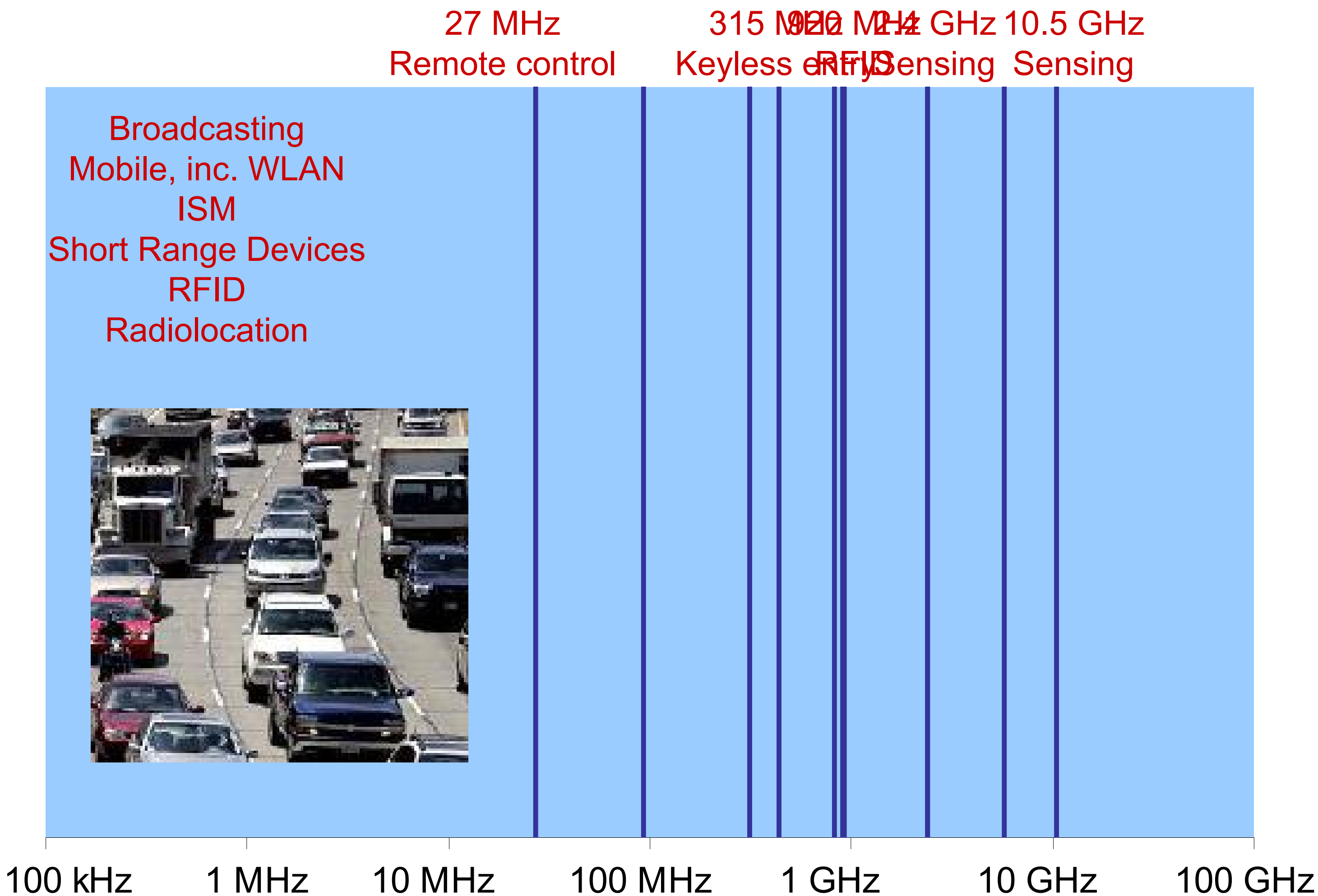
An Australian View

Carol Wilson
Chairman, ITU-R Working Party 3M
Wireless Technologies Lab
CSIRO ICT Centre
Sydney, Australia

5:30 am

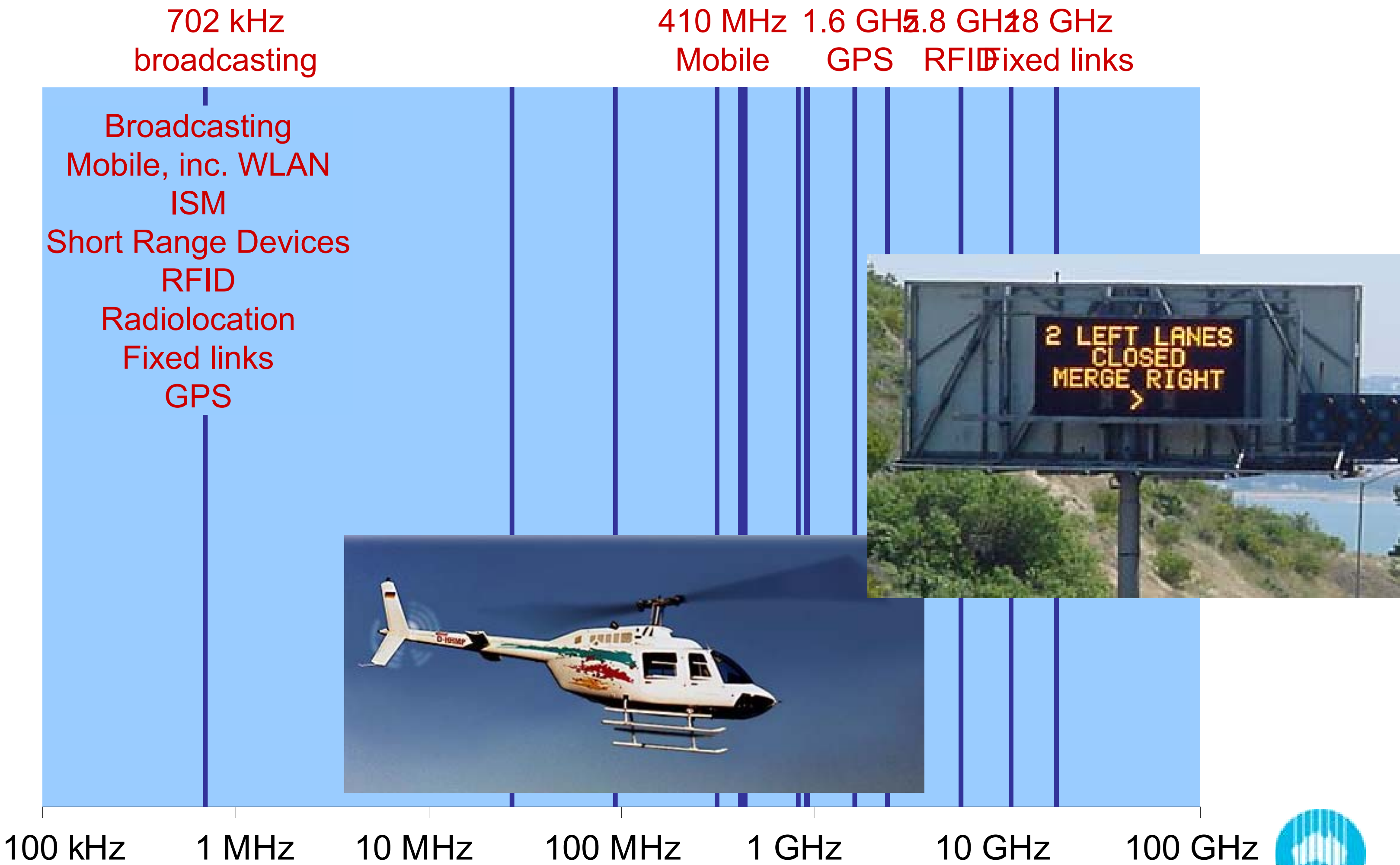
433 MHz
92.9 MHz
Short-range
900 MHz
2.45 GHz
5.8 GHz
Broadcasting
devices
Mobile
ISM
WiFi
Broadcasting
Mobile, inc. WLAN
Ind, Scient, Med
Short Range Devices
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

6:15 am



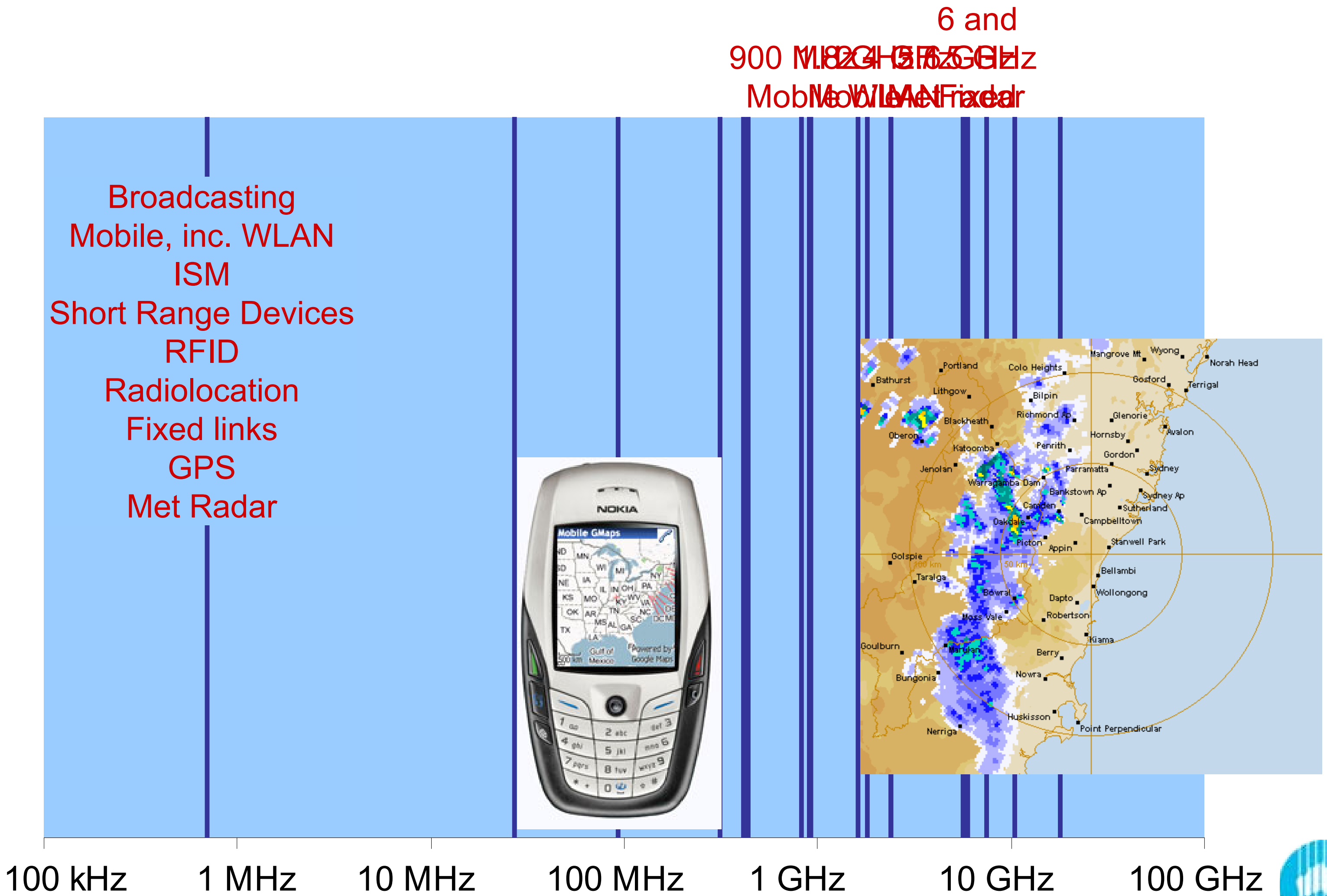
27 MHz
Remote control
315 MHz
Keyless entry
920 MHz
RFID
2.4 GHz
Sensing
10.5 GHz
Sensing
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

