Spectrum co-existence for satellite/terrestrial systems

Professor Barry Evans
ICS University of Surrey

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The Regulation Regime

Main Satellite Bands:

L/S **1-3** GHz---Mobile satellites e.g.Inmarsat

C **3-7.5** GHz---Fixed satellite-now vacating in US for 5G

Ku **10-14.5** GHz---Fixed broadcast and BB-downlinks for GEO and non-GEO

Ka **20-30** GHz---Fixed BB, vHTS e.g.KaSat, Konnect, Viasat1-3. Also non-GEO feeder and user links.

Q/V **40-50** GHz—proposed feeders for vHTS GEO and for non-GEO.

W **70-80** GHz—proposed feeders for vHTS and for non-GEO.

- Exclusive satellite sub-bands up to and inc Ka band but not above!

Spectrum overview Ka /Q/V/W bands

	Ka band	
Allocation	**Down (GHz)**	**Up (GHz)**
Exclusive	19.7 – 20.2	29.5 – 30.0
Shared	17.7 – 19.7	27.5 – 29.5
Government	20.2 – 21.2	30.0 – 31.0
BSS (coord)	17.3 – 17.7	
Available to use	**2.5 /2.9 GHz**	**2.5 GHz**

	Q/V bands	
Allocation	**Down (GHz)**	**Up (GHz)**
Unplanned FSS	37.5 – 39.5	42.5 – 43.5 + 49.2 – 50.2
Government	39.5 – 40.5	50.4 – 51.4
BSS (coord)	40.5 – 42.5	47.2 - 49.2
Available to use	**4 GHz**	**4/5 GHz**

	W bands	
Allocation	**Down (GHz)**	**Up (GHz)**
Unplanned FSS	71 - 76	81 - 56
Available to use	**5 GHz**	**5 GHz**

GEO and non-GEO satellites

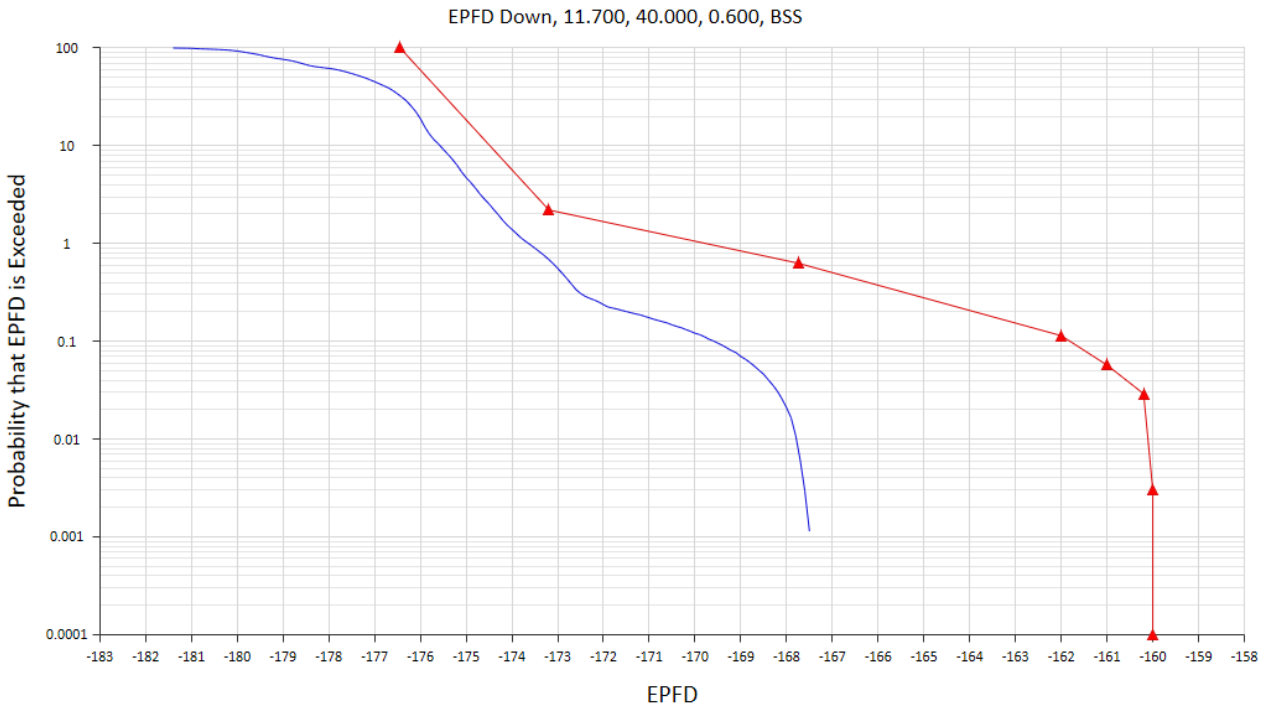
- GEO-vHTS—BB Ka user beams; Ka or Q/V band feeders
- Non-GEO---Constellations –LEO—Starlink, OneWeb, (Telesat, Keiper)

