ICT KTN – Stuart Revell

Wireless Technology & Spectrum challenges and opportunities

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ICT KTN

- Established by an industry led group of key players with funding from the Technology Strategy Board
- Bringing competitive advantage to the UK by:
  - Facilitating the exchange of knowledge on ICT technology and services
  - Accelerating innovation in the sector
  - Facilitating focused working groups
- Acting as a Network-of-Networks, working through other networks, industry associations, support organisations and communities of interest
- We have a comprehensive network of members spanning the entire value chain
- Membership visit us at www.ictktn.org.uk and join for free

The ICT KTN brings together the former Digital Communications and Digital Systems KTNs.

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Digital Communications
+
Knowledge Transfer Network
Digital Systems
=
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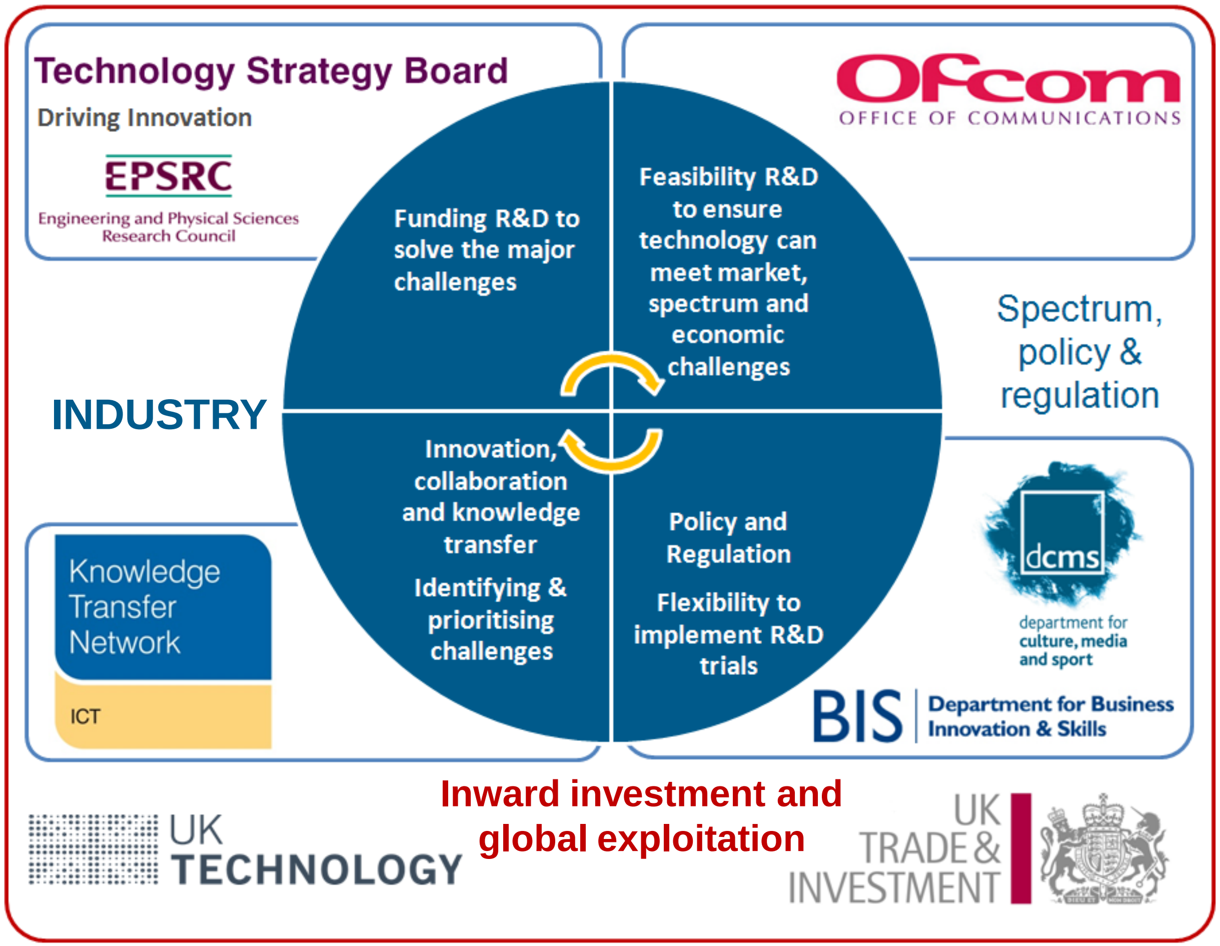
UK Critical Infrastructure:
Drive UK societal and economic value through globally exploitable UK innovation



ICT the 21st century utility !

Working group 2012 priorities

- **Spectrum usage: Wireless WAN & LAN below 6GHz Key technologies**
  - Efficiency and best use, taking into account: Energy, Size, Cost and Spectral efficiency
  - How to control and manage usage (inc. interference and coexistence).
  - Cost and economies of scale – how to leverage at continent level (Europe minimum).

- **Mapping technology capability, co-existence, interference issues and timescale.**
  - <1GHz innovation, DTG LTE test bed, deployment, interference and co-existence challenges
  - RF Front End Technology challenge. Including new materials.
  - Future spectrum release. Issues arising from the release of new spectrum supporting the 500MHz of Spectrum by 2020 initiative.
  - Spectrum sharing, management and trading. Technology and deployment challenges, secondary use / dual use of spectrum inc white Space, cognitive radio, spectrum management and trading.

https://ktn.innovateuk.org/web/spectrum

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Presentation themes

- Importance of radio link quality
- Picking the right trade offs
- Challenge, the landscape is changing, we need radical new ideas, approaches, materials or do we carry on with conventional radio evolution?

Material used

- Wireless Technology & Spectrum group papers developed by industry.
  - Digital Dividend – a great example to use and learn from
  - Radio Technology challenges

Papers available, join for free
https://ktn.innovateuk.org/web/spectrum

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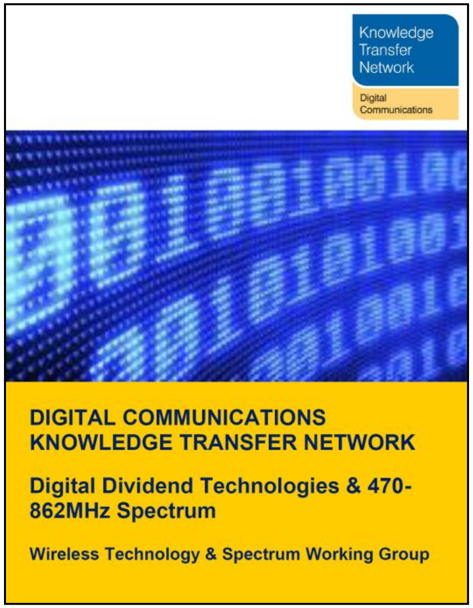
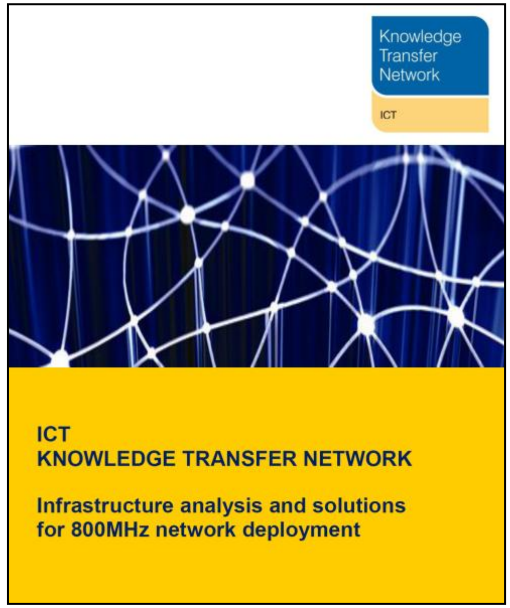
Three reports -> Innovation test bed



June 2010



May 2011

August 2011

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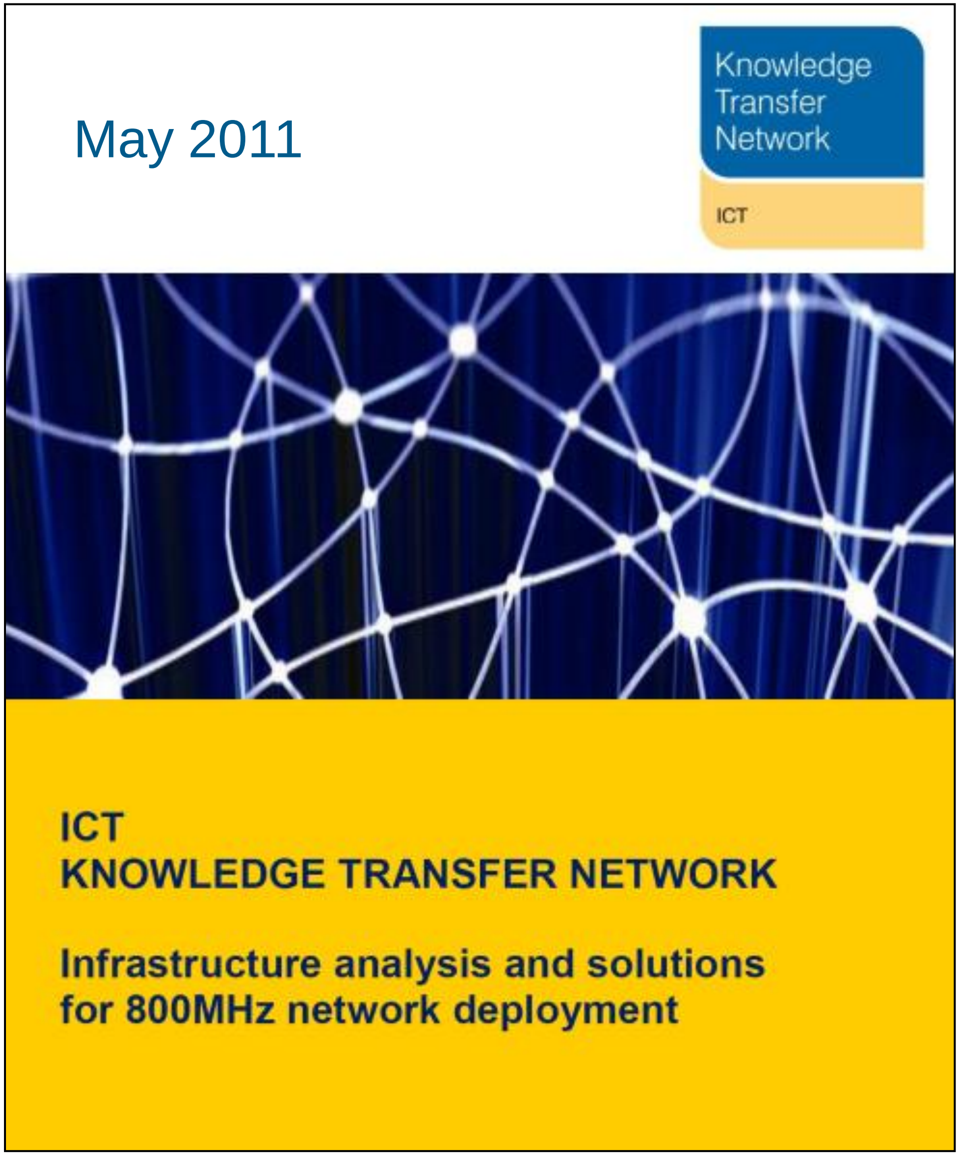
800MHz coverage



May 2011

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Infrastructure analysis and solutions for 800MHz network deployment

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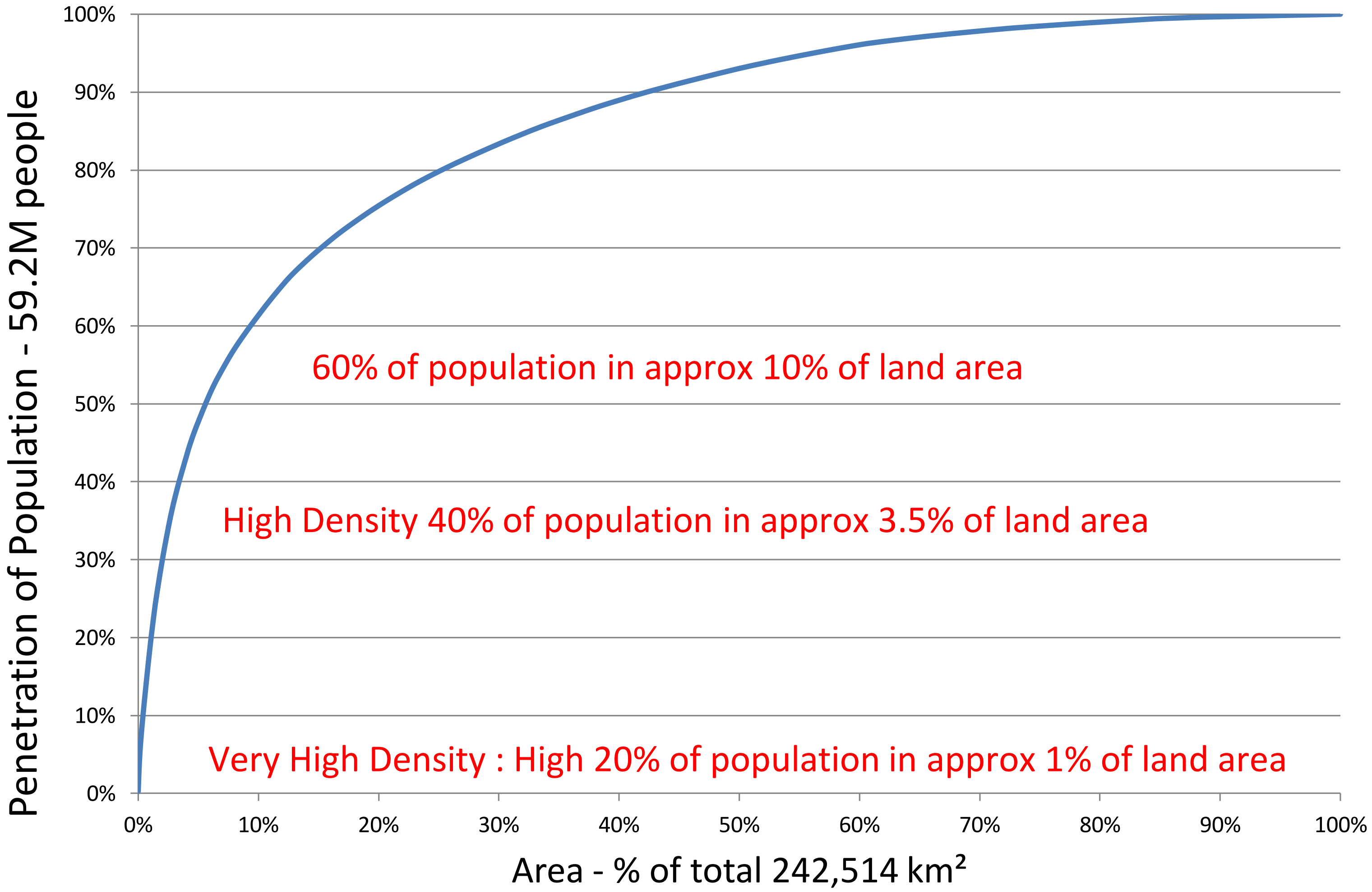
% of Population penetration 'v' Area (Sq kms) of UK