7:00 am



702 kHz
broadcasting
410 MHz
Mobile
1.6 GHz
GPS
5.8 GHz
RFID
18 GHz
Fixed links
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
2 LEFT LANES
CLOSED
MERGE RIGHT
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

7:30 am


6 and
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
100 kHz
1 MHz
10 MHz
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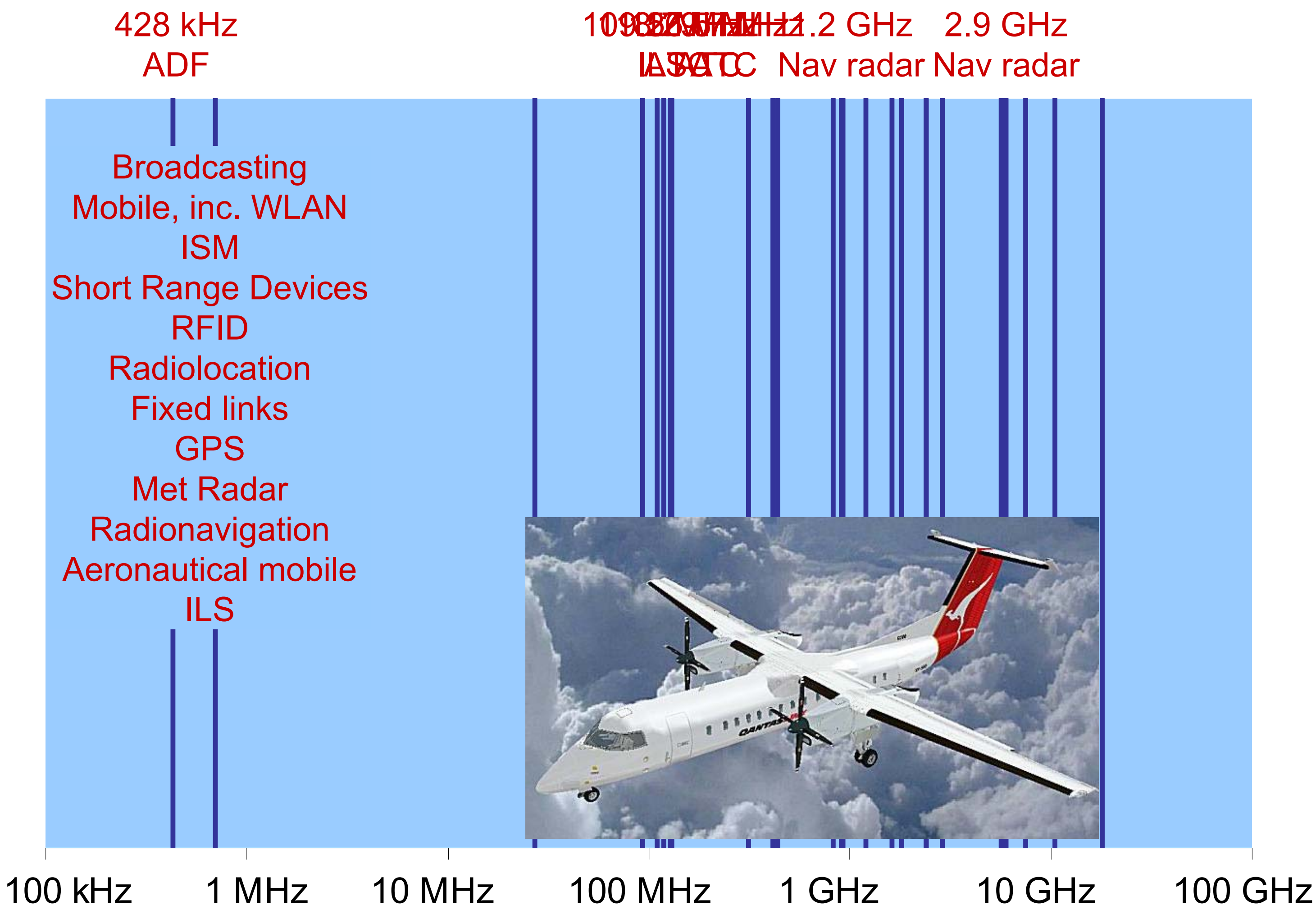
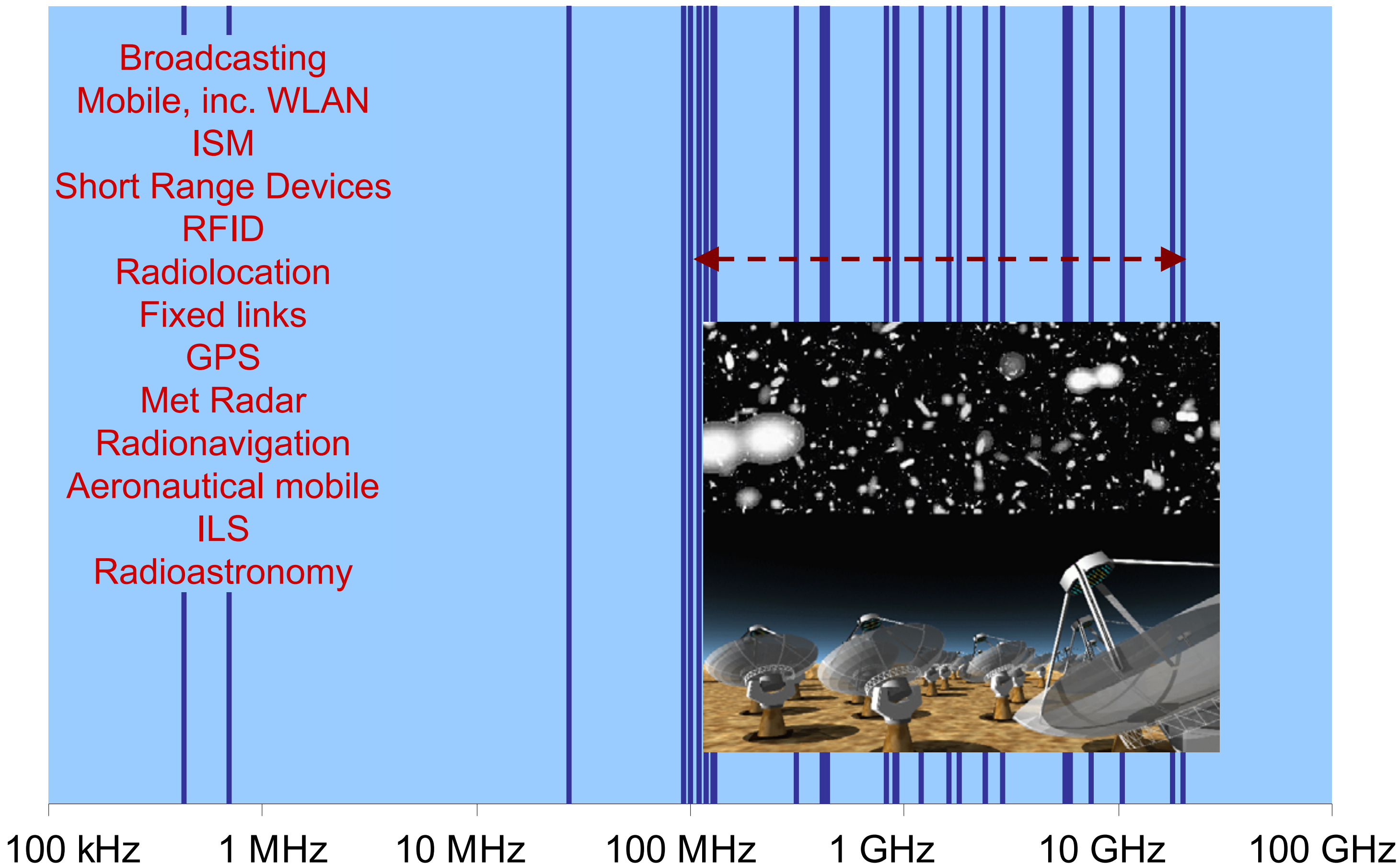
1 GHz
10 GHz
100 GHz

8:30 am

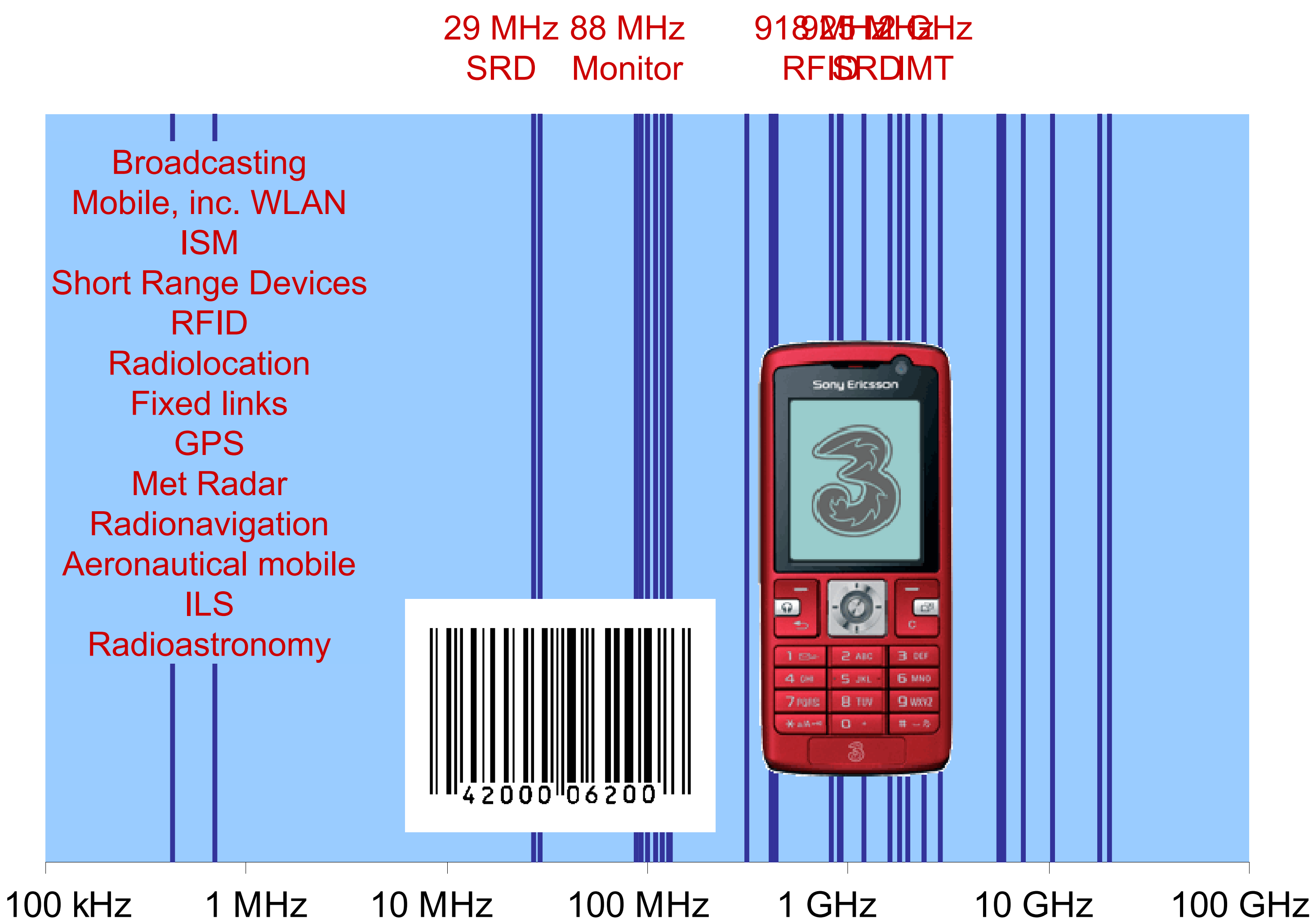


428 kHz
ADF
2.9 GHz
Nav radar
Nav radar
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