  --Ka feeder links and Ku user beams (Ka both feeder and user)

  --Ku band uses old Skybridge agreed spectrum co-od plan

  --Interference issues-complicated between all systems
- Non-GEO---MEO constellation O3b(SES) equatorial coverage
- Non-GEO to GEO Ku interference –epfd masks (ITU)
- Non-GEO to Non-GEO still TBD and rely on dynamic beam steering and resource allocation to achieve spectral efficiency.

Starlink –EPFD mask for Ku band BSS



Sharing mechanisms

- **Fixed exclusive frequency bands**—baseline but spectrally inefficient.
- **Centralised static spectrum schemes**—Geographic exclusion zones based on protection of incumbents (used in C and Ka bands)
- **Centralised dynamic spectrum schemes**—e.g. data base driven (demonstrated in CoRaSat project and applicable to fixed terminals)

----Both of the above based on channel/interference modelling and I/N thresholds—not based on QoS.

- **Distributed dynamic spectrum schemes** –based on cognitive spectrum sensing and brokerage engines.

Above needed where mobility of users or satellites is involved.

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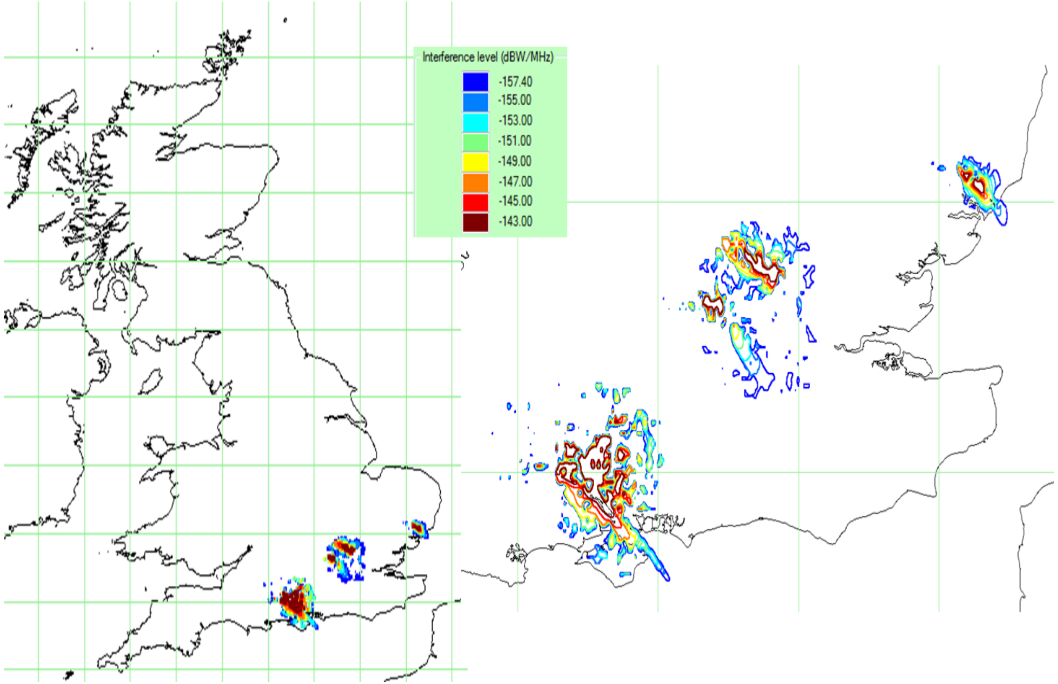
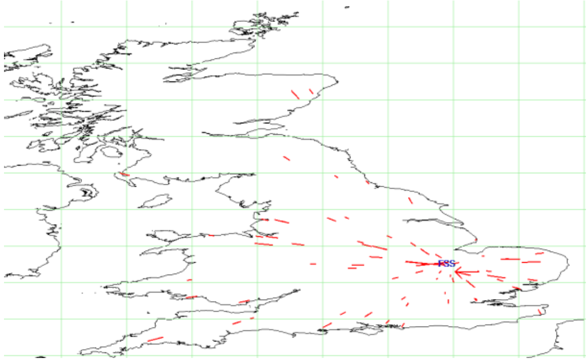
Centralised static schemes



