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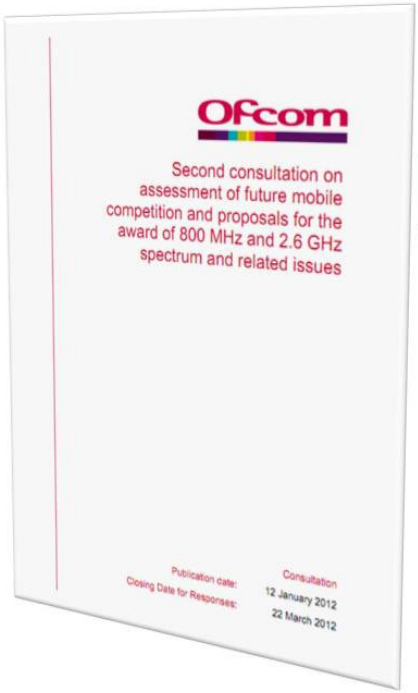
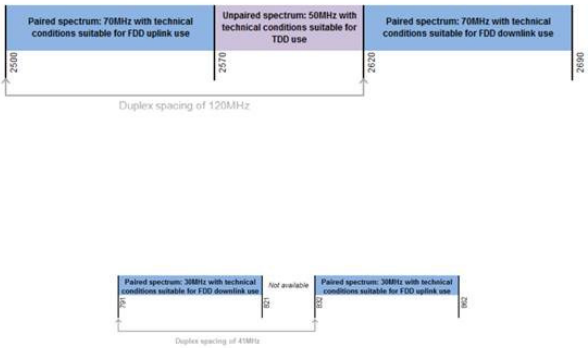
Investigations of technical issues related to the combined award of 800MHz and 2.6GHz spectrum

Matters arising from January 2012 consultation





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Executive summary

This technical note summarises and collates a number of short studies carried out by Real Wireless to provide feedback to Ofcom on a number of technical issues related to the combined award of 800MHz and 2.6GHz spectrum that were raised by respondents to Ofcom's January 2012 consultation [1] on this subject. In particular these issues stem from comments received from respondents on Ofcom's LTE technical model used within this consultation document to assess differences in anticipated coverage, user data rates and capacity for different portfolios of spectrum.

The technical issues investigated by Real Wireless are listed below with an overview of our findings in each of these:

- **Appropriate Building Propagation Loss (BPL) assumptions** - We conducted a survey of previous studies on building propagation loss measurements and found that these cover a very wide range depending on building type, geometry and construction materials. The BPL cases above 900MHz used in Ofcom's consultation fit at the extremes of the range of values found across these previous studies.
- **Neglecting to use Reference Signal Received Power (RSRP) to limit coverage estimates** – We reviewed 3GPP LTE standards and LTE literature for the trade-offs and requirements for measuring LTE coverage based on RSRP, Signal to Interference and Noise Ratio (SINR) or a combination of these. We have found that Ofcom's approach of basing LTE coverage on SINR is reasonable as:
  - The Ofcom models aims to model active connected user behaviour rather than idle mode devices
  - The existing SINR cut-off applied in Ofcom's model implicitly applies a minimum RSRP within the range of values allowed by the 3GPP standard.
  - Use of SINR ensures that coverage estimates allow for both noise and interference limited scenarios whereas the use of RSRP alone would only allow for noise limited scenarios.
- **Failing to apply a minimum uplink data rate to limit coverage estimates** – We reviewed the 3GPP LTE standards and LTE literature for a requirement that a minimum uplink data rate is required to maintain uplink connectivity regardless of downlink data rate. We were unable to find a source for this requirement and found evidence that the downlink SINR cut-off currently applied in the Ofcom model should be sufficient to ensure that uplink connectivity is also maintained across a range of cases, although we noted that this depends on the scenario and that some level of uplink throughput is required to sustain a high quality of service when TCP traffic is taken into account.
- **Appropriateness of the propagation model used by Ofcom at 2.6GHz –** We carried out an extensive literature review of issues with propagation models above 1800MHz. It was found that the current propagation model based on the European Communications Office (ECO) SEAMCAT modelling tool Version 1 description of the extended Hata model is not particularly representative for measurements above 2GHz and suggested a range of correction values for Ofcom to take into account.
- **Appropriate downlink overhead and loading levels to assume** – We reviewed the 3GPP standards, 3GPP contributions and other studies on LTE network

performance to compare assumptions for downlink loading and overheads in the open literature against those made by Ofcom. It was found that Ofcom's loading assumption is not excessive compared to other sources but no information was available to quantify the exact impact of loading on user experience. In terms of overhead, it was found that both the Ofcom assumed level of 20% and the proposed 30% level by stakeholders are relevant for different scenarios depending on the number of active connections (which is not necessarily the same as loading) within a cell.