10:15 am

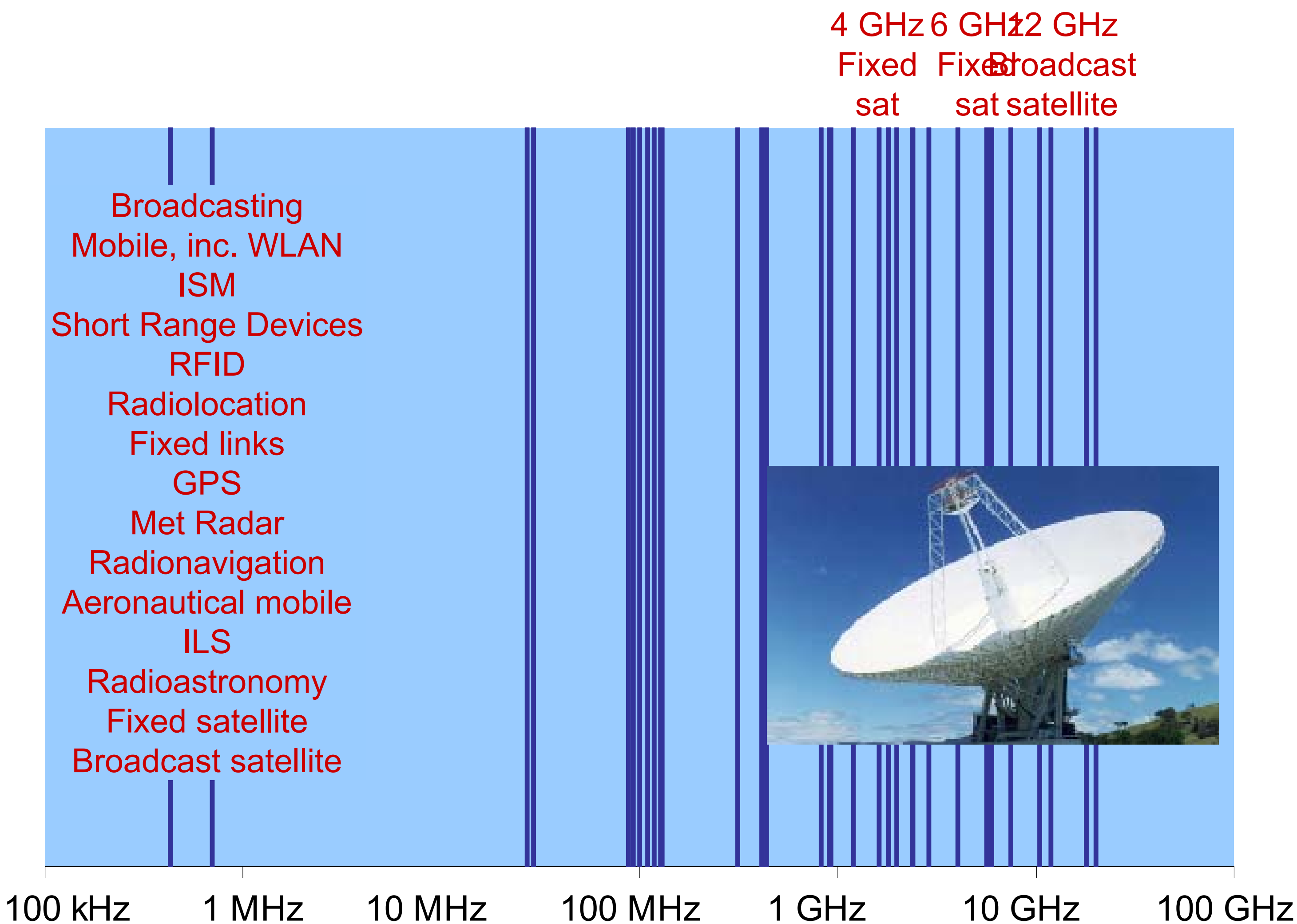

Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
Radioastronomy
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

12:30 pm

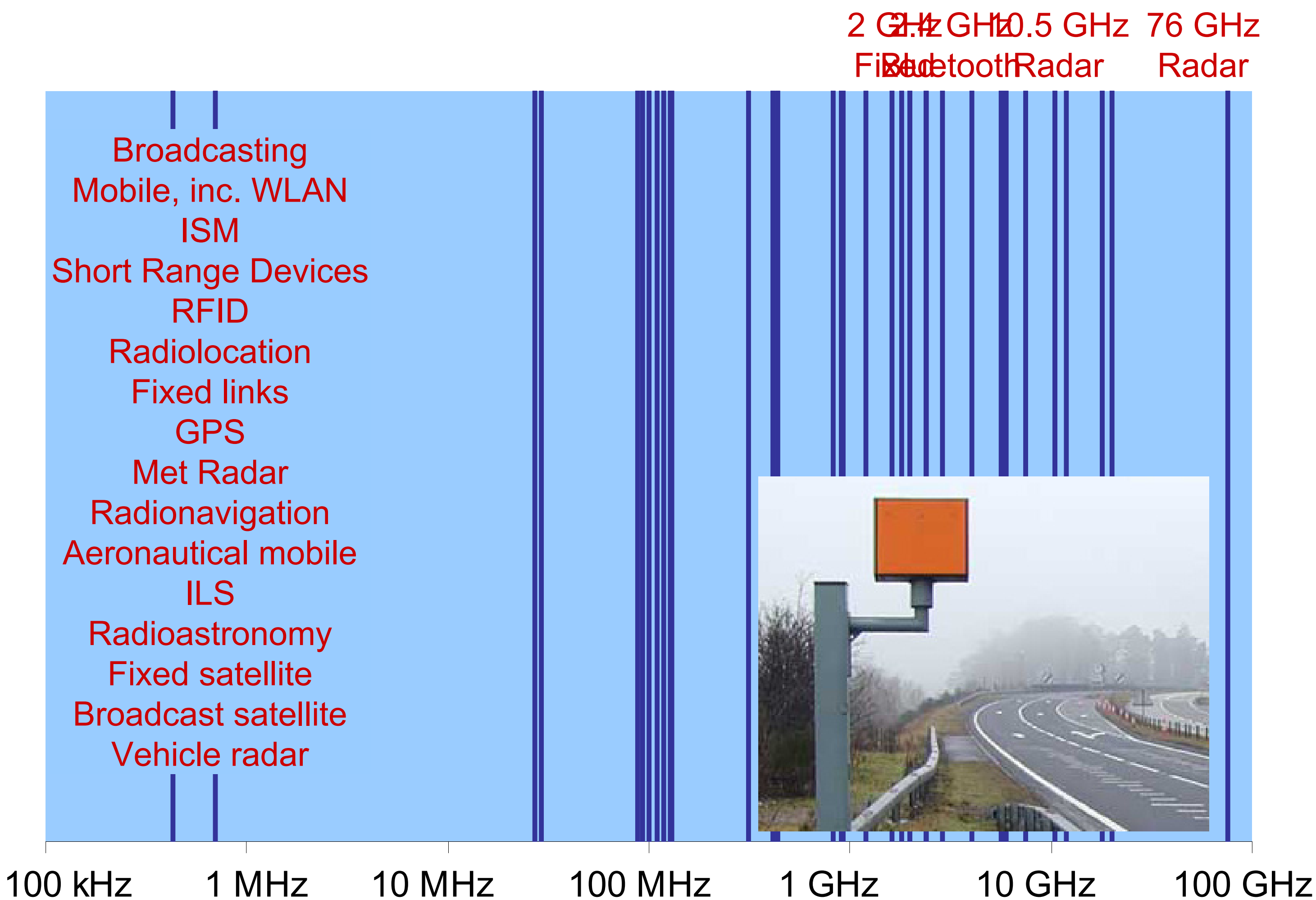


29 MHz
SRD
88 MHz
Monitor
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
Radioastronomy
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

4:00 pm


4 GHz
Fixed
sat
6 GHz
Fixed
sat
12 GHz
Broadcast
satellite
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
Radioastronomy
Fixed satellite
Broadcast satellite
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

5:30 pm



2 GHz
Fixed
2.4 GHz
Bluetooth
10.5 GHz
Radar
76 GHz
Radar
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
Radioastronomy
Fixed satellite
Broadcast satellite
Vehicle radar
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