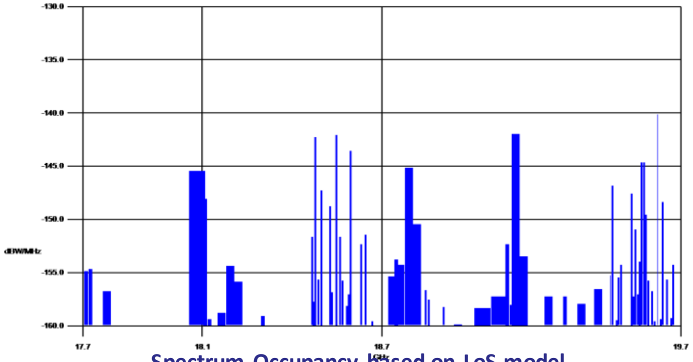
- 17.3 to 17.7 GHz band allocated primary to BSS uplinks.
- Modelling of interference from FS links in the UK using data from regulators.
- Interference contours demonstrating exclusion zones for vsat installation.
- Areas around BSS up-links which are few.
- Most areas in the UK would be free of interference.
- Similar studies have been performed at C band.
- Exclusion bands are static and hence do not provide optimum spectral efficiency.

Centralised Dynamic Scheme

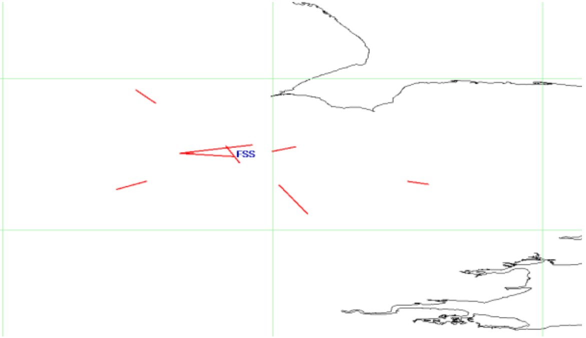
Example of all UK FS links, interfering to FSS terminal at a particular location 1 (lat of 52.5 degs, long of -0.1 degs)C

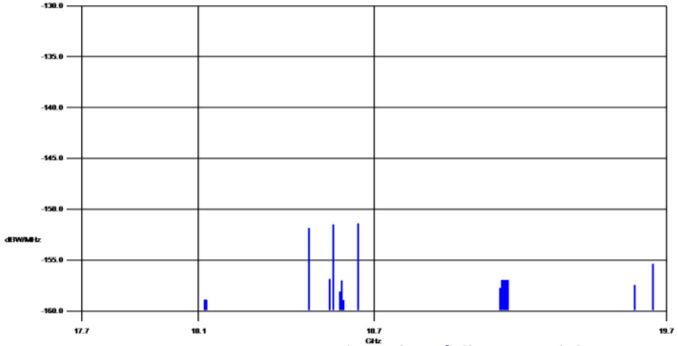


Interfering FS links based on LoS model



Spectrum Occupancy based on LoS model
(X: 17.7 - 19.7 GHz; Y: PSD from -160 to -130 dBW/MHz)