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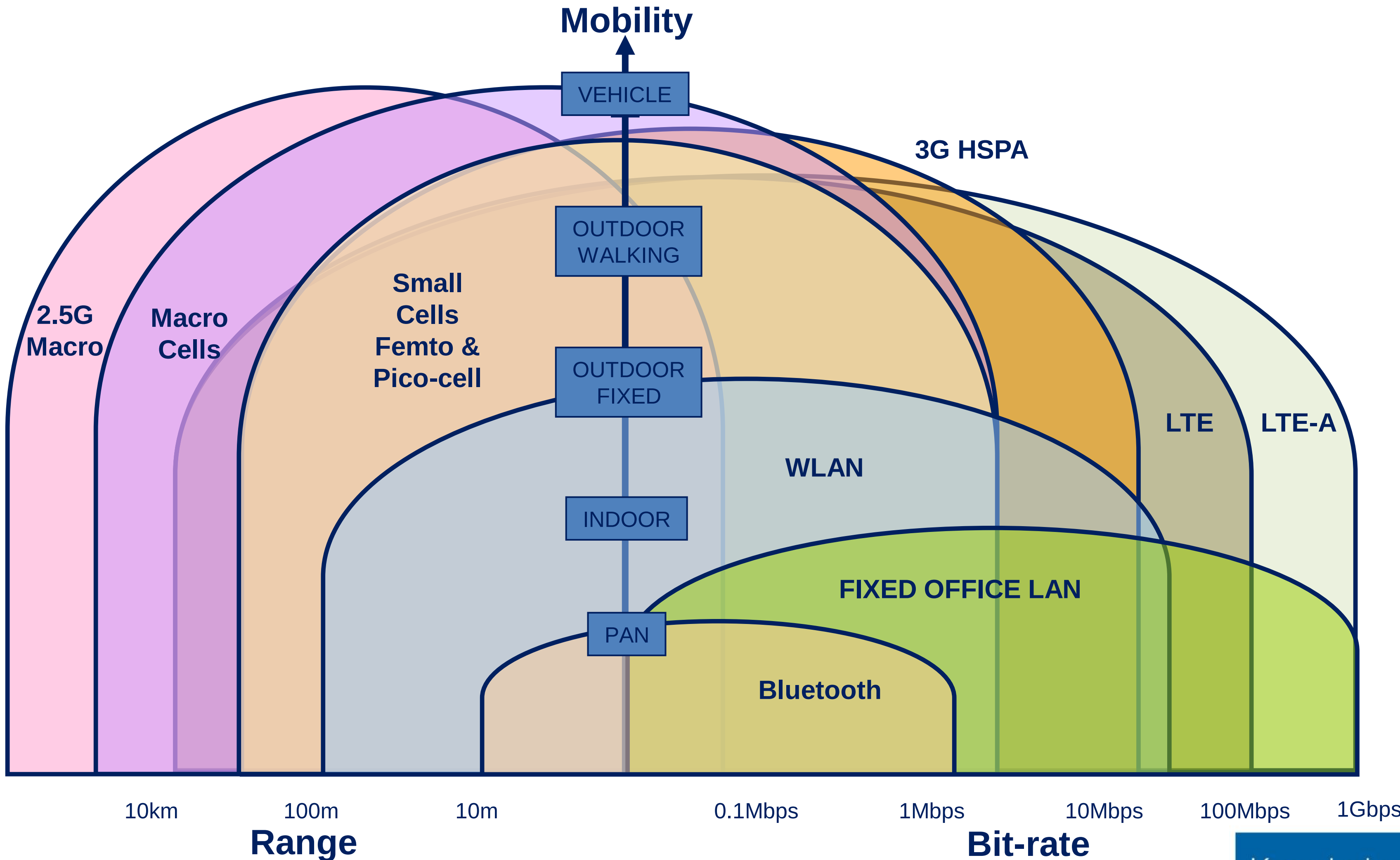
Mobile Technology Landscape Range ‘v’ Mobility ‘v’ Data Rate



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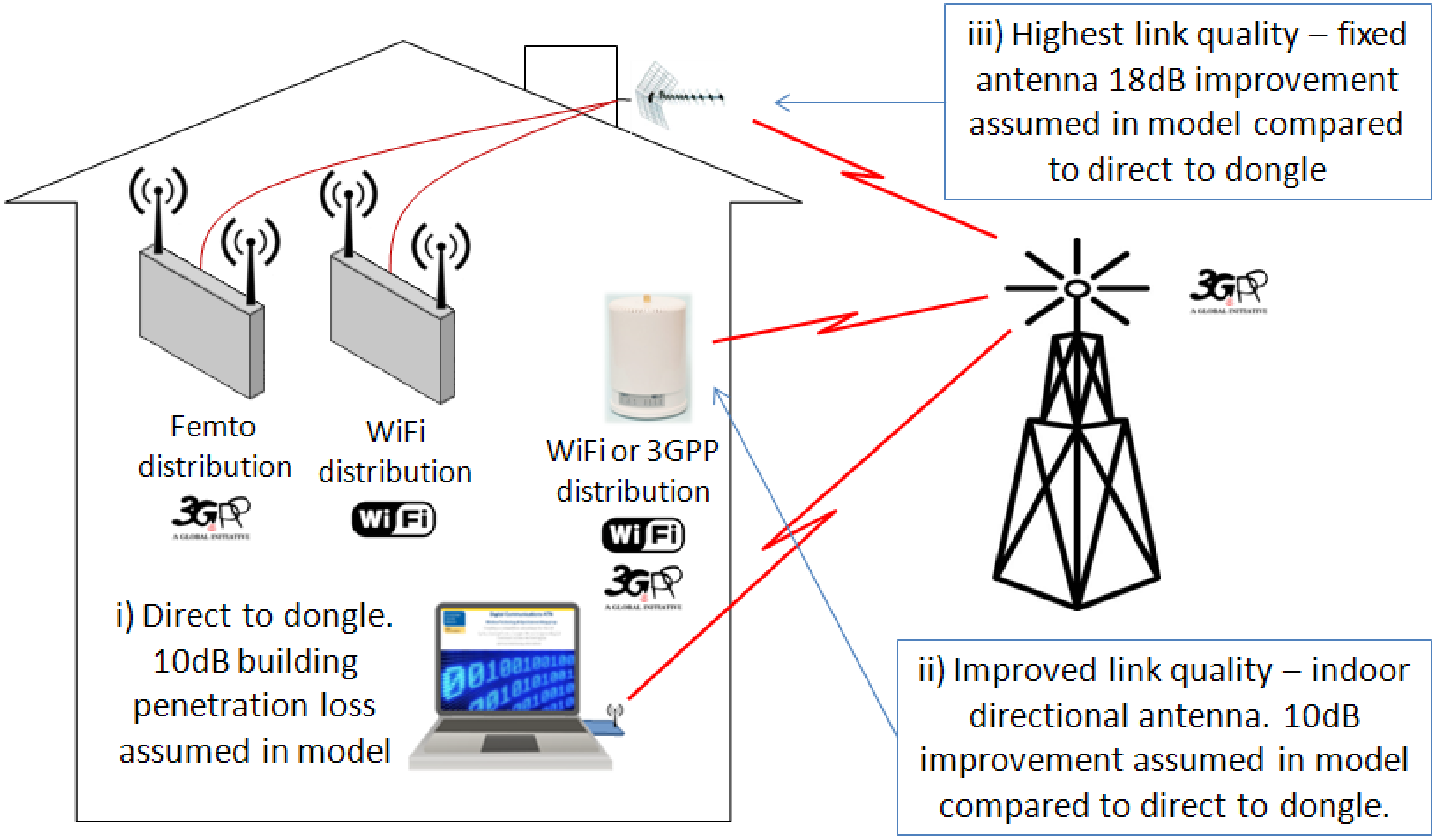
Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep ‘12

Link budget scenarios



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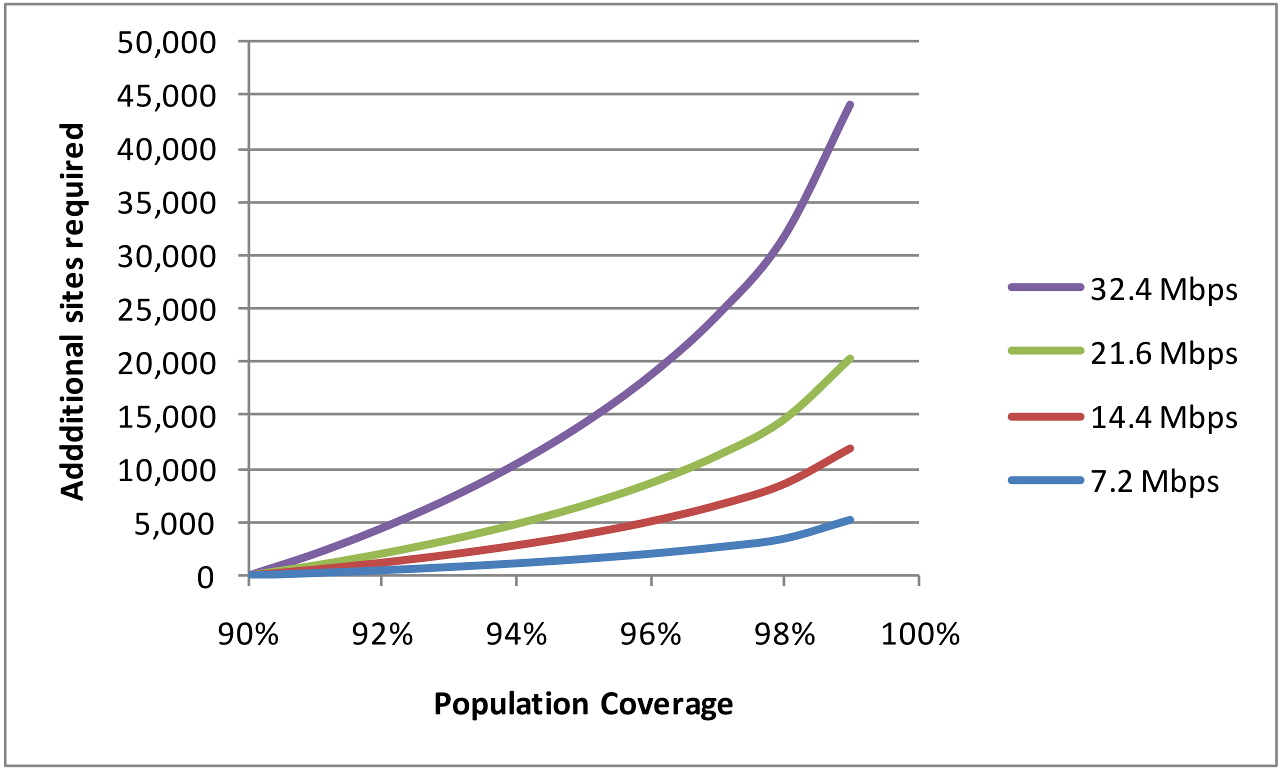
Additional base stations required for coverage expansion with USB dongle at 800 MHz (2 x 10MHz carrier)



In this scenario it is assumed that the terminal device has a zero gain antenna and that there is an average 10 dB building penetration loss. The rural cell size (radius) as a function of available peak bit rate is estimated to be as follows (based on a typical LTE link budget and COST-Hata propagation model)

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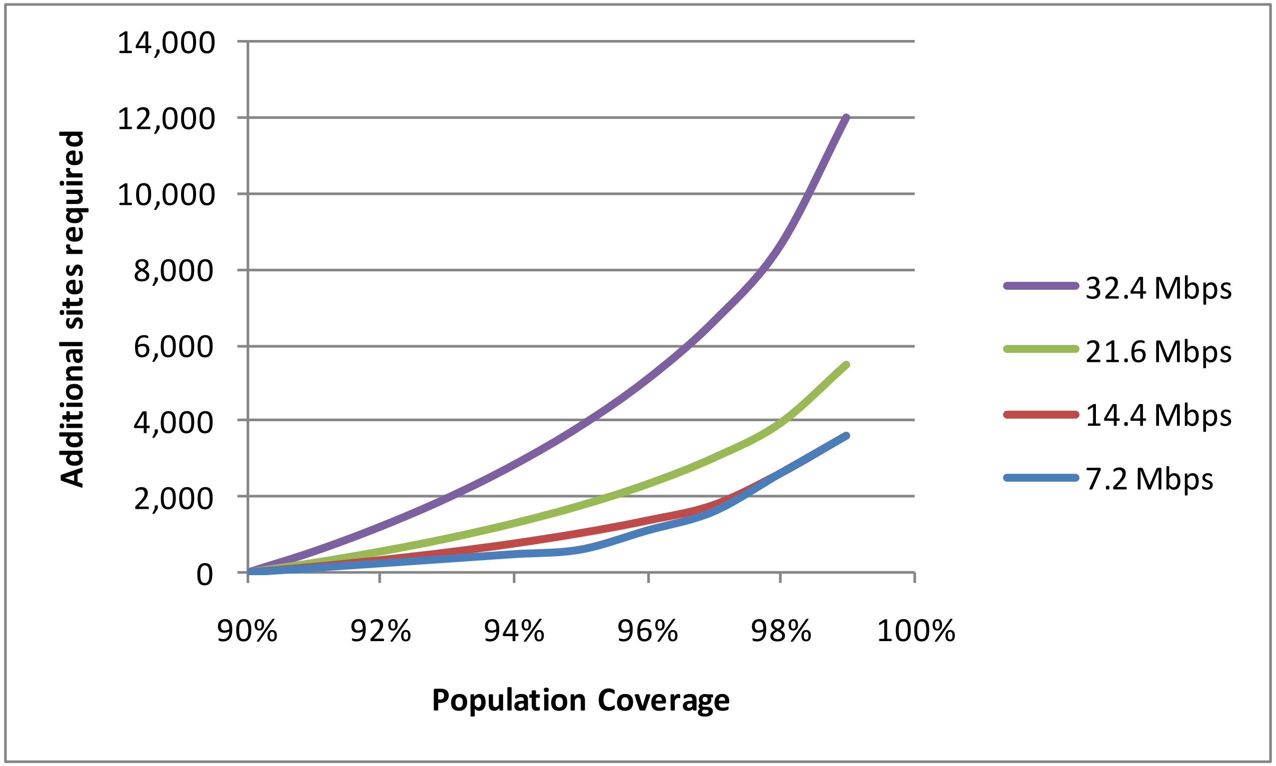
Additional base stations required for coverage expansion with desktop modem or signal booster at 800 MHz (2 x 10MHz carrier)