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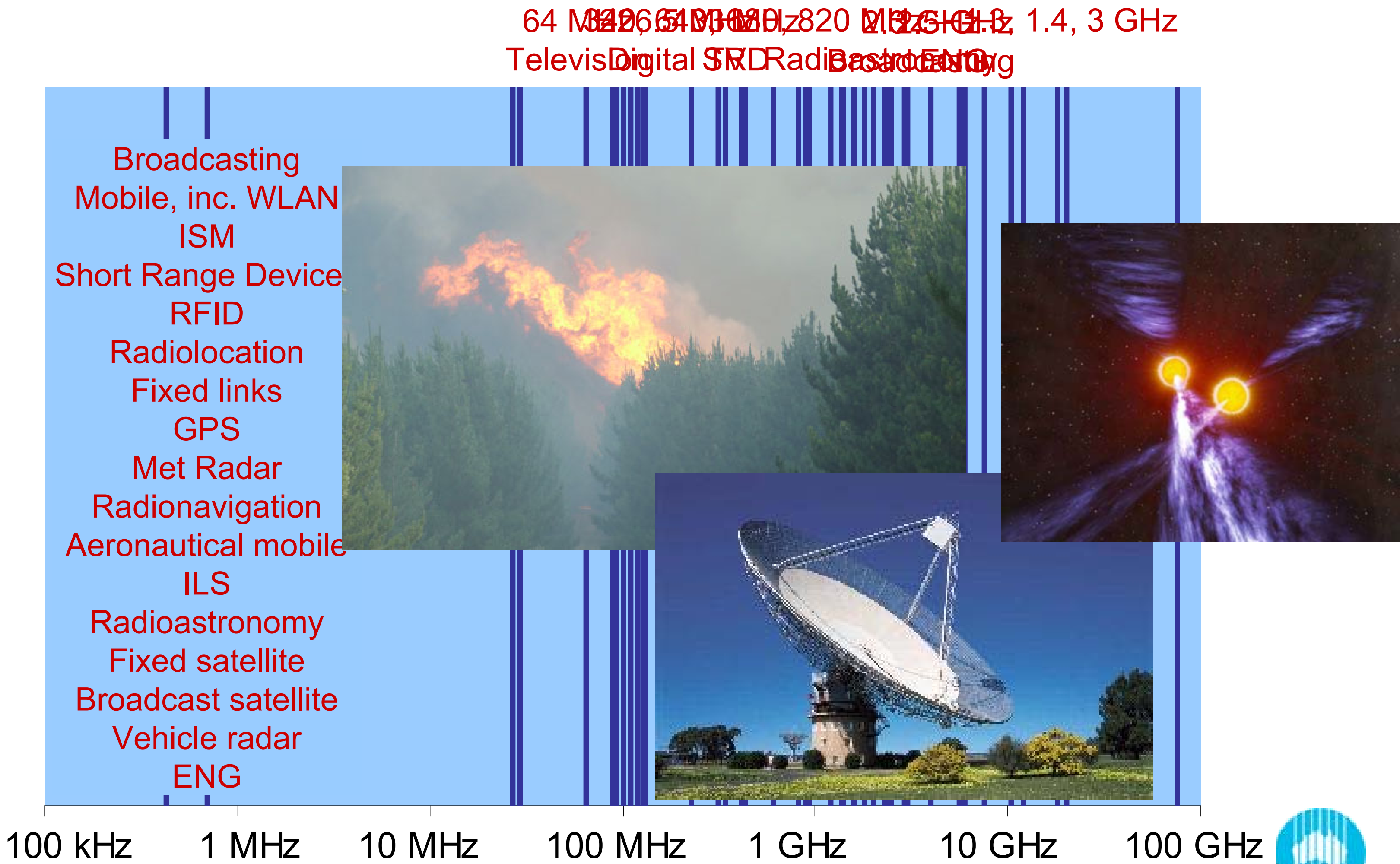
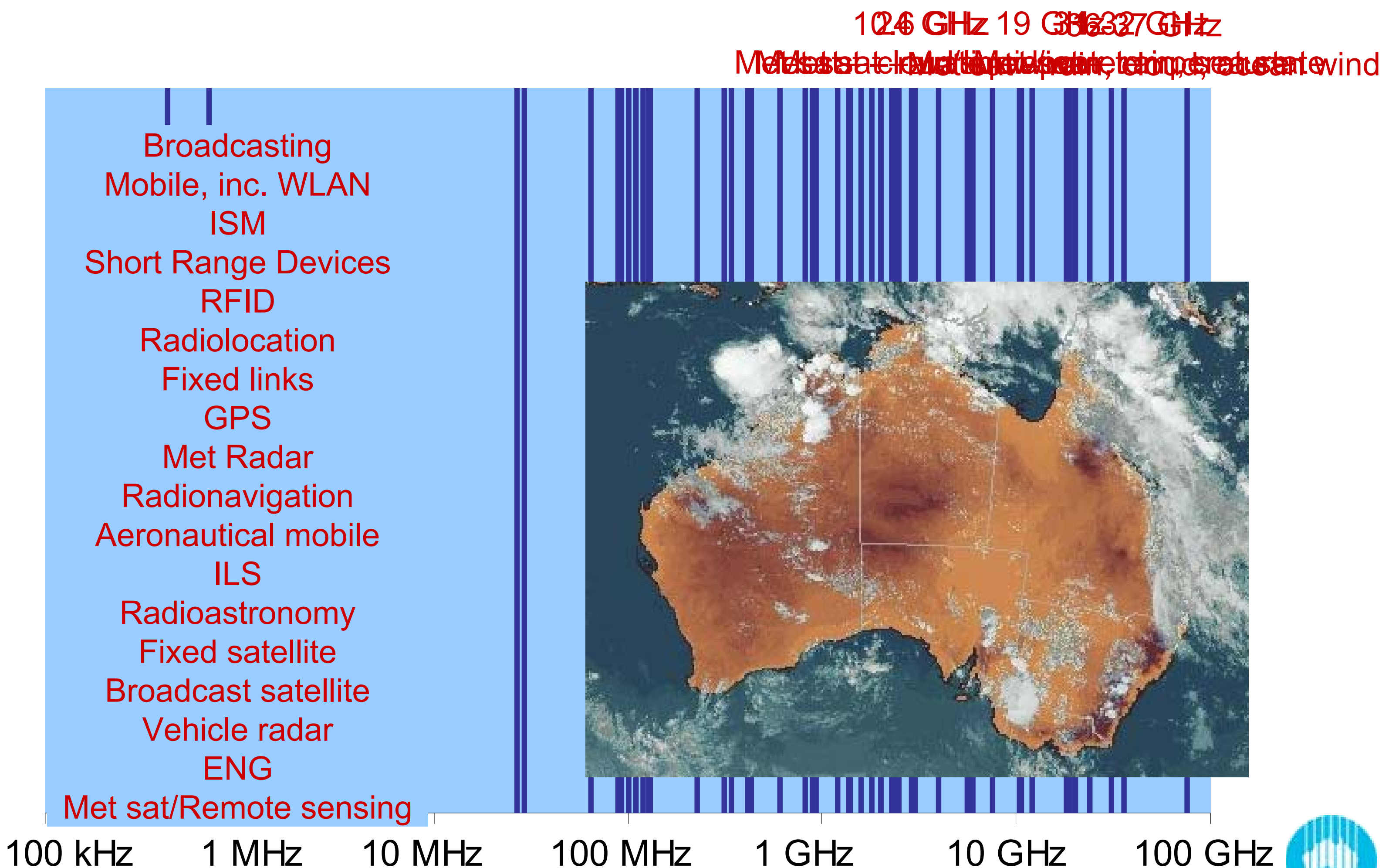
8:00 pm



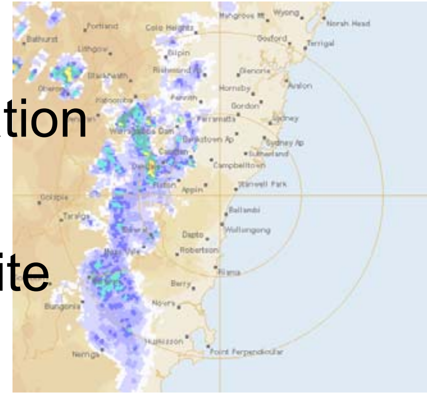
Broadcasting
Mobile, inc. WLAN
ISM
Short Range Device
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
Radioastronomy
Fixed satellite
Broadcast satellite
Vehicle radar
ENG
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

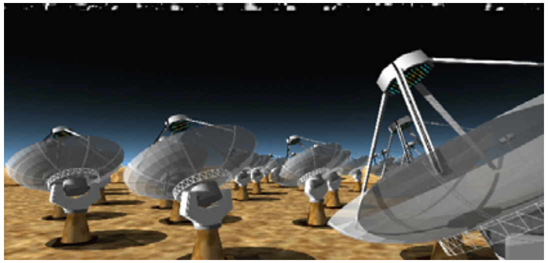
10:00 pm


Broadcasting
Mobile, inc. WLAN
ISM
Short Range Devices
RFID
Radiolocation
Fixed links
GPS
Met Radar
Radionavigation
Aeronautical mobile
ILS
Radioastronomy
Fixed satellite
Broadcast satellite
Vehicle radar
ENG
Met sat/Remote sensing
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz

Radio services as defined by the ITU

- Aeronautical mobile
- Aeronautical radionavigation
- Amateur
- Broadcasting
- Earth-exploration satellite
- Fixed (terrestrial)
- Fixed satellite
- Inter-satellite
- Land mobile
- Maritime mobile
- Maritime radionavigation
- Meteorological aids
- Meteorological satellite
- Mobile satellite
- Radioastronomy
- Radiolocation
- Radionavigation
- Space operations
- Space research
- Standard frequency and time



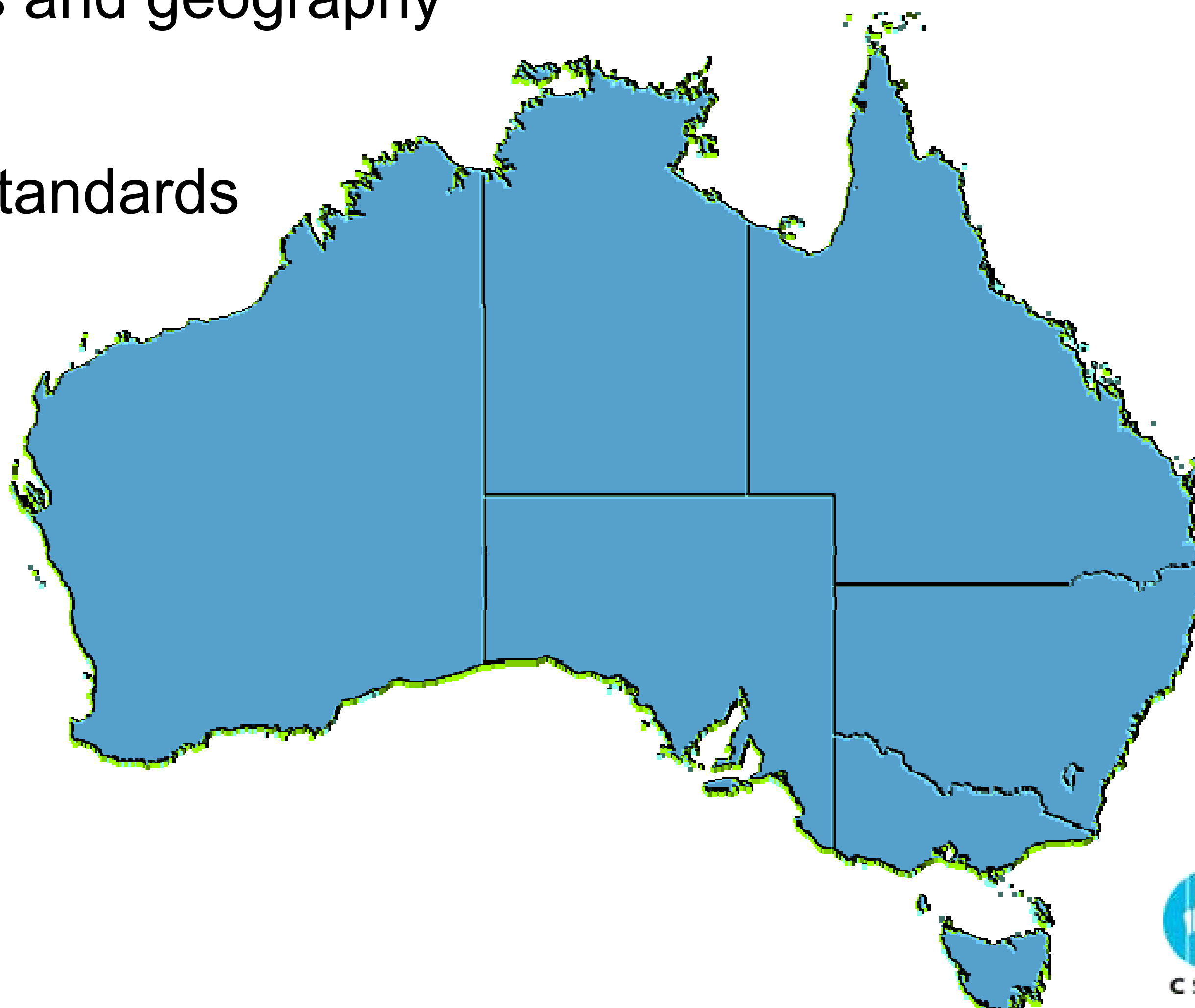


Outline of presentation

- Australian challenges and opportunities
- Solutions to spectrum challenge
  - Science – new understanding
  - Engineering – new technologies
  - Regulatory – new approaches
- Conclusions – better communications for better radiocommunications

Australian challenges and opportunities

- Demographics and geography
- Climate
- Industry and standards
- Science



Australian demographics

	Australia	USA	UK
Population (millions)	20.7	301	60.6
Area (,000 sq km)	7,687	9,631	245
Population density (per sq km)	2.7	31.3	247.6