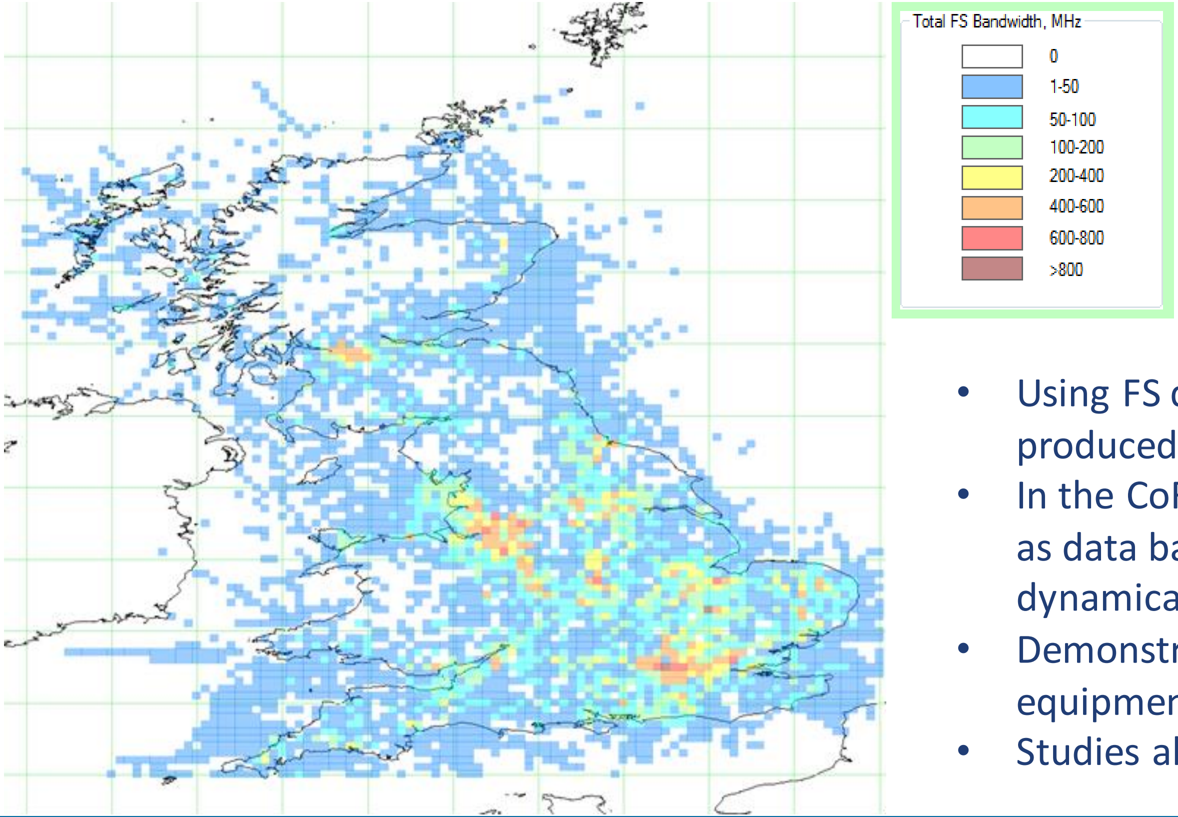


Spectrum Occupancy based on full ITU model
(X: 17.7 - 19.7 GHz; Y: PSD from -160 to -130 dBW/MHz)