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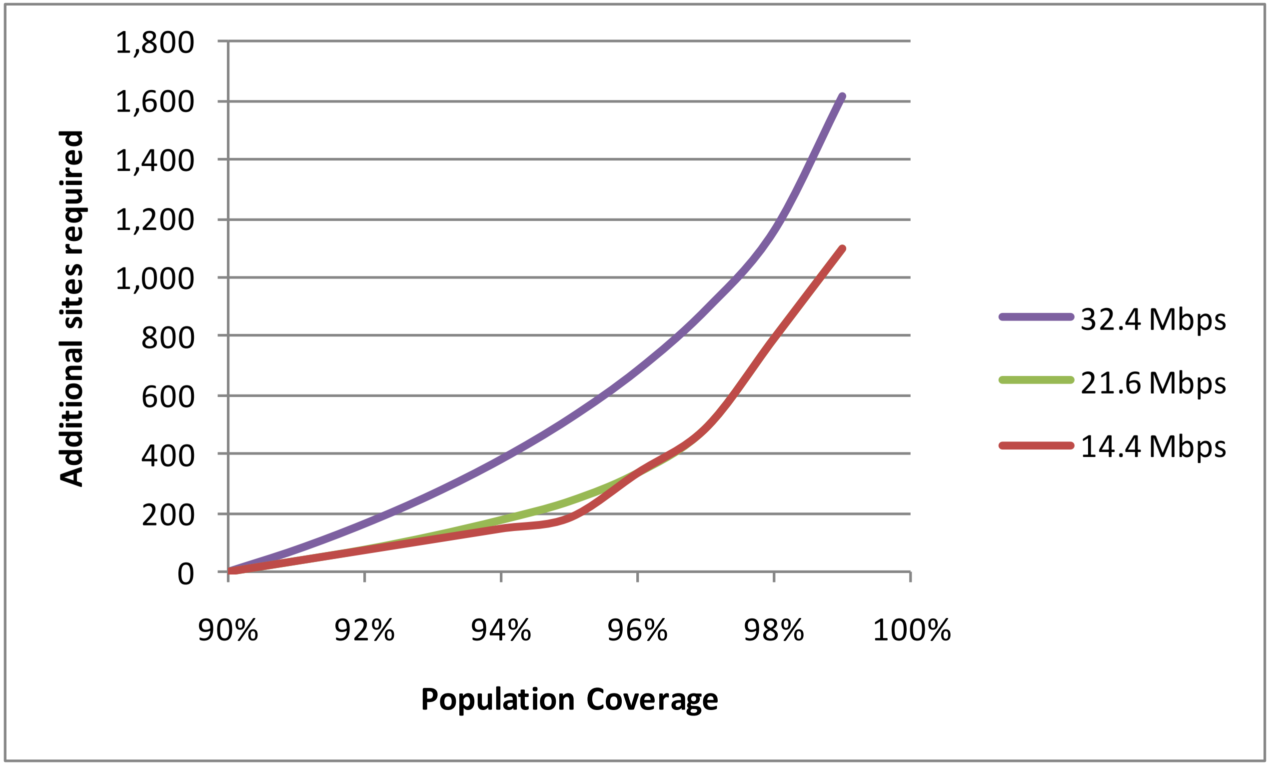
Additional base stations required for coverage expansion with external antenna at 800 MHz (2 x 10MHz carrier)



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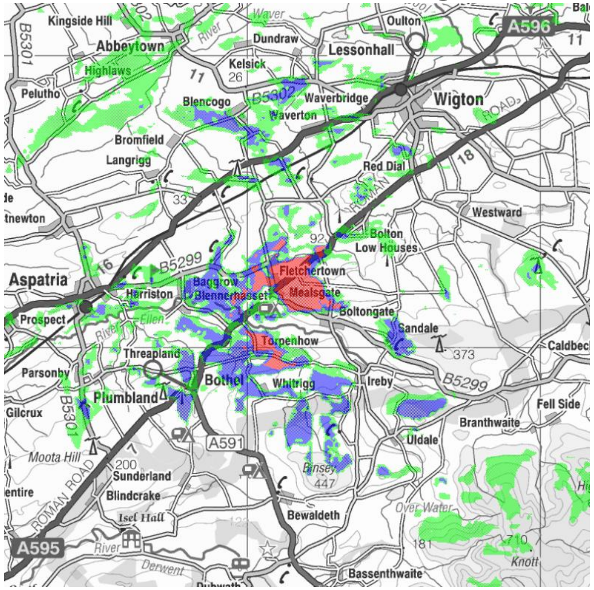
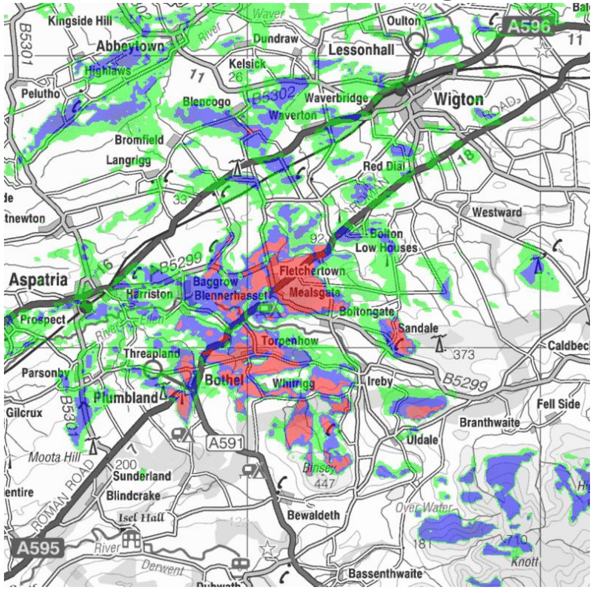
2 GHz indoor dongle

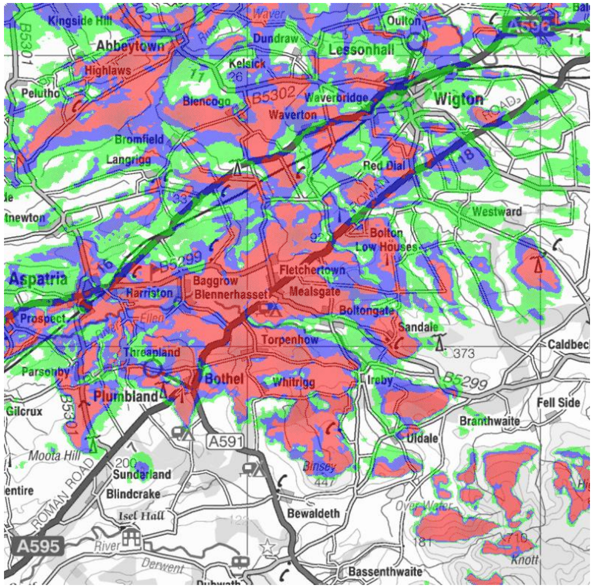


800 MHz indoor dongle

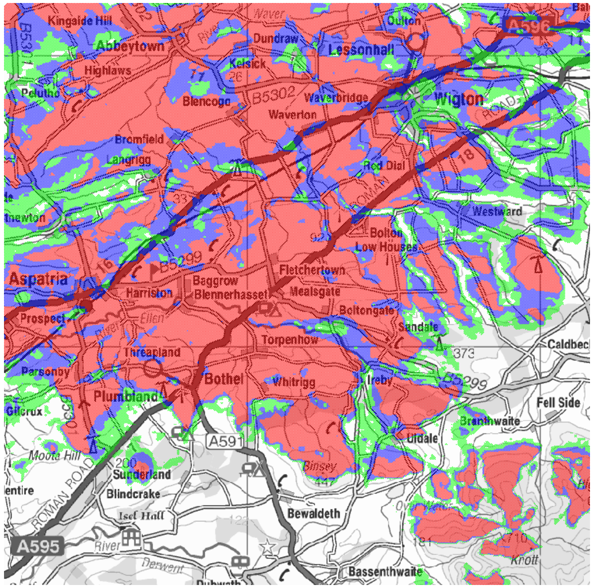


Typical coverage to indoor dongles

800 MHz indoor smart antenna



800 MHz external antenna (5 m)



Coverage improvement example using enhanced UE antennas

7.2 Mbps 14.4 Mbps 32.4Mbps

Source: Ofcom 'Sitefinder' Mobile Phone Base Station Database http://www.sitefinder.ofcom.org.uk/

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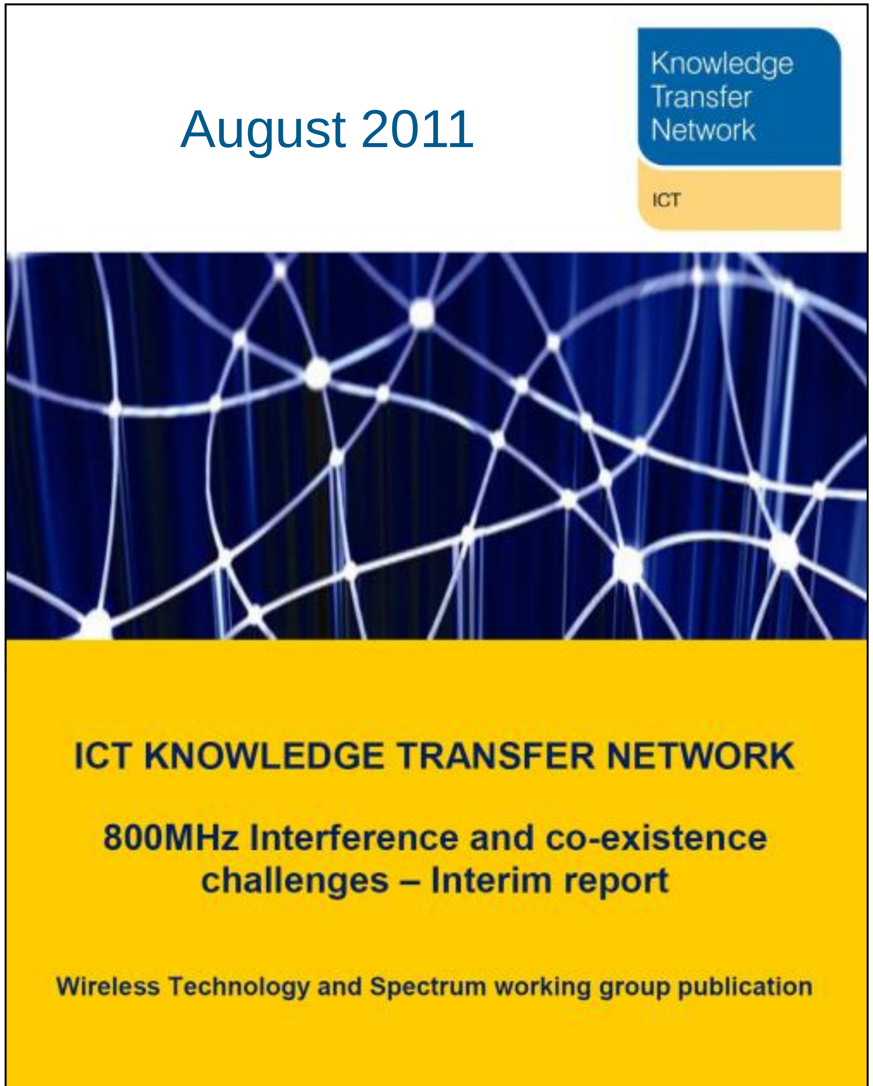
Interference and co-existence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800MHz Interference and co-existence challenges – Interim report

Wireless Technology and Spectrum working group publication

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Interference and co-existence matrix

Spectrum users		Potential Interferers: Cable (15-862MHz)	Cellular (791-862MHz)	Digital TV (470-790MHz)	Short Range Devices (863-870MHz)	PMSE (470-790MHz)
Services impacted	Cable (15-862MHz)		Yes – potential co-channel and on channel breakthrough into CPE	Close proximity to broadcast transmitter / repeaters	No interference	No interference
	Cellular (791-862MHz)	No interference		Yes – responsibility of Cellular to solve	Yes – potential adjacent channel interference and blocking	Yes, low probability – potential adjacent channel interference and blocking
	Digital TV (470-790MHz) Conventional Systems	No interference	Yes – Adjacent channel ch60 and image channels +9. Potential interference up to 100MHz away from Tx channel.		No interference	No – prevented through band / power management
	Digital TV (470-790MHz) Communal Antennas	No interference	Yes – same as conventional with potential increase dues to higher amplification stages and antenna gain / height.		No interference	No – prevented through band / power management
	Short Range Devices (863-870MHz)	No interference	Yes - Potential adjacent channel interference and blocking	No interference		No Interference
	PMSE (470-790MHz)	No interference	Yes - Potential adjacent channel interference and blocking	No – prevented through band / power management	No interference	

Co-existence and interference challenges

Existing services:

1. Broadcast Television – Digital TV (470-862MHz, Ch60)
2. Communal Antenna Systems (distribution of terrestrial broadcast to multiple dwellings)
3. Cable Television and home media consumer platforms 15-862MHz
4. Short Range Devices (Adjacent band 863-870MHz, e.g. social alarms)
5. PMSE applications (e.g. wireless microphones, in-ear monitors)

The challenges and opportunities this represents, provides the UK with some significant opportunities for our R&D community to address locally and benefit through global exploitation.

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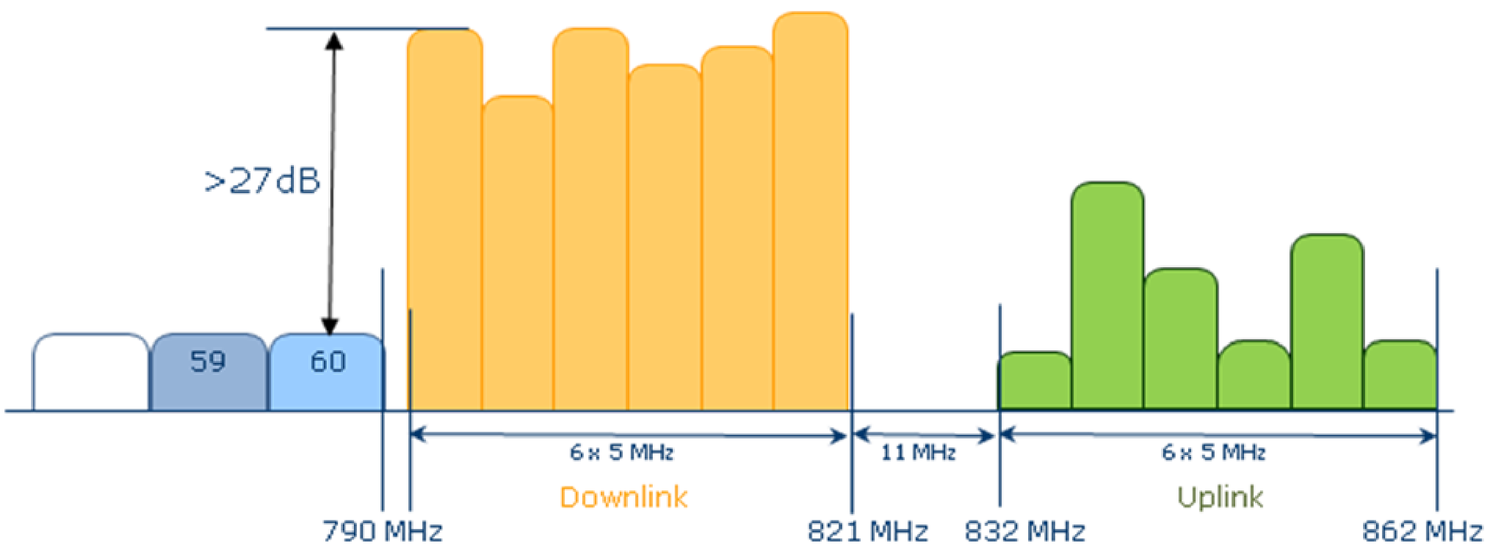
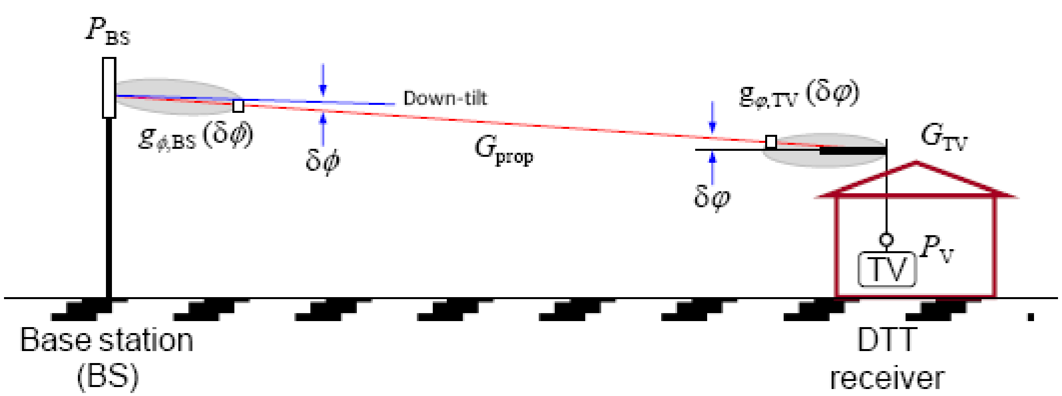
LTE-800 Base station (BS) interference to DTT CH60