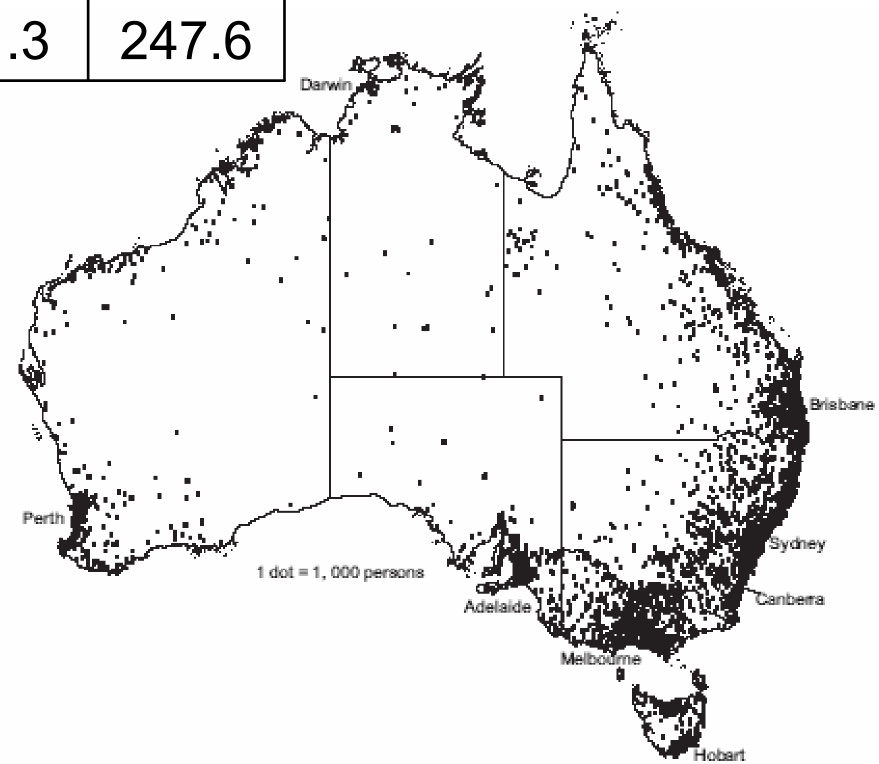
85% of population within 50 km of coast

75% in urban areas (60% in five cities)

No land boundaries with other nations

Closest neighbours are Indonesia, Papua New Guinea, East Timor

Major trading partners: Japan, China, US, Europe



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Australian continent

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Implications of Australian demographics

- Coverage of mobile telephony, broadband (wired and wireless) in urban areas = majority of population
- Challenge to service regional and remote areas
- Opportunities for satellite, HF technologies
- Large coastline with sparse population a challenge for customs, security, defence – development of Over-the-Horizon radar
- Isolation – independence in spectrum management

Australian climate

- Range of climates from mountainous temperate, desert, tropical.
  - Dry lakes, rivers throughout central Australia that fill irregularly
  - High year-to-year variability
- Extremes of weather conditions – droughts, floods, bushfires, cyclones
  - Severe drought in south, east Australia for six years
  - Hailstorm in Sydney in 1999 – A$1.5 Billion in damage: 20,000 homes, 40,000 vehicles, 25 aircraft
  - March 2006 – Cyclone Larry in Queensland – Category 5
  - January 2007 – Heavy floods through central and north Australia, bushfires in Victoria consume over 1 Million hectares (3800 square miles)

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Implications for radiocommunications

- Dependence on short- and long-term weather forecasting – requires good quality remote sensing and measurement networks.
  - Cyclone forecasting days in advance allow evacuations
  - Storm forecasting hours in advance minimises property damage
  - Real-time bushfire behaviour saves lives and property
- Climate predictions inform policy
- Predicting system availability, especially for rain-limited systems, challenging due to variability and lack of long-term data.

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Protection of meteorological sensing

Contamination of passive biomass estimation at 10.6 – 10.68 GHz by backhaul network fixed links

Australian industry and economy

- Industry dominated by primary industry – mining, agriculture
- No major manufacturing in radiocommunications area. Good R&D leading to value-added spinoffs.
- Technology purchased from overseas – US, Europe, Asia.
  - Choice of technologies and standards
  - Little scope for adopting own standard
- Specialised systems (e.g. military telemetry) built to foreign standards – limits Australian spectrum decisions.
- Australia active in harmonising spectrum internationally.

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Australian science

- Radioastronomy a major research activity for decades
  - Parkes – "The Dish" 64 metre telescope
  - Narrabri compact array – 6 telescopes (22 metres)
  - Deep space tracking for NASA

- Future developments
  - Extended New Technology Demonstrator (xNTD) for next generation large arrays
  - A potential site for Square Kilometre Array. 100 MHz to 20 GHz, plus other co-sited telescopes at other frequencies

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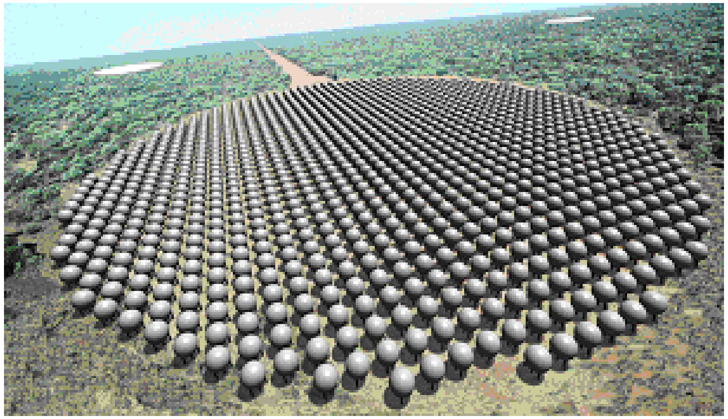
Science implications for radiocommunications

- Protection of sensitive radioastronomy sites a key issue in spectrum management – radio quiet zones



- Regulators must balance needs of radioastronomy and industry - mining, broadcasting, transport
- Technical challenges of radiotelescopes extended to radiocommunications research within CSIRO – strong record in antennas, signal processing, RF engineering

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Chris Chapman, Chairman of ACMA*, Dec 2006:

“Talk to any big user of spectrum, as we do – to telecoms operators, defence, space scientists, meteorologists, and you, the practitioners in this very room – and they (and you) will all say that more and more spectrum is needed every year.

However, unlike demand, our ability to ‘supply’ spectrum, to make it available for use, is increasing very slowly. Even the higher bands, while able to carry more data, can only carry it over very short ranges. In effect, then, we will indeed run out of spectrum, unless we do something about it.”

*Australian Communications and Media Authority

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Solutions to spectrum challenge

- Science – new understanding
- Engineering – new technologies
- Regulatory – new approaches

- And links between these three areas!

Science for better spectrum usage

- Propagation – understanding behaviour of radio in complex environments. Critical for new technology developments.
  - Getting more out of systems requires performance prediction.
  - Balance between efficiency and reliability in spectrum management relies on prediction of interference.
  - Australia involved in ITU-R Study Group 3 – developing international radio propagation prediction methods.
- Other key science areas
  - Signal processing, communications theory
  - Materials science – new devices

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Propagation prediction in ITU-R Study Group 3

- Prediction of wanted signal for system design.
  - Fixed terrestrial systems
  - Satellite systems – fixed and mobile-satellite
  - Indoor and short-range outdoor systems
  - Broadcasting and land-mobile systems
  - New! – Ultrawideband systems
  - Coming soon – Path-specific point-to-area predictions
- Prediction of unwanted signal level for interference analysis.
  - Between terrestrial systems
  - Between terrestrial and space systems
  - Coordination distance for regulatory application

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Short-range indoor systems

Recommendation P.1238 for indoor systems

- Path loss model accounts for frequency, distance, loss through multiple floors. Tables for loss coefficients and floor loss factor, based on measurements at selected frequencies
- Site-general delay spread model and advice on site-specific (ray-tracing) calculations
- Effect of polarisation, antenna pattern, building materials, people moving.

Further work needed:

- Angular spread model (for MIMO systems)
- Path loss coefficients at other frequencies of interest
- Diversity models (space, polarisation, frequency)
- Model for interference from DSL, powerline communications, high speed data networks

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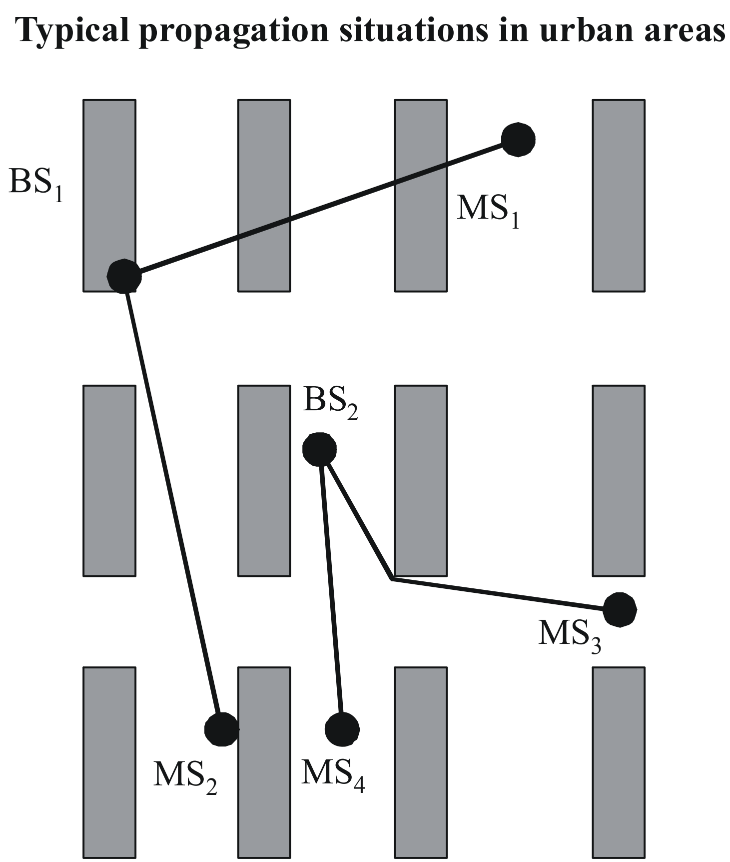
Outdoor short-range systems

Recommendation P.1411 for outdoor systems < 1km



- Path loss and multipath models for line-of sight, street canyon, non-line-of-sight and over-rooftop paths
- Models at UHF (mobile phone), SHF (WiFi, WiMax) and mm-wave frequencies
- The effect of traffic on the road (light vs heavy)
- Building attenuation at 5.2 GHz – used for international decision on WiFi allocation in a satellite band.

New Recommendation on Ultrawideband

The basic transmission loss $PL(d)$ experienced by UWB signals could be derived from the following model:

$$PL(d) = PL_0(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \qquad \text{dB} \qquad (1)$$

where:

$PL_0(d_0)$: basic transmission loss (dB) at the reference distance d_0 (where d_0 =1 m)

d : separation distance (m) between the UWB transmitter and the receiver (d > 1 m)

n : path loss exponent

X_σ : log-normal shadow fading, i.e. a zero mean Gaussian random variable with standard deviation σ (dB).

If the basic transmission loss at the reference distance cannot be measured it can be approximated by:

$$PL_0(d_0) = 20\log(\frac{4\pi d_0\sqrt{f_1 \cdot f_2}}{0.3}) \qquad \text{dB} \qquad (2)$$

where f_1 (GHz) and f_2 (GHz) are the frequencies at the -10 dB edges of the UWB radiated spectrum.