Interfering FS links based on full ITU model

Centralised dynamic scheme

Data base Driven



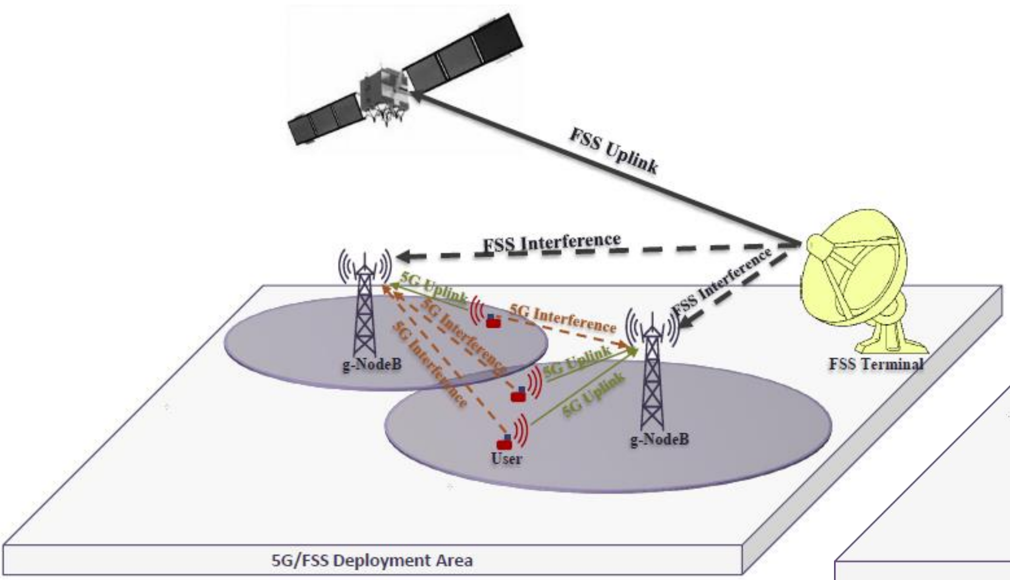
13E UK -154.5 dBW/MHz

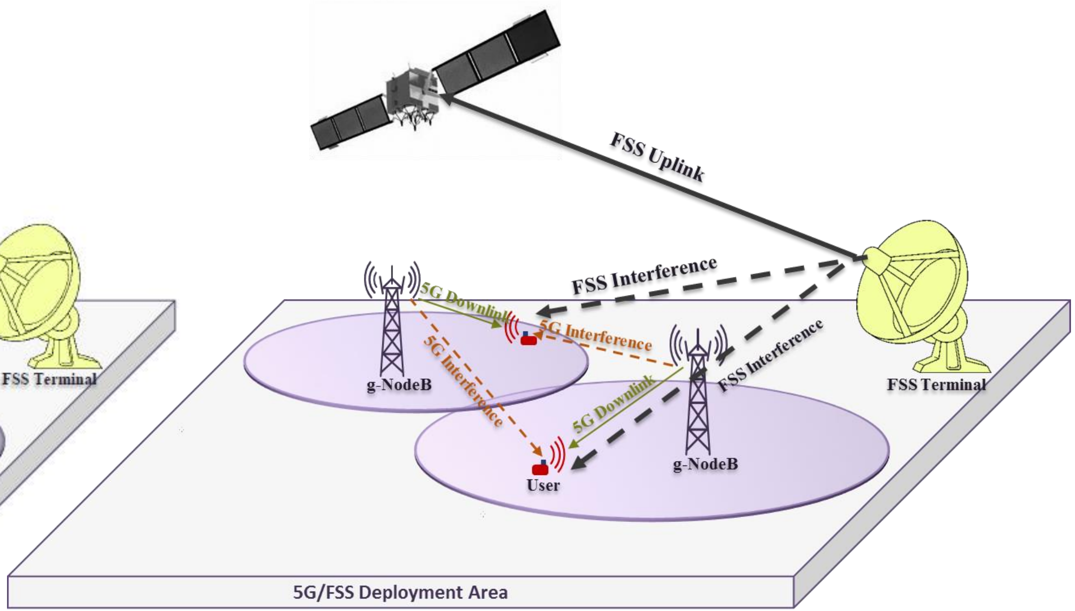
Spectrum availability maps

- Using FS data bases maps have been produced for major EU countries
- In the CoRaSat project these were used as data bases in the satellite gateway to dynamically assign carriers.
- Demonstrated on Newtec gateway equipment.
- Studies also included ESIM's air and sea.

Satellite return link and 5G cells (28GHz)