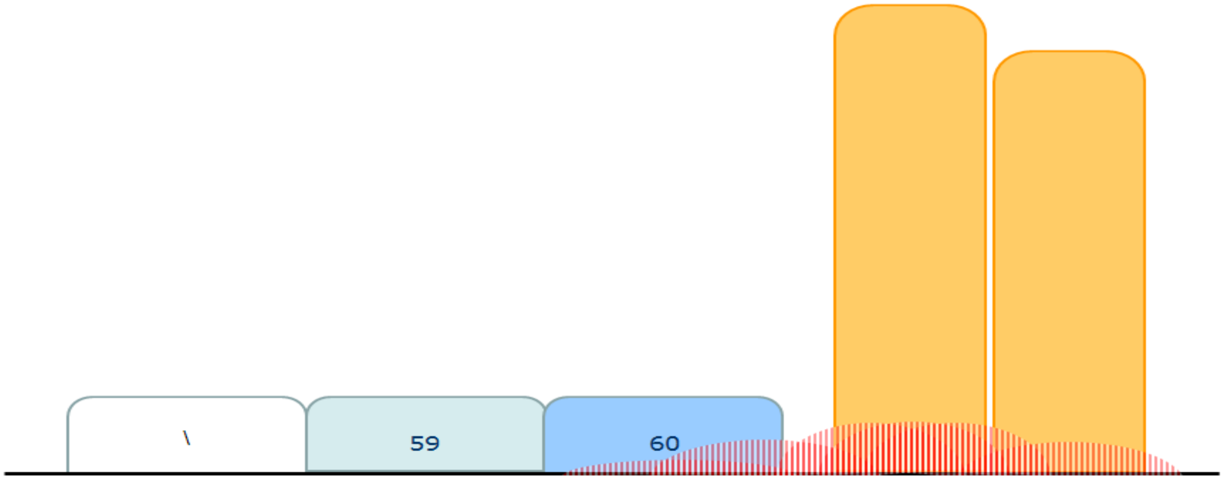


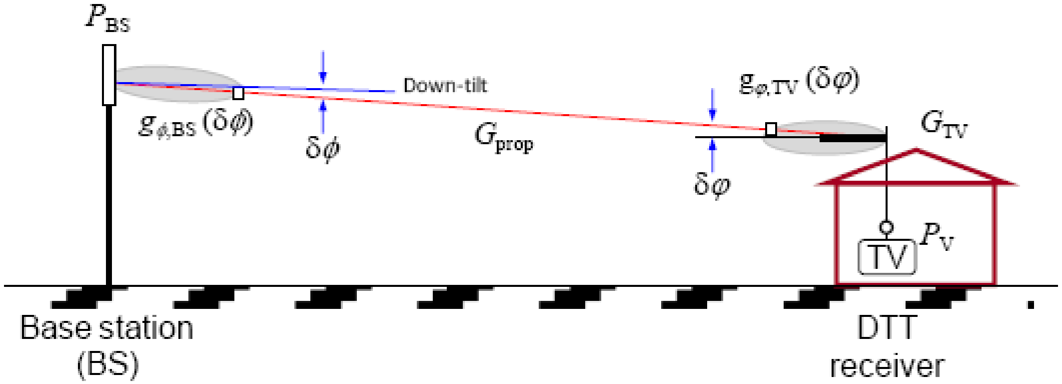


Geometry of base station to TV radio link.

Source: Ofcom Technical workshop 5/7/11

LTE base station OOB causing interference to DTT CH60





Geometry of base station to TV radio link.

Source: Ofcom Technical workshop 5/7/11

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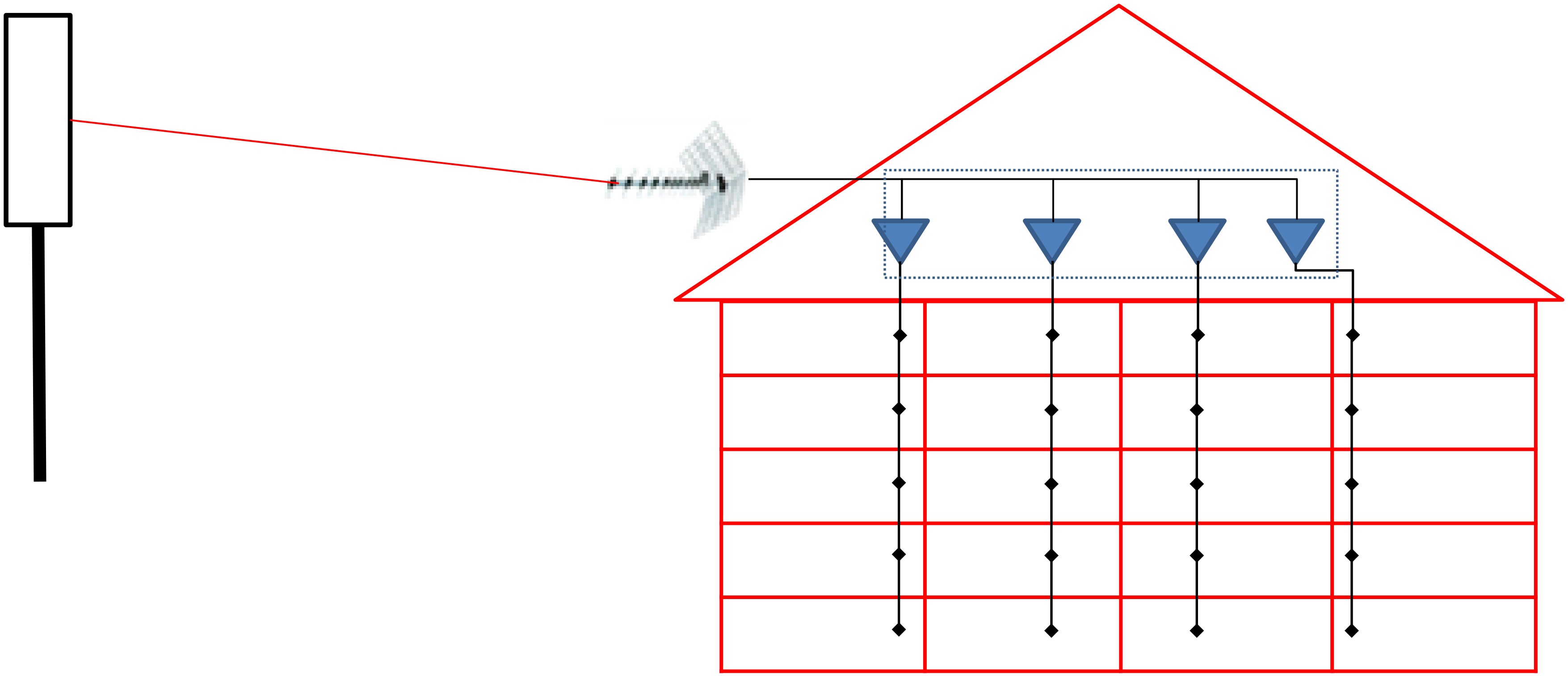
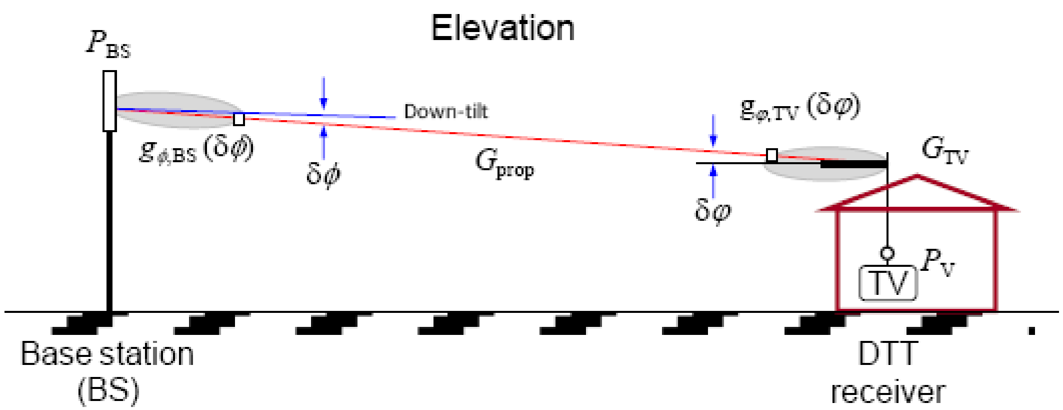
Communal aerials



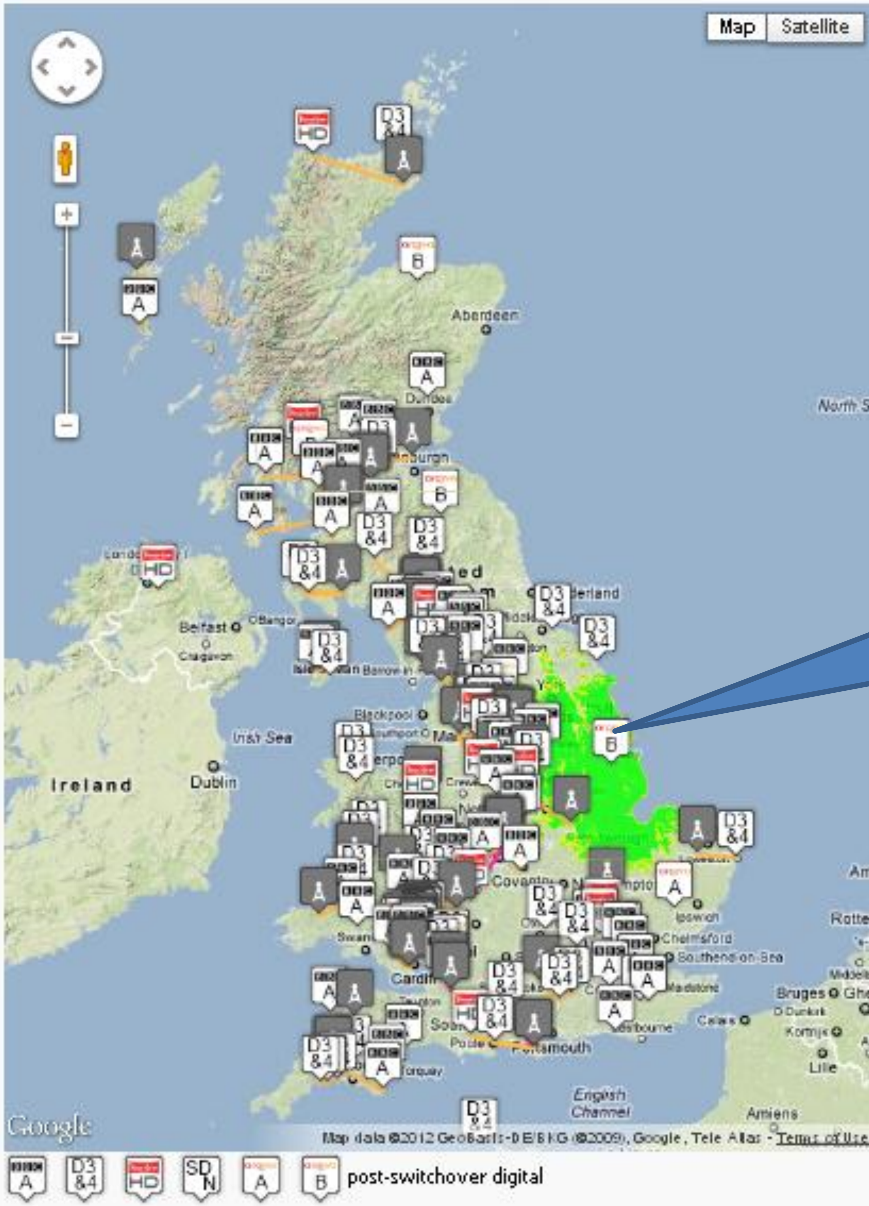


Geometry of base station to TV radio link.

Source: Ofcom Technical workshop 5/7/11

UK TV Frequency map - channel C60 (786.0MHz) after switchover

The map below shows all the transmitters in the UK using C60 once digtial switchover is complete. Please click the icon to see the coverage area, and double click for more information.



Ch 60 UK TV Frequency Map

Single TX coverage area indicated in green

Source : http://www.ukfree.tv/mapsofsignal.php?c=60&a=1

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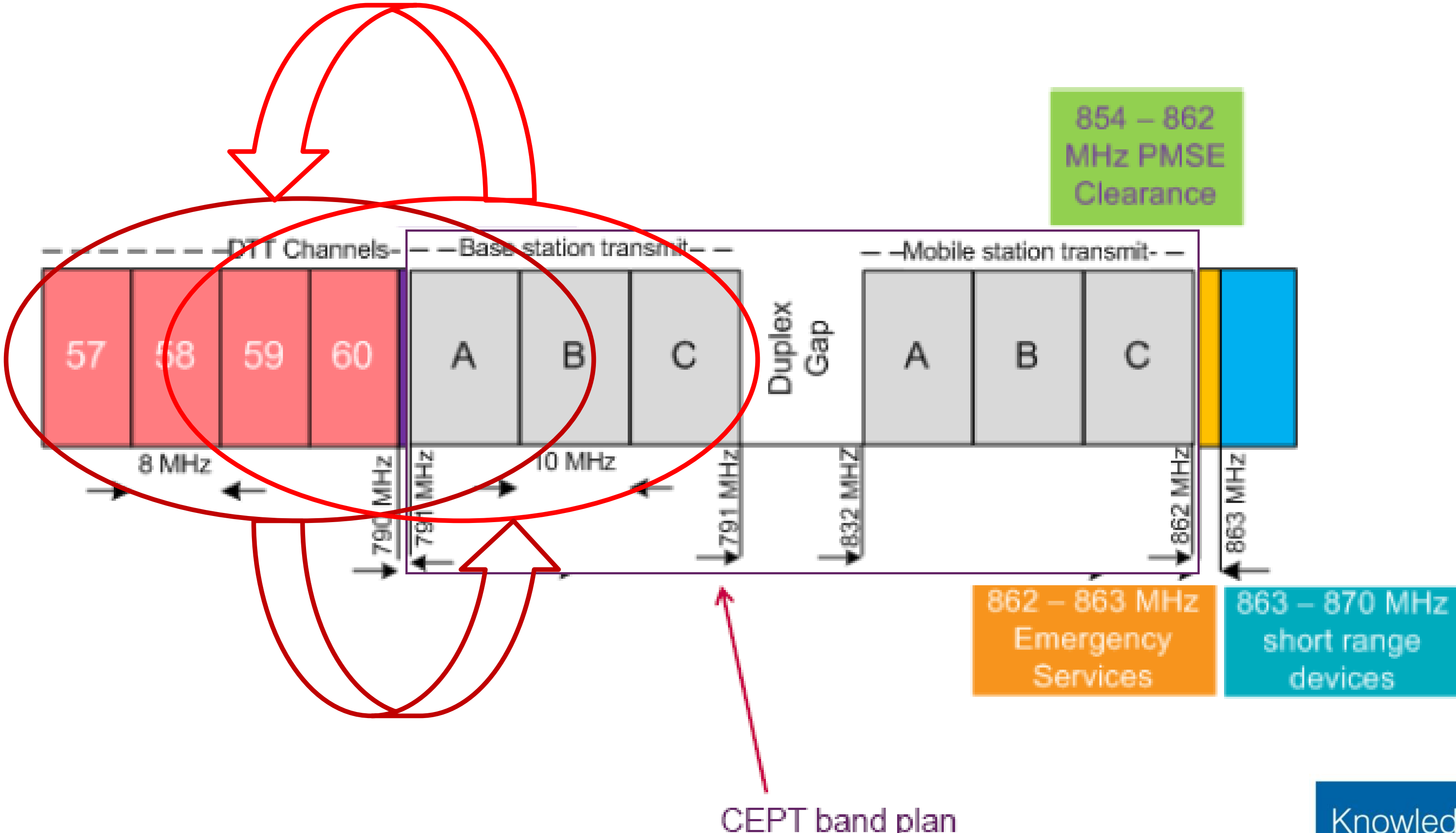
800MHz Spectrum plan