UWB - continued

Parameters for transmission loss calculation (applicable to 20 metres)

Environment	**Path category**	***n***	**σ, dB**
Indoor residential	LoS	~ 1.7	1.5
	Soft-NLoS	3.5 - 5	2.7 - 4
	Hard-NloS	~ 7	4
Indoor industrial	LoS	~ 1.5	≥ 0.3
	Soft-NLoS	2.5-4	1.2-4
	Hard-NloS	4-7.5	≥ 4
Outdoor	LoS	~ 2	–
	NLoS	3-4	–

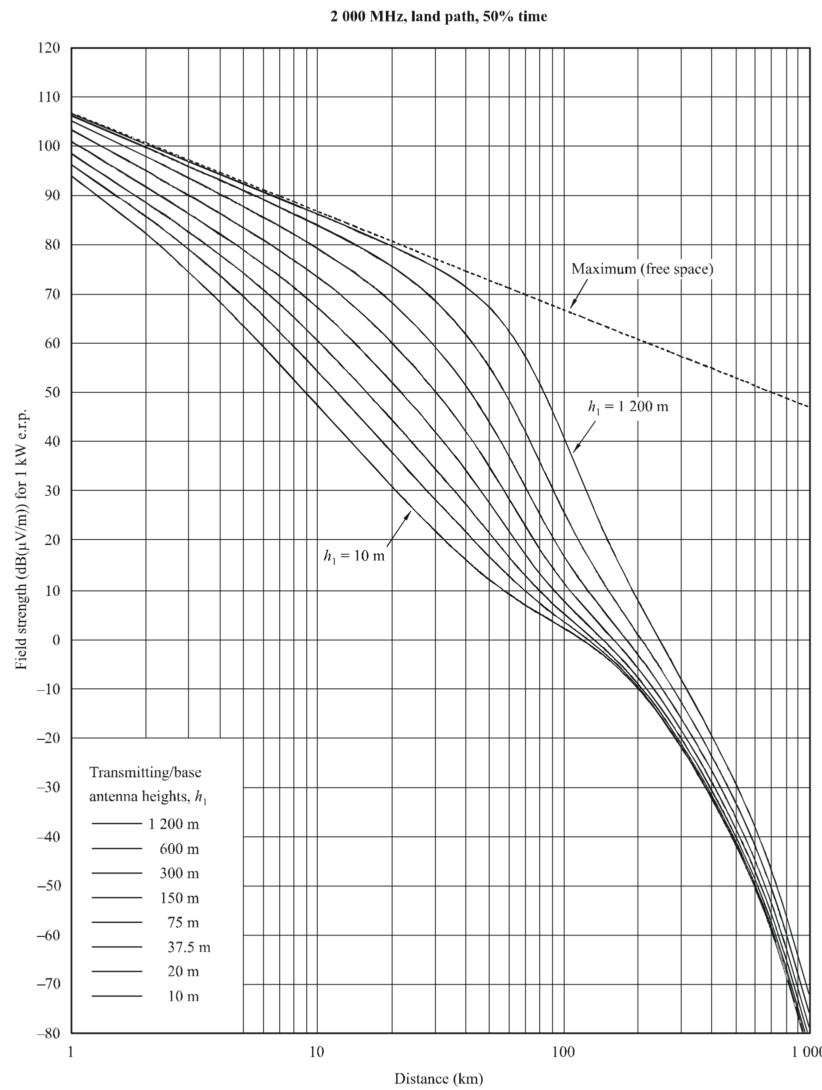
Further work needed:

- Distances greater than 20 m
- Indoor-to-outdoor loss (building attenuation)
- Parameters for more specific environments

Land-mobile and broadcasting

Recommendation P.1546 for 30 MHz to 3 GHz

- Curves represent field strength exceeded at 50% of locations for 1kW ERP transmission as function of:
  - Frequency: 100, 600, 2000 MHz
  - Time: 50%, 10%, 1%
  - Tx antenna height: 10 to 1200 m; Rx antenna height: local clutter height (minimum 10 m)
  - Path type: land, warm sea, cold sea
  - Distance: 1 to 1000 km
- Curves are based on extensive measurement campaigns in Europe, North America, the North Sea and Mediterranean.



Land-mobile and broadcasting – continued

- Calculation methods are provided for extrapolation or interpolation to:
  - Frequency 30 MHz to 3 GHz
  - Times from 1 to 50%
  - Transmitting antenna heights up to 3000 m
  - Receiving antenna heights above 1 m
  - Mixed land/sea paths (accounting for proportion of land to sea)
- The method can also be adapted to take account of local terrain information.

This Recommendation was the technical basis for a process in mid-2006 to determine broadcasting allocations across Europe, the Middle East and Africa.

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Predictions for satellite system - P.618

- Propagation loss:
  - attenuation by atmospheric gases, precipitation and clouds;
  - diversity improvement in rain;
  - decrease in antenna gain due to wave-front incoherence;
  - scintillation and multipath effects;
  - total attenuation due to multiple effects (rain, clouds, scintillation)
  - attenuation by sand and dust storms (mentioned).
- Cross-polarisation effects
  - Long-term statistics of cross-polarisation due to rain
  - Frequency, polarisation scaling
- Propagation delay
- Angle of arrival variation
- Statistics for non-GSO paths

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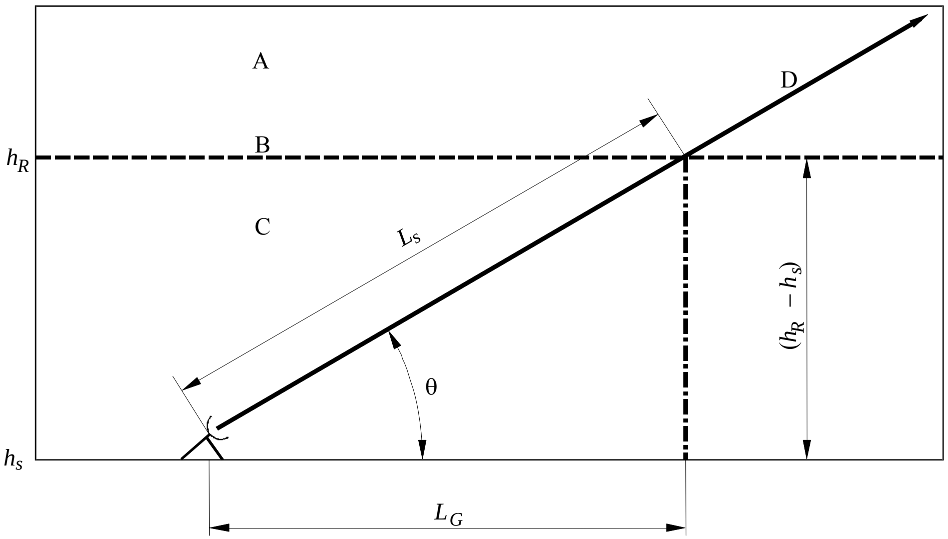
Rain attenuation model in Rec. P.618

FIGURE 1

Schematic presentation of an Earth-space path giving the parameters to be input into the attenuation prediction process



A: frozen precipitation
B: rain height
C: liquid precipitation
D: Earth-space path

Step 4: Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min).

Step 5: Obtain the specific attenuation, γ_R, using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \qquad \text{dB/km}$$

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\dfrac{L_G\,\gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)}$$

Step 7: Calculate the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\dfrac{\sqrt{L_R\,\gamma_R}}{f^2} - 0.45\right)}$$

Step 8: The effective path length is:

$$L_E = L_R\,\nu_{0.01} \qquad \text{km}$$

Step 9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R\,L_E \qquad \text{dB}$$

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Future directions for Recommendation P.618

- Extend all models to 50 GHz (or beyond?) and for higher time percentages – particularly for VSATs
- Rain attenuation model:
  - Use of full rainrate distribution; move towards physical basis.
  - Ongoing testing of alternative models.
- Fade dynamics: fade slope, fade duration, inter-fade duration
- Possible new model for cross-polarisation
- Diversity improvement – clarify model(s)

Input needed:

Attenuation and rain data from a wide range of climates, especially tropical

Fade dynamic, cross-polarisation, diversity measurements

Alternative models (with testing results)

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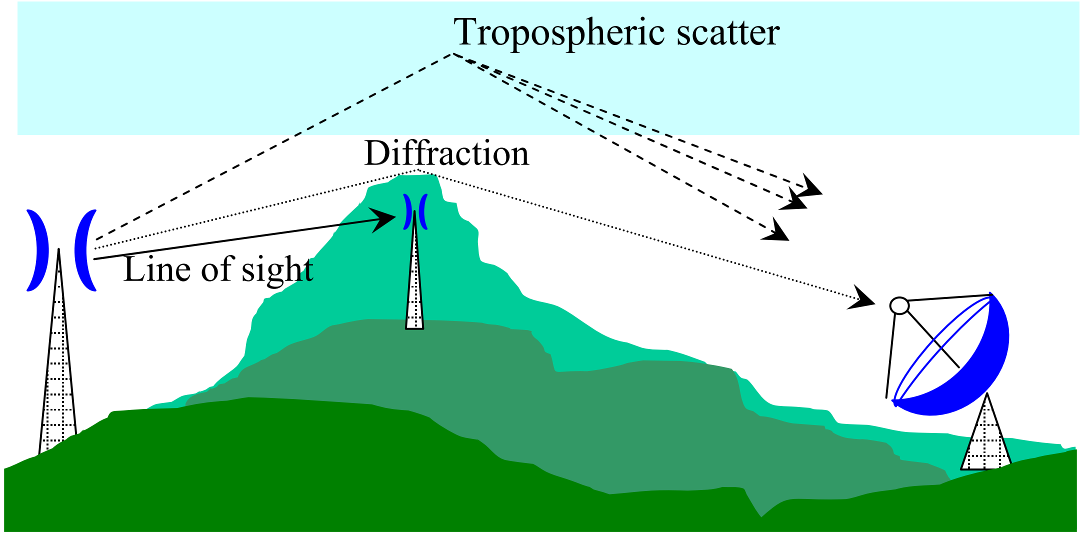
Interference between terrestrial stations

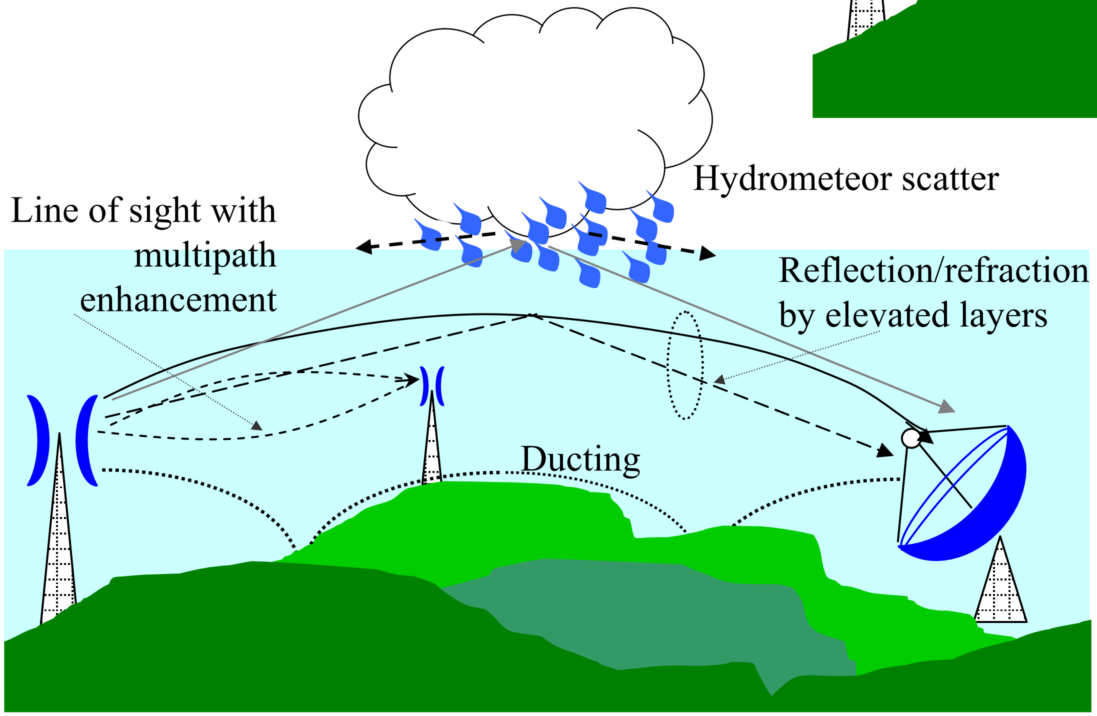
Recommendation P.452 for interference above 700 MHz