Coexistence Scenarios





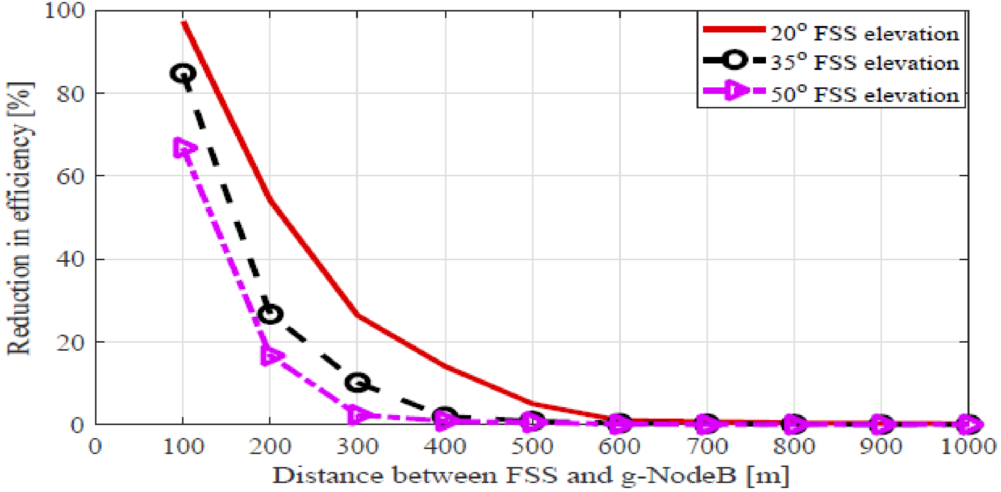
5G NR TDD Uplink and FSS Uplink

5G NR TDD Downlink and FSS Uplink

Coexistence Scenarios: 3GPP Dense Urban Single Tier Scenario

200 m g-NodeB Inter-site distance

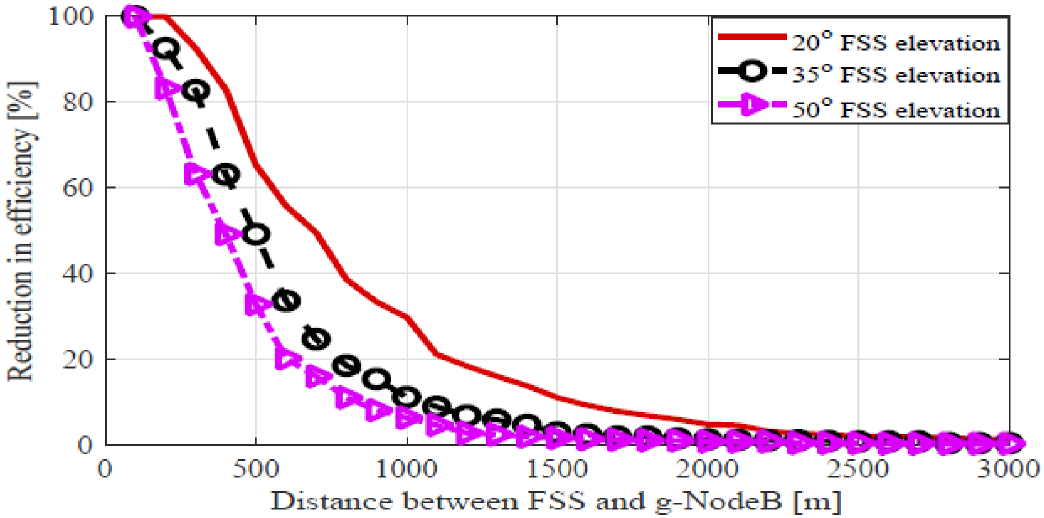
- Deploying the FSS at the edge of the g-NodeB cell (i.e., at 100 m) results in a significant loss in the 5G uplink efficiency.
  - 97%, 84%, and 67% loss in the efficiency is observed with 20°, 35° and 50° FSS elevation respectively
- With a maximum tolerable loss of 5%, a protection distance of 500 m will be required with 20° FSS elevation.
- A stricter target of ≤1% efficiency loss requires 640 m protection distance.



Coexistence Scenarios :3GPP Urban Macro Scenario

500 m g-NodeB Inter-site Distance

- A complete (100%) loss of the 5G uplink can be observed with FSS/g-NodeB distance of 100 m irrespective of the FSS elevation angle.
- With a maximum tolerable loss of 5% and 1%, a protection distance of 2 km and 3 km, respectively, will be required with 20° FSS elevation.
- The protection distance in the urban macro scenario is 4x-5x the protection distance in the dense urban scenario.



Conclusions

- We investigated coexistence of 5G NR with FSS in the mm-wave band.
- The developed model considers both the 5G system interference and the coexistence interference.
- Several 5G NR features are exploited to enable the coexistence (antenna arrays, adaptive coding/modulation) with a controllable expense/penalty.
- To develop a generic framework applicable to different 5G configurations and frame structures, we proposed using the resource element efficiency as a measure for the tolerable loss, i.e., sharing constraint.
- Simulation results indicate that the 5G deployment scenario is a key factor in determining the protection area.
    - We found that 5G deployment in urban macro scenarios requires 400% increase in the protection distance compared with 5G deployment in dense urban scenarios.

Spectrum coexistence for Satellite/terrestrial systems

Conclusions and future work

- Future spectrum sharing is essential to meet capacity demands.
- Geographic exclusion zones are not spectrally efficient
- Dynamic data base systems can increase spectral efficiency for fixed terminal systems but have practical limitations for mobility
- Distributed cognitive sensing schemes with brokerage can improve spectral efficiency for mobile systems but accurate spectrum sensing is an issue
- Two key spectrum co-existence areas are;

  Non-GEO to Non GEO satellite

  5G cellular to satellite
- Distributed cognitive spectrum sharing is a key enabler for 6G.