DTT: Digital terrestrial television
PMSE: Programme-making and special events

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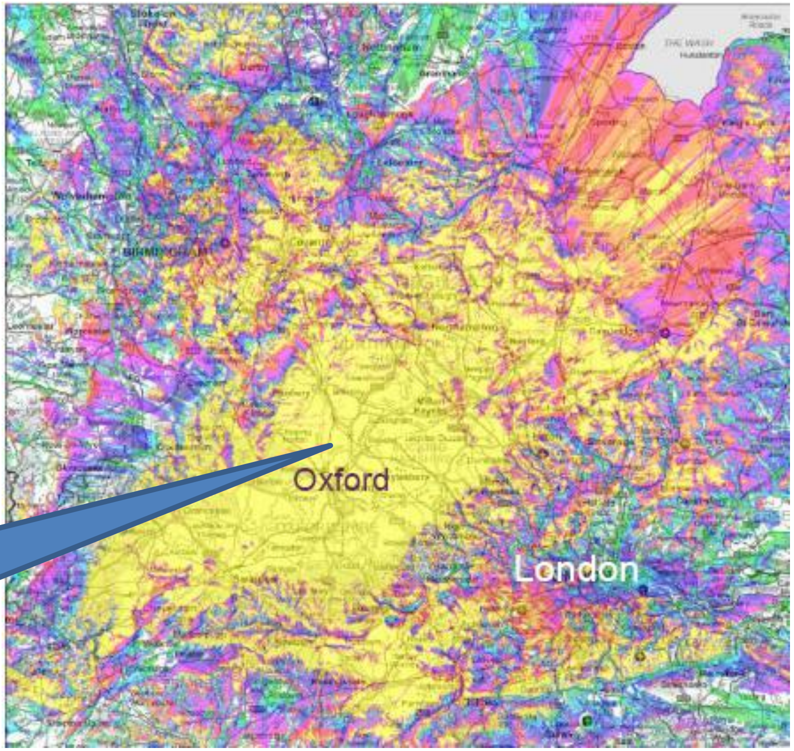
Co-channel interference between adjacent areas

The emergent DTT clearance plan proposes that DTT clearance programme will take place on a site by site basis through 2013



Field strength key

Colour	Field Strength (dBµV/m)	
White	< 10	
Dark green	10 – <13	
Bright green	13 – <16	
Teal	16 – <19	
Cyan	19 – <22	
Blue	22 - <25	
Navy	25 – <28	25 = 1dB desensitisation noise limited
Violet	28 – <31	28 = 1dB desensitisation interference limited
Magenta	31 – <34	31 = 3dB desensitisation noise limited
Red	34 – <37	34 = 3dB desensitisation interference limited
Orange	37 – <40	>3dB desensitisation
Yellow	≥40	>3dB desensitisation

Potential impact of DTT on LTE

1) Co-channel interference from the remaining high power DTT services into any LTE services operating in adjacent regions

2) Co-channel interference from any LTE deployment affecting the reception of DTT services in the remaining pre clearance areas

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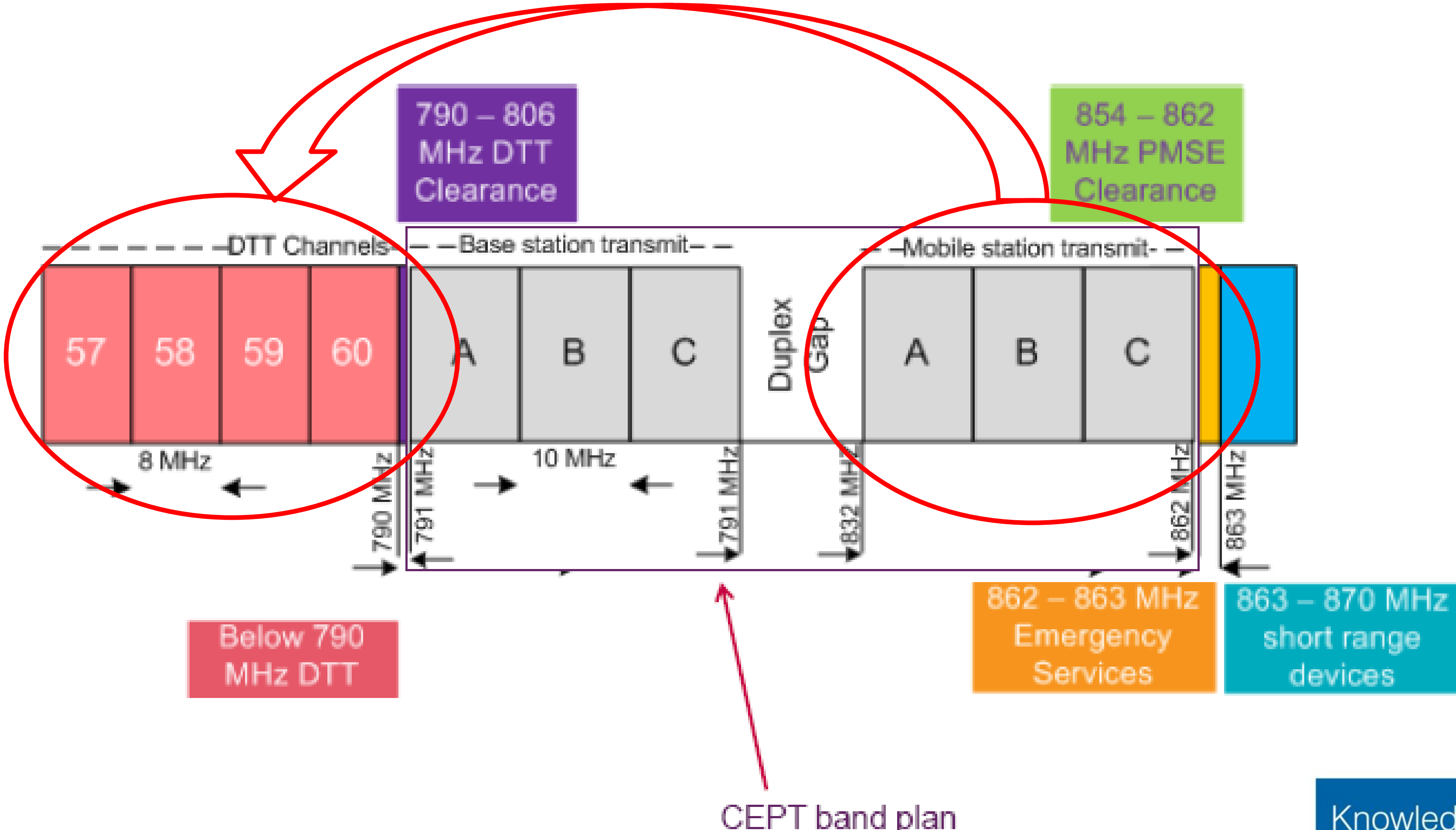
Do you ever watch TV at home and go on the internet at the same time?

Source: Ofcom Understanding International Communications Behaviour research, October 2008
Base: All adults aged 18+ who use the internet (UK 1001, France 1000, Germany 1002, Italy 1003, USA 1010, Canada 1000, Japan=1003)
Note: As the questionnaire was answered online it may not reflect the attitudes of a representative sample of the whole population

Nielsen:
40 Percent of People Use Smartphones, Tablets While Watching TV

Source: http://www.pcmag.com/article2/0,2817,2394619,00.asp

800MHz Spectrum plan



DTT: Digital terrestrial television
PMSE: Programme-making and special events

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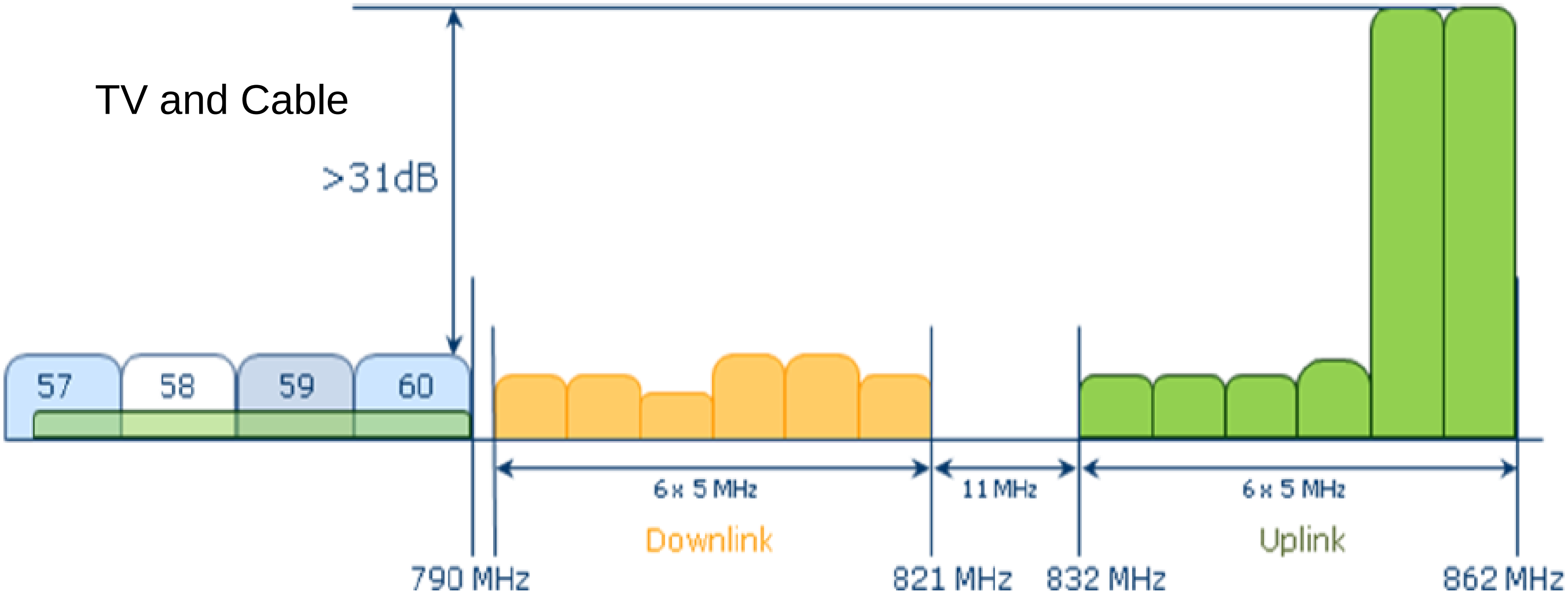
LTE handset (UE) interference to DTT CH57-60

TV and Cable



72MHz offset from the wanted DTT channel can produce picture break up.

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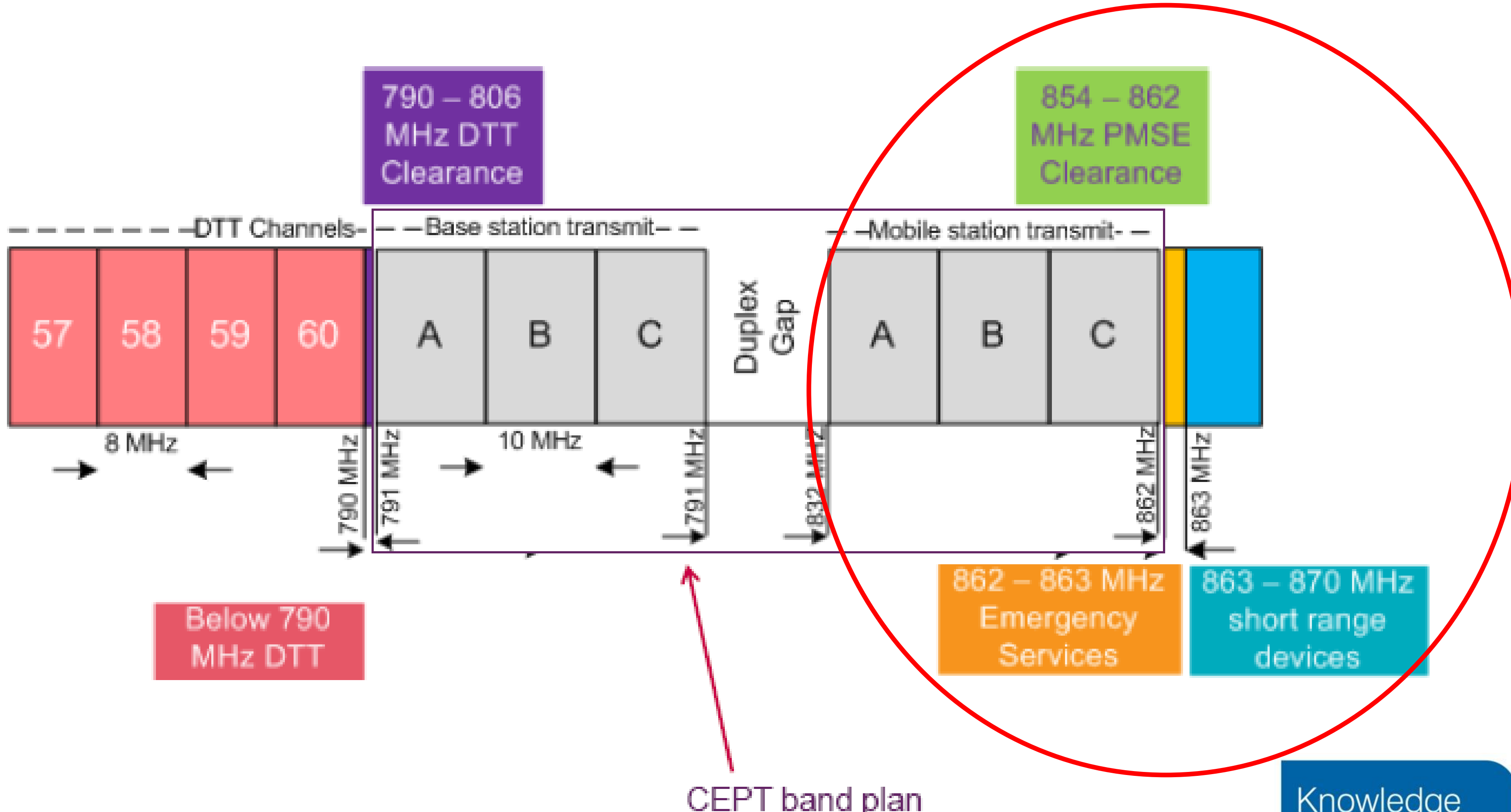
800MHz Spectrum plan