- Prediction of *wanted* signal estimates largest loss/ weakest signal due to rare attenuating events.
- Prediction of *unwanted* signal estimates lowest loss/ strongest signal due to rare enhancing events.
  - Long-term mechanisms
  - Short-term mechanisms
  - Meteorological information (rain, atmospheric conditions)
  - Terrain and path type (land, water, mixed)
  - Calculates maximum loss for given small percentage of time due to combination of mechanisms

Interference mechanisms modelled in P.452

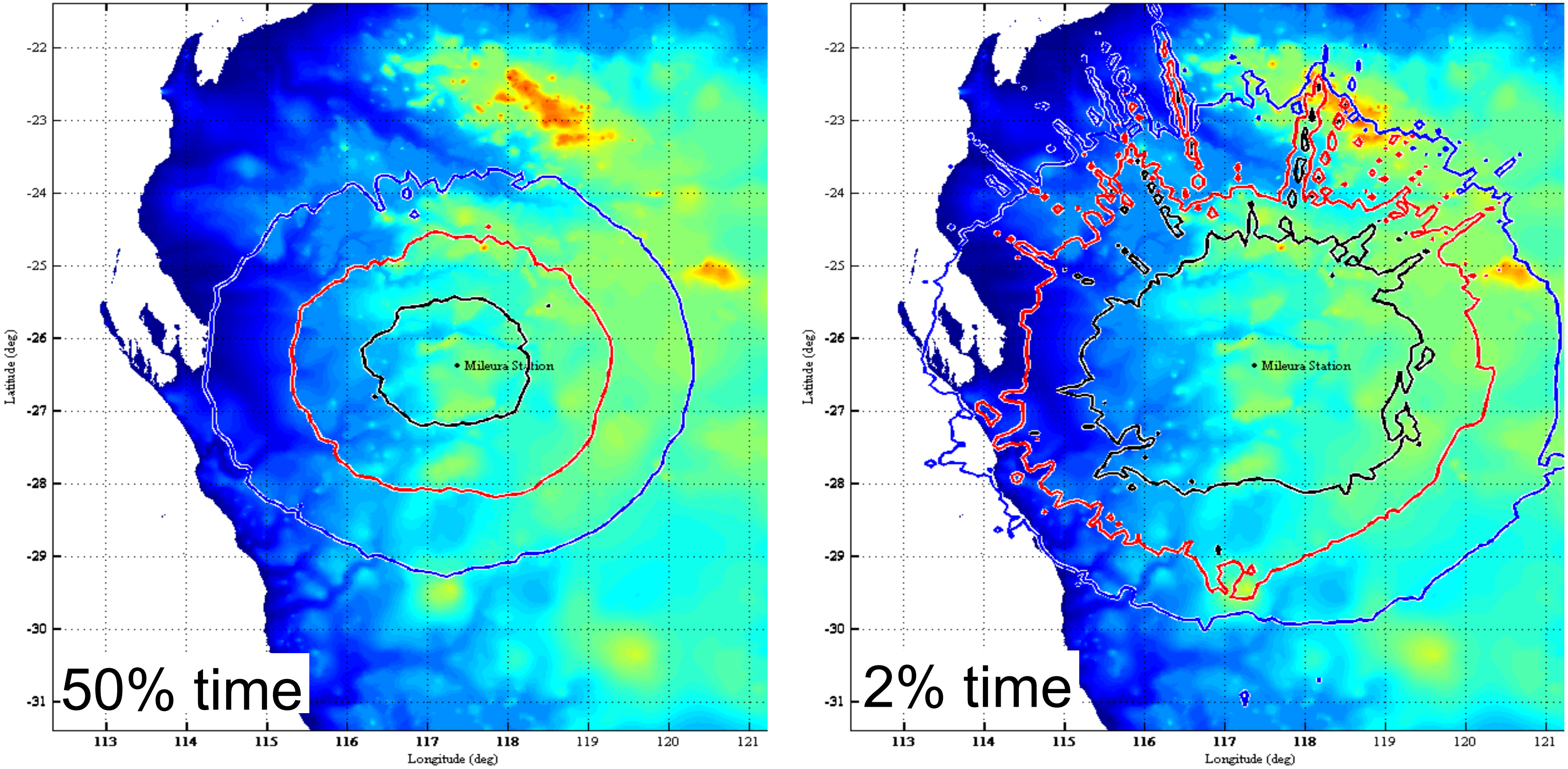
Long-term effects ⇨





⇦ Short-term effects

Predictions for radio quiet zone with Rec P.452



Transmitter: -16 dBm/Hz,
1 GHz, 90 m height

Receiver height 30 m

Black: VLBI threshold (-204 dBm/Hz)

Red: spectral line threshold (-223 dBm/Hz)

Blue: continuum threshold (-240 dBm/Hz)

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Coordination distance for satellite Earth stations

Recommendation P.620 for 100 MHz to 105 GHz

- Before installation of satellite earth station, assess possible interference to/from terrestrial links
  - Estimate zone of interference due to clear-air effects: line-of-sight, diffraction, troposcatter. Takes account of terrain shielding and antenna pattern
  - Estimate zone of interference due to scattering from rain
  - Overlay two zones, take larger distance at each azimuth
- Terrestrial stations within zone then subject to detailed analysis

This prediction method is included in the Radio Regulations and is important for international negotiations on interference.

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Supporting data and information

- Terrain and building databases
- Terrain diffraction
- Loss due to building materials
- Vegetation loss (particularly at higher frequencies)

- Climatic descriptions
  - Rain rates, rain height, refractive index profile
  - Duration of rain events, inter-event duration, spatial distribution of rain
- Specific attenuation due to rain, atmosphere
  - Need quality data from all world climates
  - Particular interest in improvements for tropical regions

- Databank of propagation and meteorological measurements, used in testing prediction methods.

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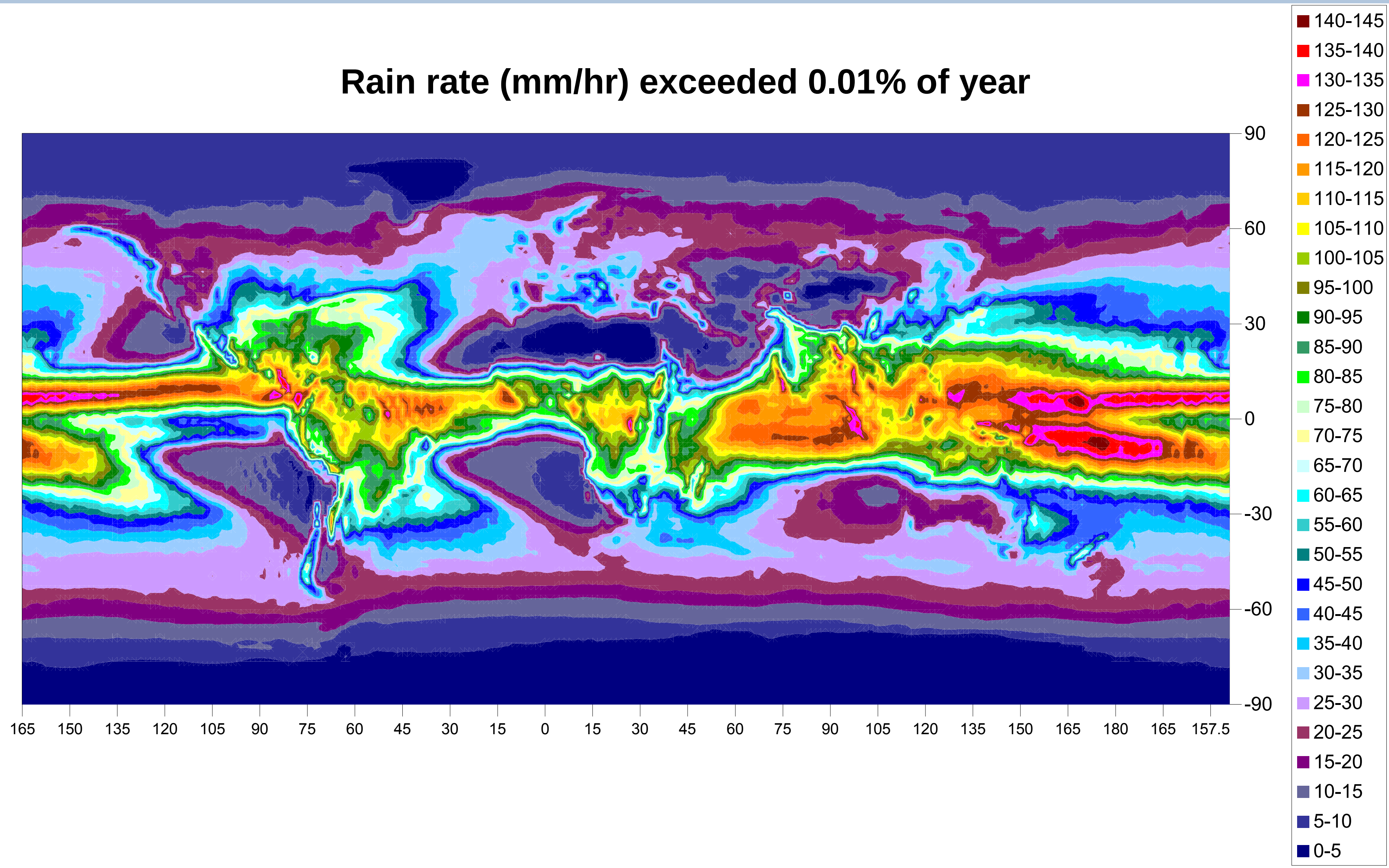
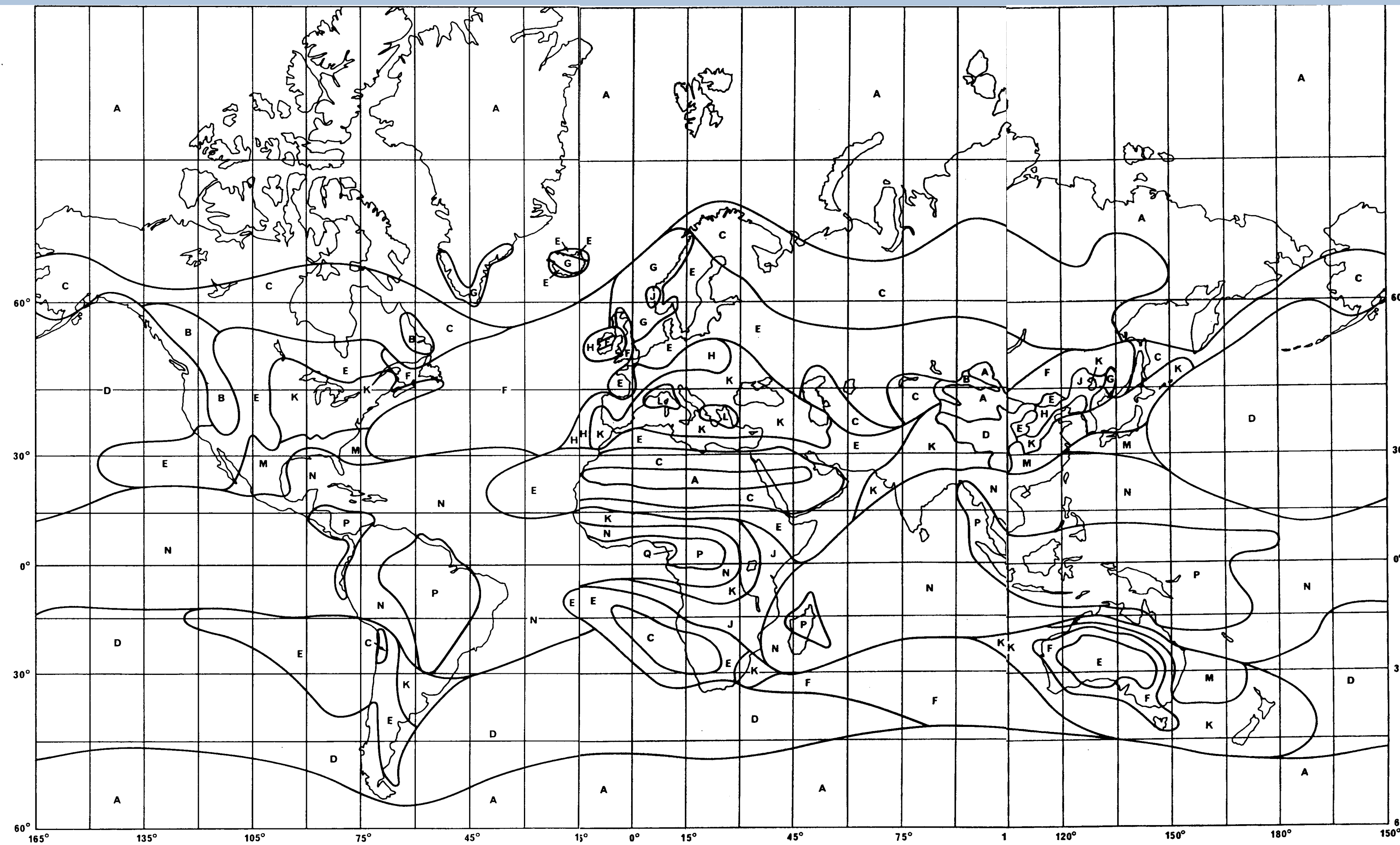
Rain rate from Recommendation P.837