DTT: Digital terrestrial television
PMSE: Programme-making and special events

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800MHz Interference and co-existence challenges: Innovation priorities proposal

Spectrum users		Potential Interferers: Cellular (791-862MHz)	Potential Interferers: Short Range Devices (863-870MHz)	Potential Interferers: White Space (470-790MHz)
Services impacted	Cable (15-862MHz)	Yes – potential co-channel and on channel breakthrough into CPE	No interference	Yes – White Space devices in close proximity to Home STB
	Cellular (791-862MHz)		Yes – potential adjacent channel interference and blocking	Yes - potential issue around 790MHz adjacent channel
	Digital TV (470-790MHz) Conventional Systems	Yes – Adjacent channel ch60 and image channels +9. Potential interference up to 100MHz away from Tx channel.	No interference	Yes – Geo-location and sensing to control access
	Digital TV (470-790MHz) Communal Antennas	Yes – same as conventional with potential increase dues to higher amplification stages and antenna gain / height.	No interference	Yes – Geo-location and sensing to control access . Could be worse…. Need to take account analogue distribution systems
	Short Range Devices (863-870MHz)	Yes - Potential adjacent channel interference and blocking		No interference
	PMSE (470-790MHz)	Yes - Potential adjacent channel interference and blocking	No interference	Yes – Geo-location and sensing to control access

Wireless TIC LTE Test bed

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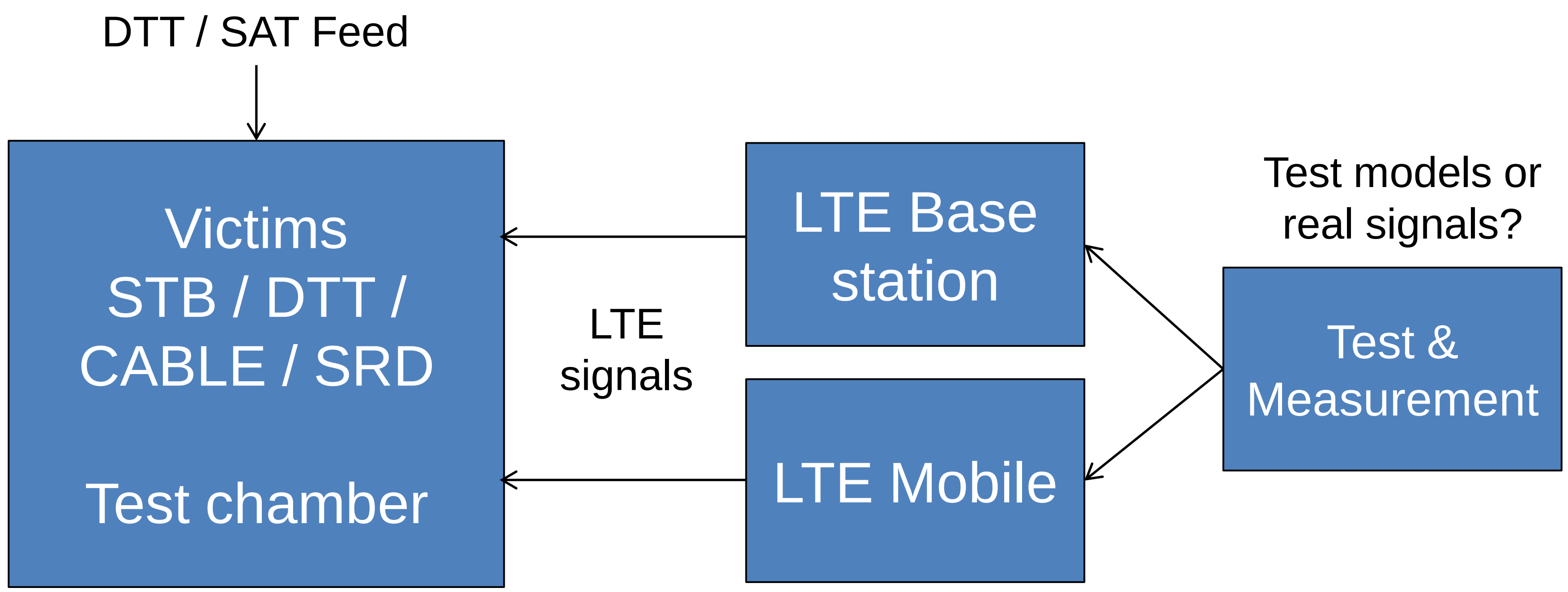
Wireless TIC



<u>Innovation opportunities</u>
- Victim solutions
- Transmitted signal (Mobile & BS)
- Terminal radiation
- Signal loading innovation – establish worse case LTE signals to avoid

<u>Test and measurement</u>
- Mobile test model
- BS test model
- Industry standard models

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Wireless TIC
Facilities – Vauxhall, London

GTEM Cell in basement

Zoo – multiple kit feeds

Signals can be patched between the two ⟷

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DTG LTE Test bed – Innovation opportunities

Short term

- Base station
  - Transmitter mask / filters / OOB
  - Antenna
  - Radio planning
- UE and Base station - L2 MAC and scheduling
- Radio planning: co-operative, cellular and broadcast
- Home / CPE
  - Antennae
  - Amplifiers
  - Filters
  - Cables
  - Connectors

Longer term

- Collaborative CPE
- Collaborative networks
- Shared infrastructure
- White Space innovation
- New spectrum allocation… 700MHz

ICT knowledge transfer network and Cambridge Wireless joint positioning paper

RF Front-End Technology Challenges

September 2012

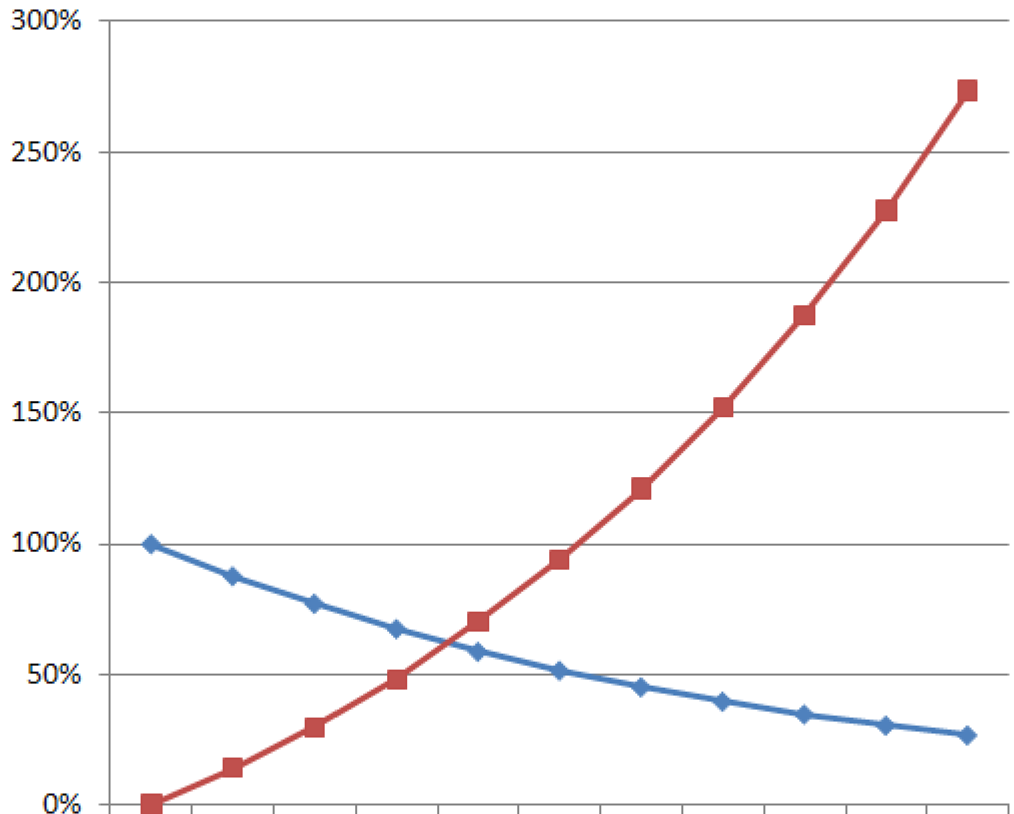
Radio performance is important:

1dB loss = 14% more sites

Pathloss [dB] = 10 n $\log_{10}$ (distance) + C

n=3.5 (typical value)

Distance $\propto 10^{(L/35)}$



Pathloss [dB] degradation	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10
Cell size area reduction	100%	88%	77%	68%	59%	52%	45%	40%	35%	31%	27%
Site Increase	0%	14%	30%	48%	70%	94%	121%	152%	187%	228%	273%

Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

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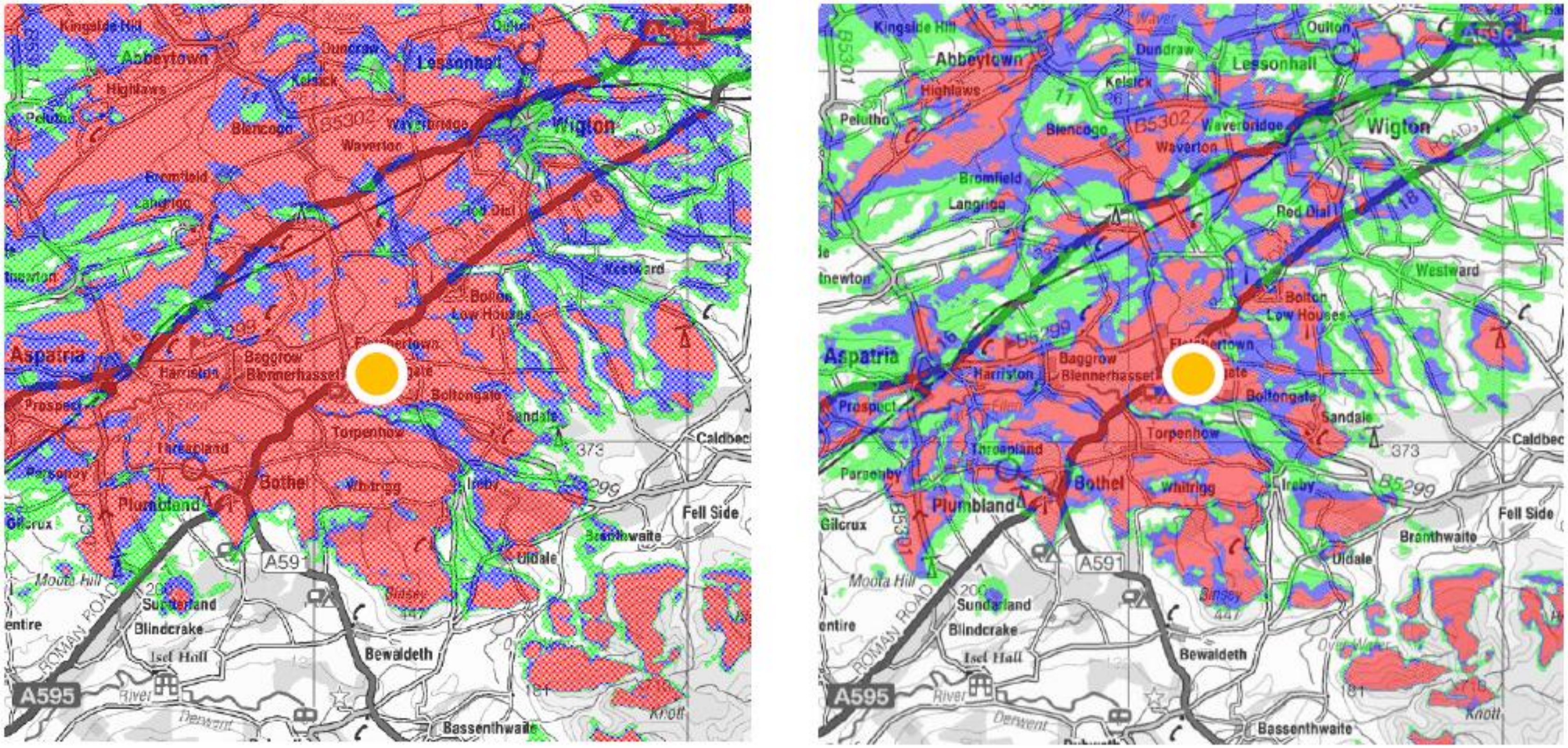
Radio performance is important:

Best case scenario | -8dB radio link degradation



7.2 Mbps | 14.4 Mbps | 32.4Mbps

Base station location | Note: white areas = no coverage

Figure 2 - Coverage degradation analysis through 8dB loss of radio link

Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

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E-UTRA Operating Band	Uplink (UL) operating band BS receive / UE transmit F_{UL_low}	–	F_{UL_high}	Downlink (DL) operating band BS transmit / UE receive F_{DL_low}	–	F_{DL_high}	Duplex Mode
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
Note 1: Band 6 is not applicable							

Table 1 - Current band plan table 3GPP TS 36 101 v10.4.0

Smart-phone system

Keyboard
Audio & Display
Applications Processor
Control Processing
Power Management
Memory / storage
Radio modem MAC (L2) & PHY (L1)

Radio: Multiple Bands / Multiple Air Interfaces

2G
3G / HSPA
LTE
GPS
Bluetooth
LTE - A
DAB
White Space
WLAN

Multiple Radio & Modem Technologies

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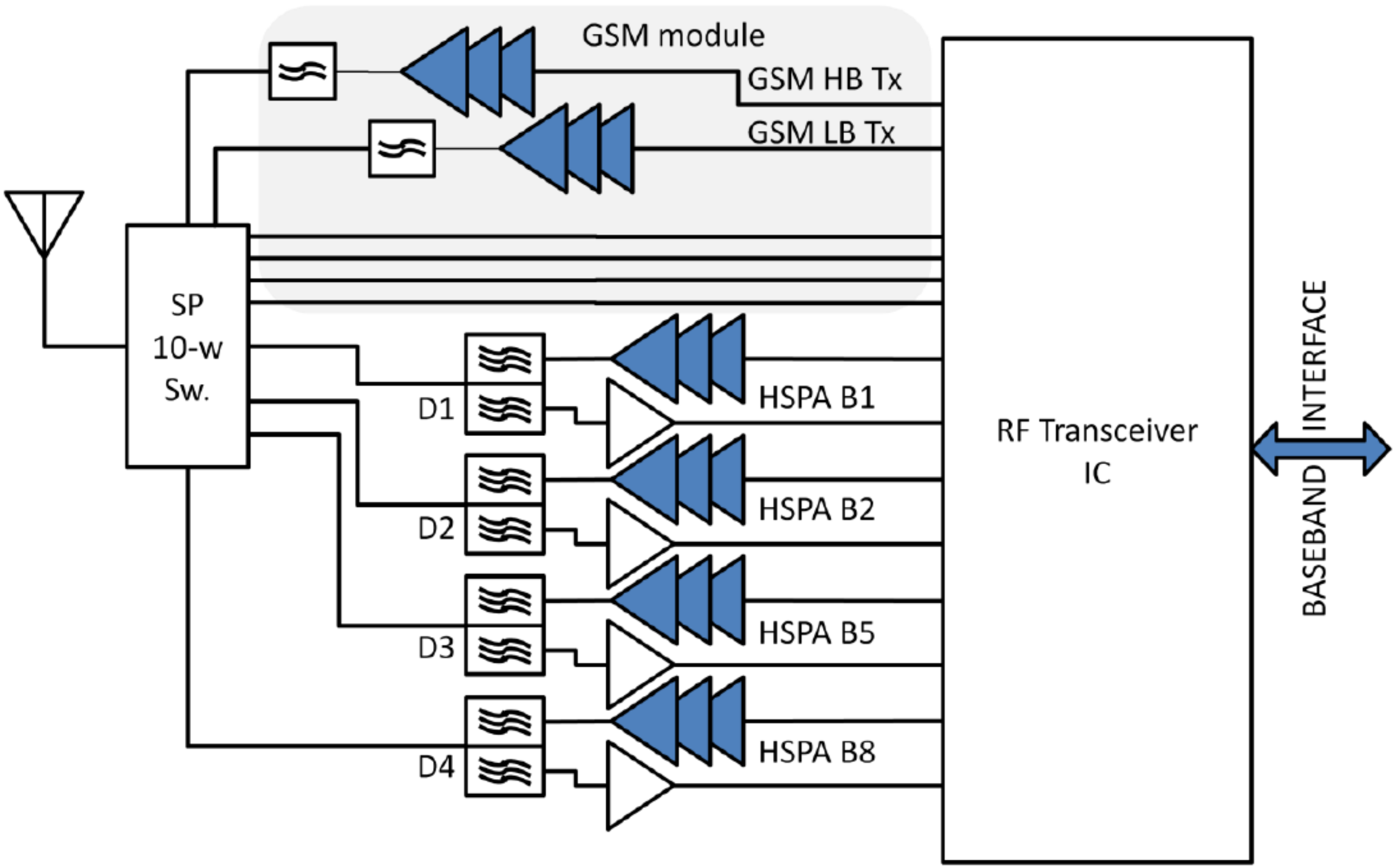
Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

Current Radio Design



Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

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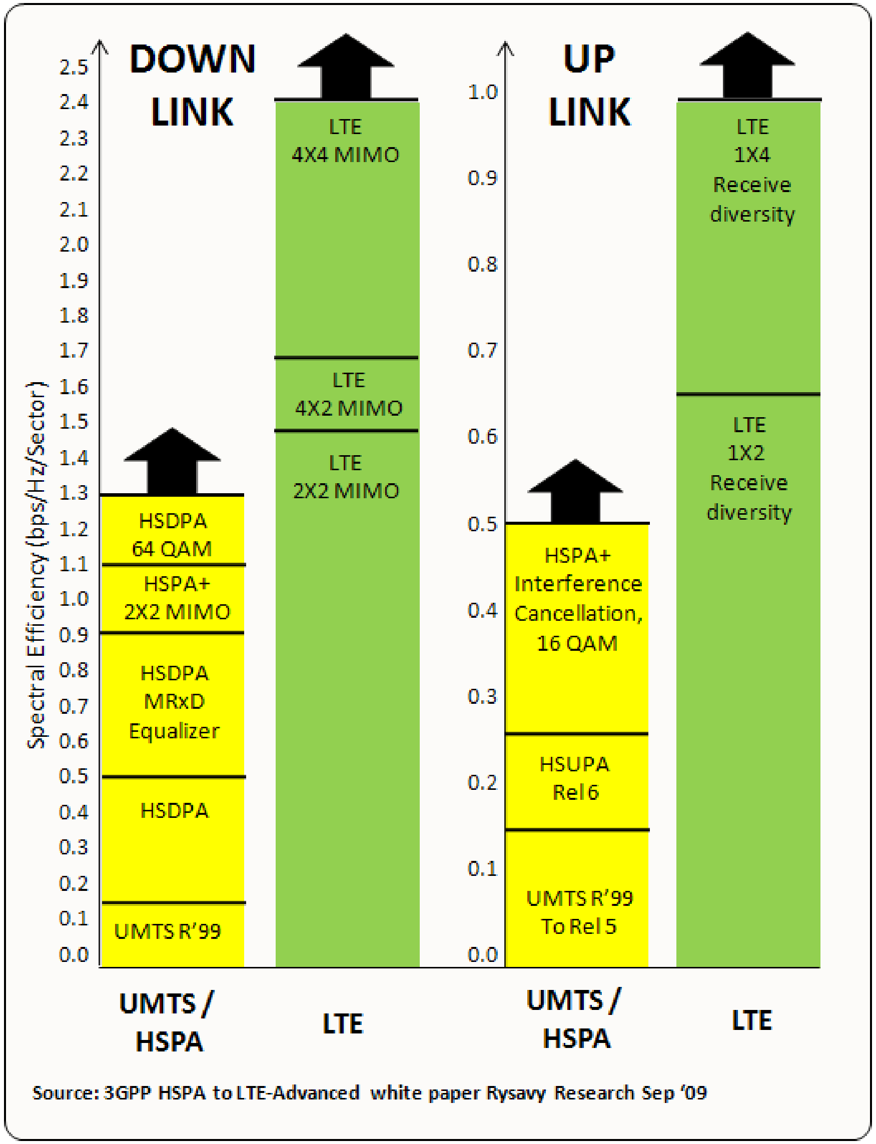
Comparison of Spectral efficiency



Comparison of downlink throughput and spectrum efficiency for various mobile data technologies

Technology	Throughput	RF bandwidth	Freq Re-use	Efficiency bps/MHz
GPRS*	115 kbps	200 kHz	12	48 k
EDGE*	240 kbps	200 kHz	12	100 k
UMTS R99*	750 kbps	5 MHz	1	150 k
HSDPA**	1.7 Mbps	5 MHz	1	340 k
HSPA+ **	4.2 Mbps	5 MHz	1	840 k
WiMAX**	11.3 Mbps	10 MHz	1	1.13M
LTE**	15 Mbps	10 MHz	1	1.5 M

Notes : *Qualcomm [1] **Vodafone [2]

Note that the assumed efficiency figures are typical and likely to depend on traffic being uniformly distributed around the cell.

[1] "HSDPA for Improved Downlink Data Transfer", white paper, 2004
[2] "Broadband through Wireless – the unfolding story of the mobile web", presentation by Prof. Michael Walker OBE FREng to Silicon South West Wireless 2.0 Conference, 2009

Source:
DCKTN Paper - Optimising Mobile Spectrum

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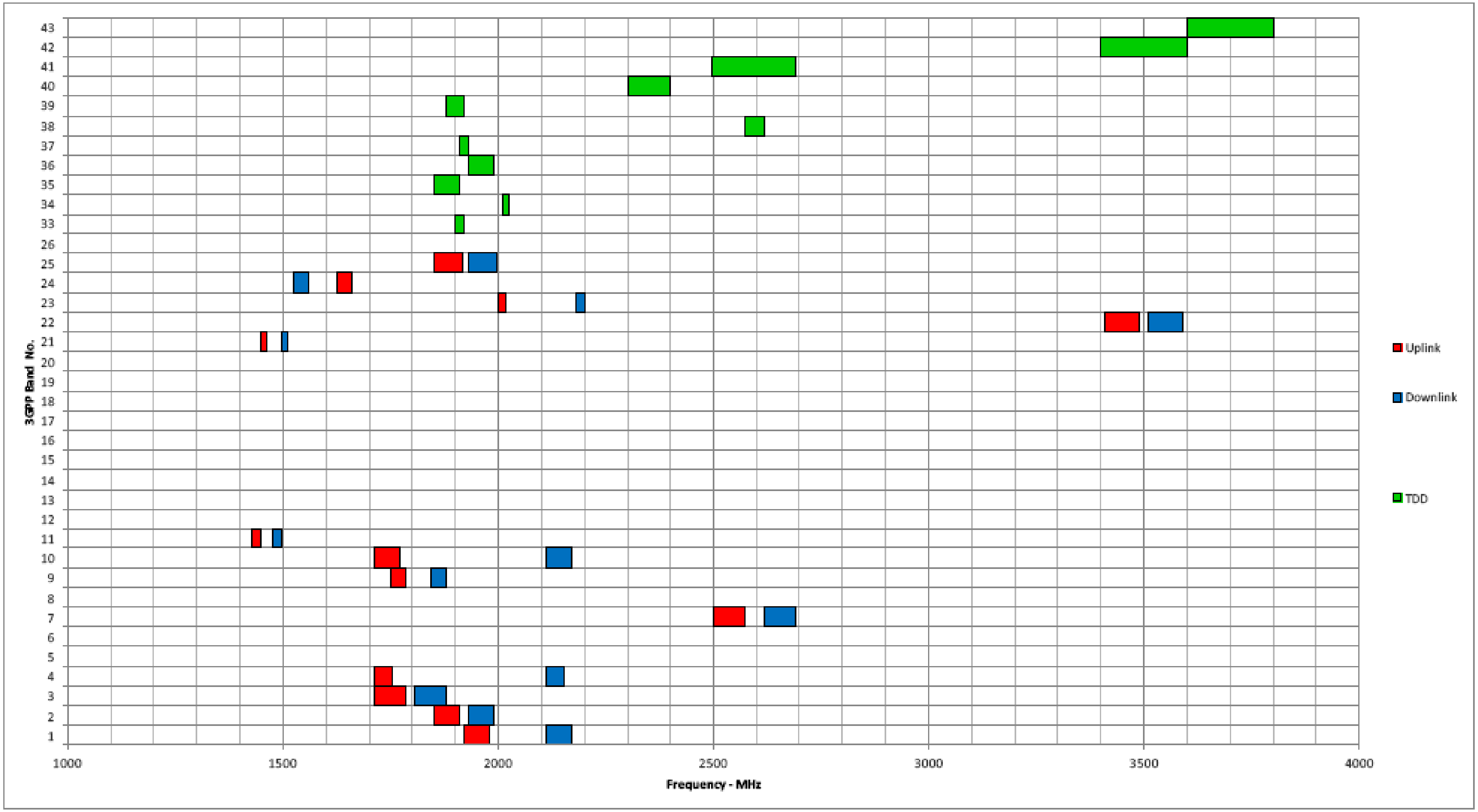
Graphical representation of 3GPP defined bands



Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

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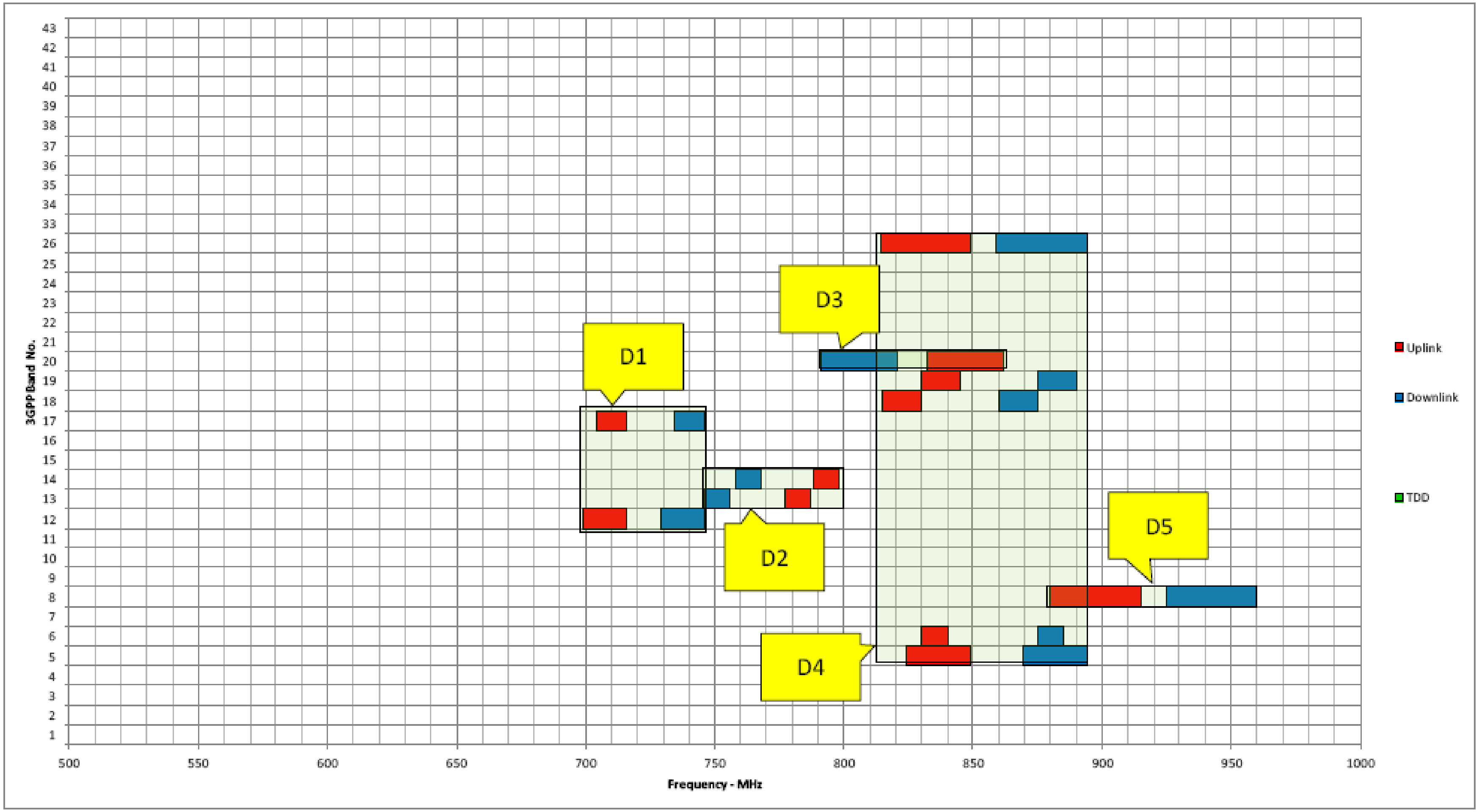
Reduced diplexer set for sub-GHz bands