Rain rate from Recommendation P.837 - old



Engineering – technology development

- “Spectrum demand is exponential; increase in available spectrum is linear”
- More efficient use of congested spectrum
  - MIMO
  - Ultrawideband
  - Cognitive Radio
- Higher frequencies
  - mm-wave communications
  - mm-wave imaging
  - Terahertz imaging
  - Infrared/Optical communications

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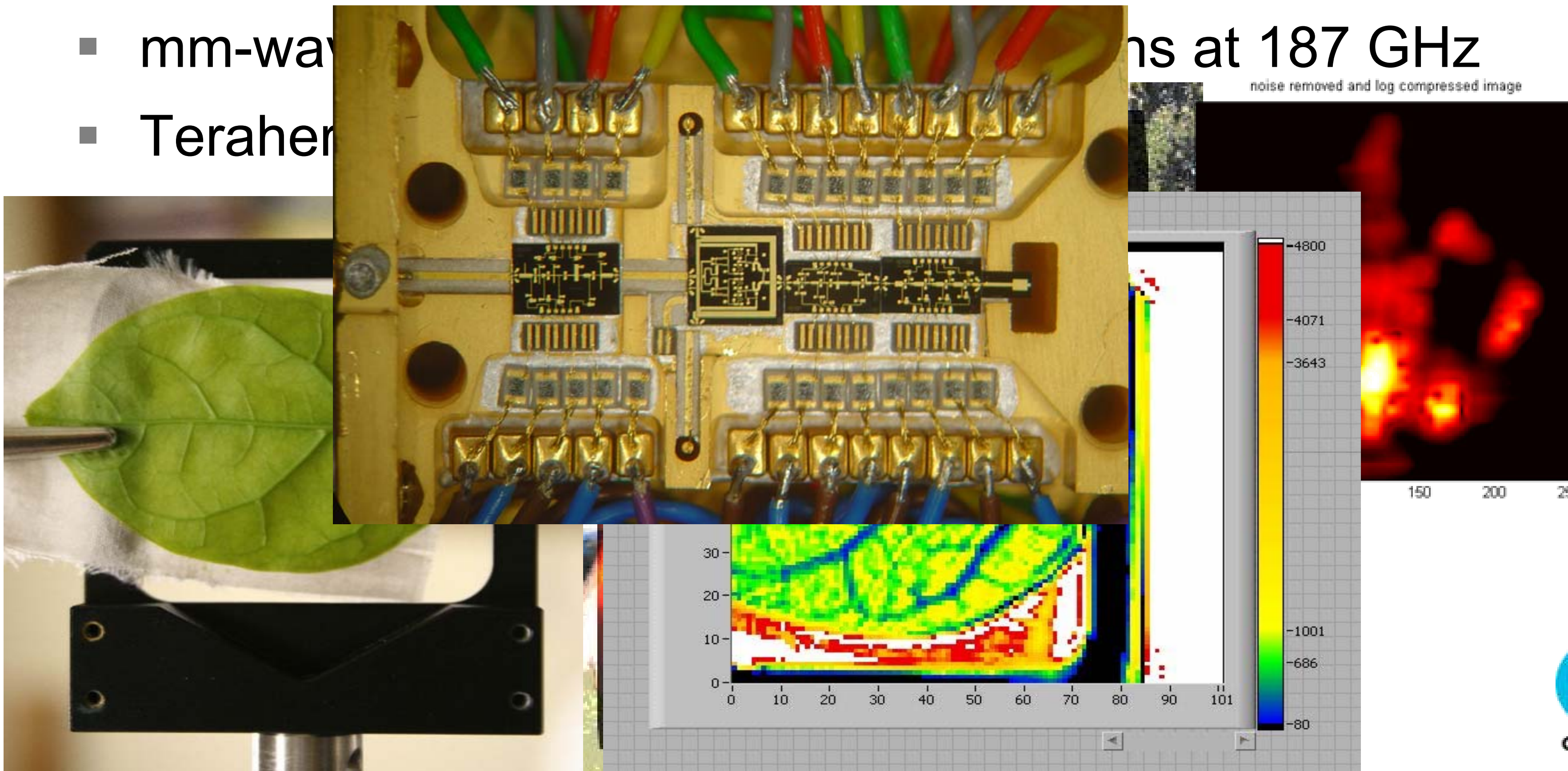
Recent CSIRO achievements

- MIMO – 600 Mbps in 40 MHz; 121 Mbps per user (4 users)
- mm-wave links – 6 Gbps at 83 GHz band over 250 m
- mm-wa ns at 187 GHz
- Teraher



Links for technology development

- Within CSIRO, engineering has strong links with
  - Science activities – provide fundamental basis
  - Industry partners – provide commercial insight
  - Government – provide regulatory context
- Communication with regulators needed to
  - Avoid complicated system interference problems before technology progresses (5 GHz WLAN vs. satellites)
  - Explain both benefits and limits of new technology (Software Defined Radio)
  - Broaden view from just economic goals!

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Spectrum regulation

- Goal – efficient use of radio spectrum for the good of the overall community.
  - No clear metric (e.g. 10.6 GHz band)
- Australia seeks international harmonisation for:
  - International circulation of devices (GSM, WiFi, Bluetooth, etc)
  - Satellite, aeronautical, maritime systems, which cross national boundaries
  - Economy of scale of common spectrum with other countries.

Australian initiatives in spectrum management

- Isolation allows some experimentation
- Good consultation with Australian industry, research
- First to introduce spectrum licences
  - Technology-flexible
  - (Bandwidth) x (geographic area) x (time).
  - Example: 3G mobile systems.
  - Allocation through auction process.
- Broadband Access systems – tiered approach proposed
  - More control, higher entry costs in major cities
  - Less restriction in smaller towns
  - Open access in regional/remote areas.
  - Balance competition with service to whole country.
- “Light licensing” approach for 71-76 and 81-86 GHz; under discussion.

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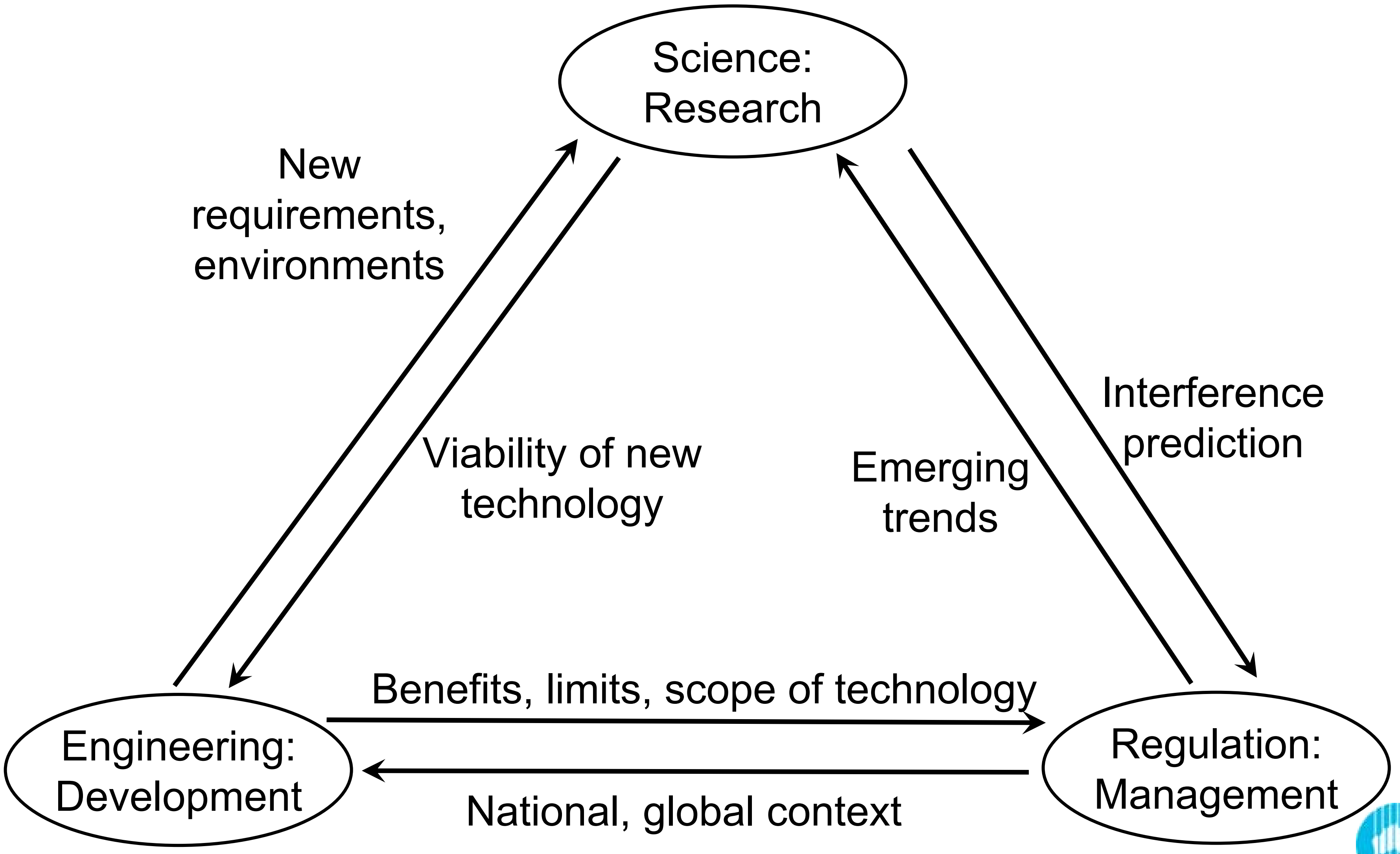
Conclusion – working together



Thanks!

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Questions???

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