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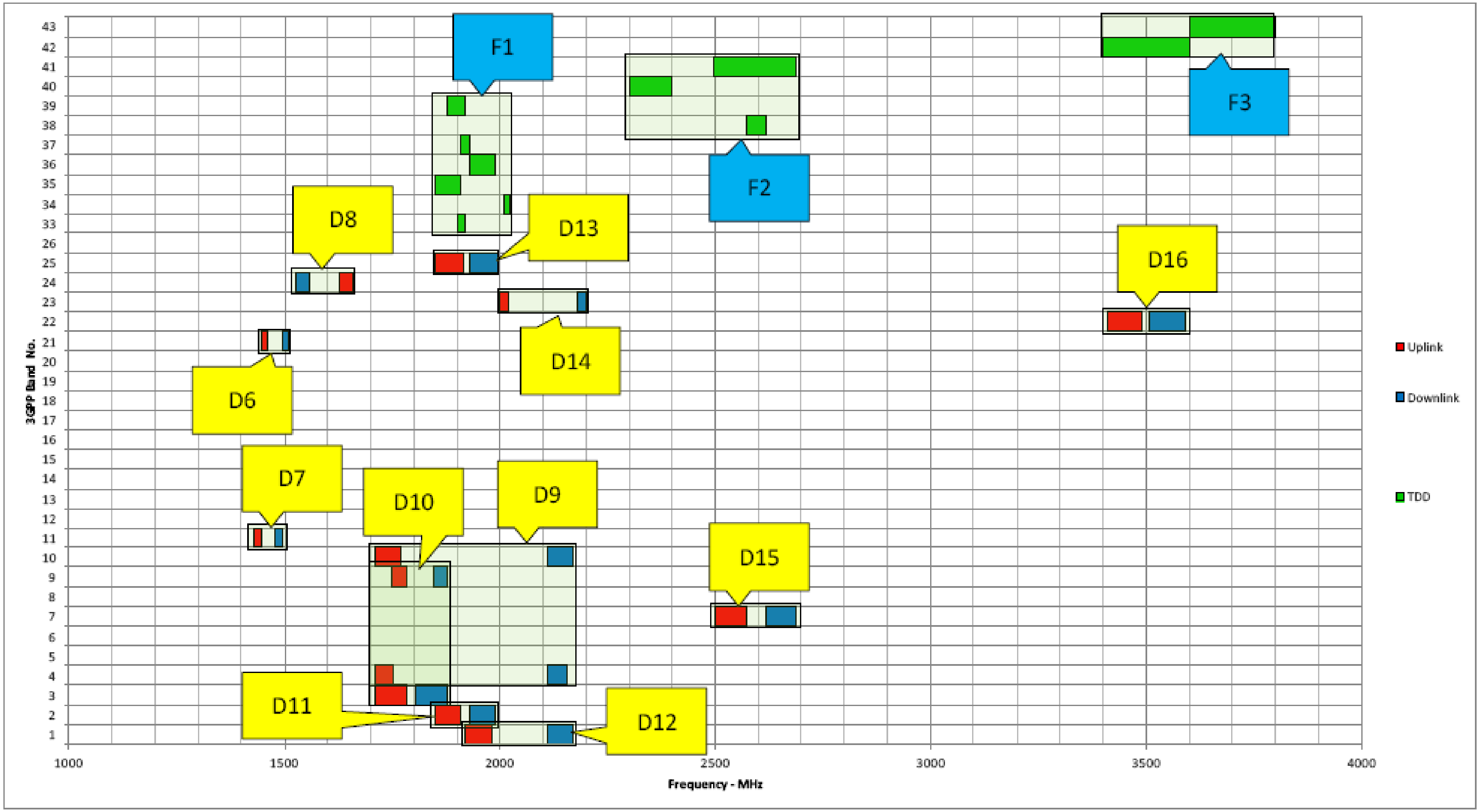
Reduced diplexer set for >1 GHz bands



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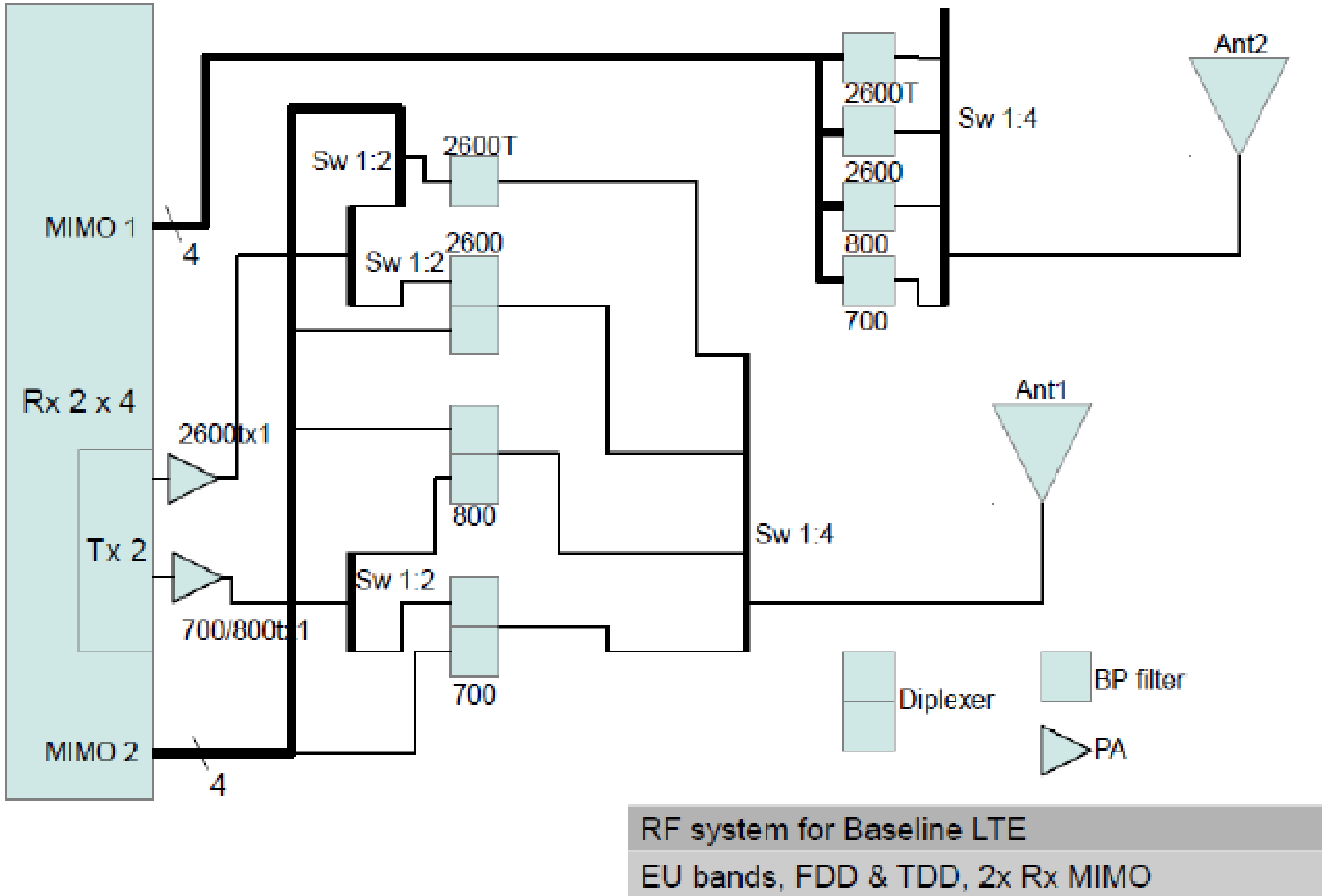
EU-Band Radio LTE Radio



Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

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LTE Advanced

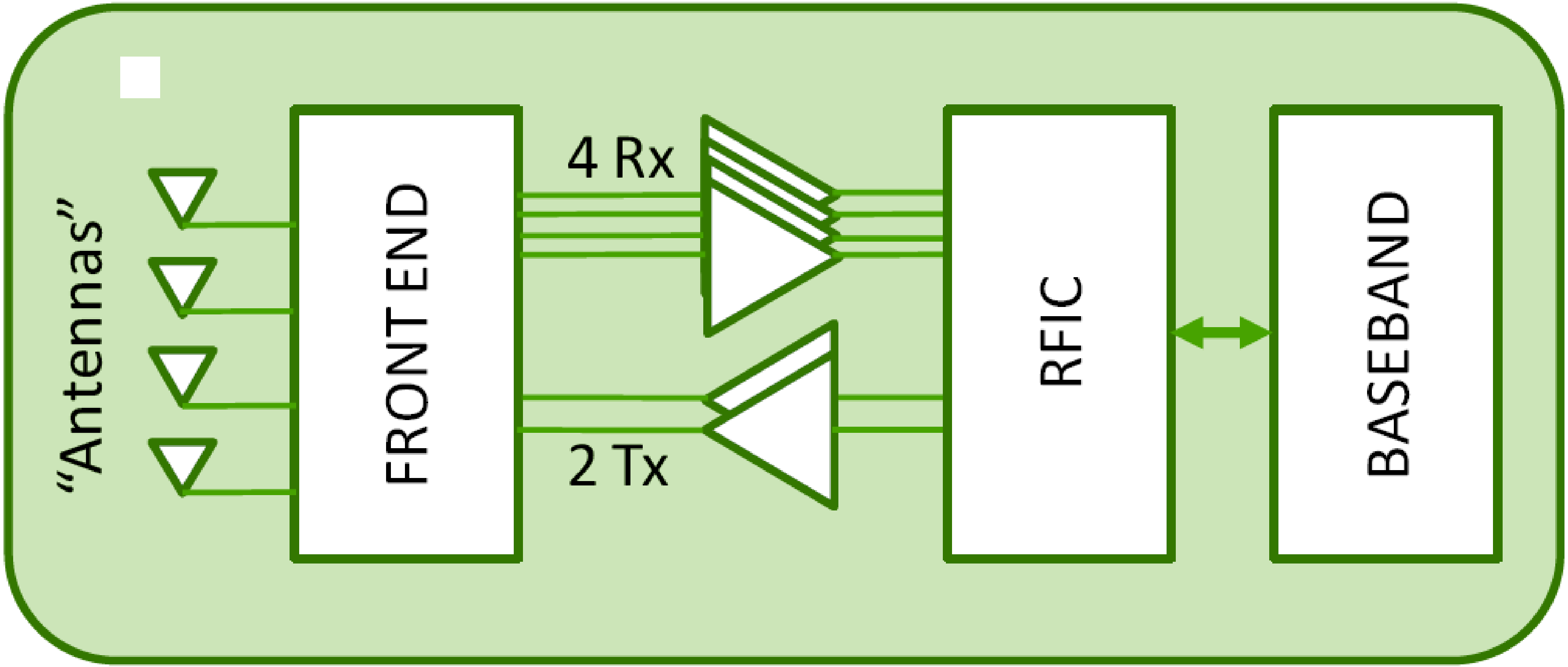

Figure illustrates the issues that will need to be addressed in future handset front end targeting LTE-Advanced.

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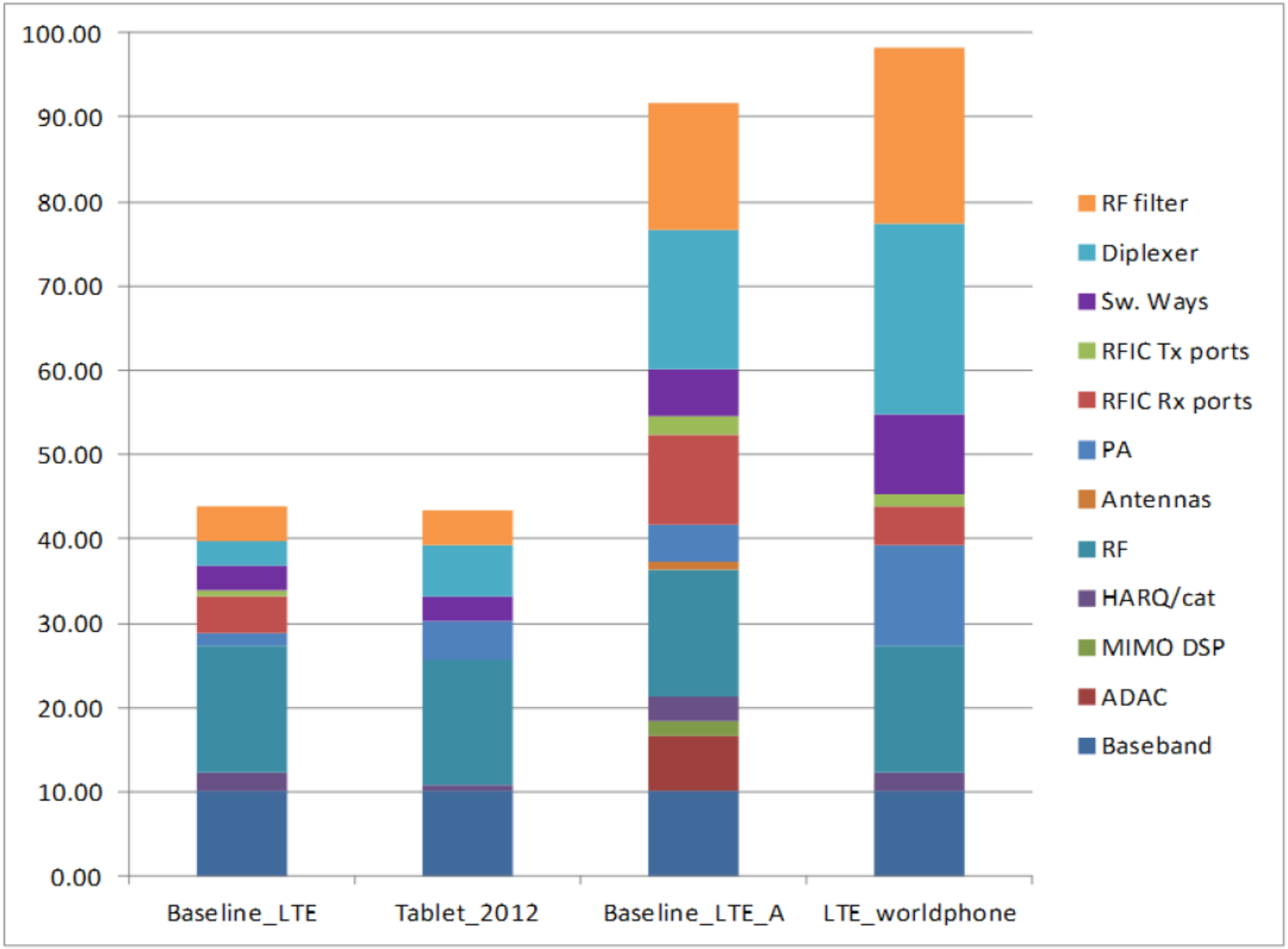
Cost modelling for LTE based solutions



Caution: Cost 'v' Performance - Total cost ownership of entire network and system will be become even more critical in future congested networks.

Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

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Suggestions for research:

- Conventional approach: Radio design require high performance diplexers (duplex filters) to ensure that the receiver is not desensitised by the transmitter. The filters also help to protect adjacent services from transmitter sidebands and protect the receiver from overload by strong signals which are part of an adjacent service. Every new band added to a terminal needs a new filter. SAW or FBAR filters are very small and cheap (~ $1) but each new band needs another filter and switch, adding cost and losses and taking more space.
- Can a technology be found that can create tuneable RF filters with lower cost, reduced losses and greater flexibility?
- Is there any technology or physical phenomenon that might be used to create a high Q tuneable resonator which could be a building block of such a filter? Are there innovative hybrid solutions based on a combination of very high Q fixed resonators with lower Q variable reactance elements that can help to simplify the design of multi-band radios ? Is it feasible to eliminate the diplexer and find new ways to achieve simultaneous transmit and receive?

Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep '12

Suggestions for research:

- Carbon nano-tubes have been used to make high Q resonators and switching devices . Is there any way these functions can be combined to make a tuneable resonator?
- Are there ways of reducing loss and increasing isolation in multi-way RF switches?
- Are there innovative solutions to both improve the bandwidth and linearity and reduce unwanted out-of-band radiation by transmitters (PA / driver) or to improve the strong signal handling of receivers (LNA / mixer)? Such solutions may be purely in the analogue domain or (more likely) may exploit DSP to correct for analogue imperfections. Can these improvements be achieved while continuing to reduce power consumption?
- Are there new digital signal processing techniques that can be used to linearise or correct for distortions in the analogue domain and consequently reduce the need for analogue filtering?
- Solutions that span the entire processing chain between the antenna and baseband digital processing. Set up multi-disciplinary programmes, to bridge the gap to find the best overall system solutions.

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Source: ICT KTN and Cambridge Wireless RF Front-End Technology Challenges Paper, Sep ‘12

Presentation themes

- Importance of radio link quality
- Picking the right trade offs
- Challenge, the landscape is changing, we need radical new ideas, approaches, materials or do we carry on with conventional radio evolution?

Material used

- Wireless Technology & Spectrum group papers developed by industry.
  - Digital Dividend – a great example to use and learn from
  - Radio Technology challenges

Papers available, join for free
https://ktn.innovateuk.org/web/spectrum

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