- **Appropriate smart scheduling assumptions –** We reviewed support for smart scheduling across the various 3GPP LTE releases, reviewed literature on the proposed benefits of smart scheduling and interviewed relevant stakeholders to get a poll of industry views on the benefits and timescales of these techniques. It was found that the smart scheduling assumptions in Ofcom's LTE model align with what is available and has been observed in LTE release 8 deployments. However, this may be pessimistic beyond 2016 when LTE release 10 devices become more dominant enabling more advanced scheduling techniques.

These investigations were provided to give an opinion to assist Ofcom in assessment of the available evidence, rather than to provide firm recommendations regarding the assumptions to use in subsequent modelling.

1 Ofcom, "Second Consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and related issues", January 2012

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1. Introduction

This section provides the background to the series of short studies carried out by Real Wireless for Ofcom detailed in this technical note. It also introduces the structure of this technical note and its related annexes.

1.1 Respondents to Ofcom's January 2012 consultation on the combined award of 800MHz and 2.6GHz spectrum have made a number of challenges to Ofcom's LTE technical model

In January 2012 Ofcom issued a consultation related to the combined award of 800MHz and 2.6GHz spectrum [1]. Within Annexes 7 and 14 of this document Ofcom detailed their LTE technical model used for modelling coverage across a range of spectrum portfolios and target data rate scenarios. Stakeholders were invited to comment on this model.

Comments received back on this technical model raised a number of issues requiring further investigation including:

- How the consultation Building Propagation Loss (BPL) assumptions compare with measurements
- The use of a Signal to Interference and Noise Ratio (SINR) rather than a Received Signal Reference Power (RSRP) as a cut-off threshold for determining coverage areas
- Whether a minimum uplink data and corresponding uplink SINR should be applied in addition to a target downlink SINR when determining coverage
- Whether the propagation model used within the consultation is suitable for predictions above 2GHz
- How the loading and overhead assumptions on the downlink in the LTE model compare with real networks
- How the smart scheduling assumptions on the downlink in the LTE model compare with what can currently be achieved on LTE networks

1.2 Real Wireless has carried out a number of short studies to investigate these challenges

Real Wireless was asked to examine each of the areas listed in section 1.1 and in particular to:

- Understand the issue being raised by the stakeholder(s) in each of the areas
- Survey 3GPP standards, LTE texts and other existing literature and draw upon industry experience to determine requirements and standard practice in these areas
- Where possible give an opinion of whether changes might be required in Ofcom's LTE model in line with the issues being raised

This document is a technical briefing note to summarise our findings and collate the work we have done on each of these areas.

1.3 Document structure

This technical note aims to give a brief summary of each study carried out in the six areas identified in section 1.1 and is structured as follows:

- Section 1, this introduction, gives the background to the series of studies undertaken and summarised in this document.
- Sections 2 to 7 provide a summary of each short study in turn and for each investigation presents:
  - An overview of the issue raised
  - Our approach in the study
  - Key findings

In addition the full details of our investigations in each of the areas listed in section 1.1 are provided in a series of six annexes published alongside this document.

2. Comparing BPL assumptions to existing measurements

This section describes our comparison of BPL values and measurements from the open literature with the BPL assumptions given in the January 2012 consultation. A full description of this work, including reference sources for our findings, is given in the report published as Annex A alongside this document.

2.1 Overview of issue raised

Within the LTE technical model used for the January 2012 consultation [1] Ofcom have presented a set of BPL parameters (consisting of sets of median BPL values in dB and associated standard deviation values) which vary with clutter type, frequency and depth.

In the case of the median BPL values this includes an upper bound and lower bound set of median BPL values for each clutter type. Each of these sets of median BPL values contains five levels of depth (intended to simulate users in easier and harder to reach locations) across five different frequency bands (800MHz, 900MHz, 1800MHz, 2100MHz and 2600MHz). In the case of the upper bound set the median BPL values increase with frequency and depth.

In addition an upper and lower bound on BPL standard deviation is given which varies with frequency but not with clutter type.

Some consultation responses have queried the validity of these suggested BPL parameter sets and suggested alternatives.

2.2 Our approach

In this study Real Wireless were requested to investigate propagation losses into and within buildings in the 800, 900, 1800, 2100 and 2600MHz bands. More specifically the aim of this work was to gather, review and analyse evidence on the dependence of building propagation losses within buildings as a function of the following key variables:

- Depth
- Frequency
- Building type and geometry

To achieve this we:

- Carried out an extensive literature review of journal papers, books, conference proceedings, research reports and COST and ITU reports and recommendations on building propagation
- Reviewed previous Ofcom consultations and supporting Spectrum Efficiency Scheme reports to understand how historically BPL assumptions had been challenged and updated in the past
- Collated and graphed mean BPL values and their standard deviation from across the sources reviewed to compare the range of values reported against those from the January 2012 consultation

2.3 Key findings

It was found that the measurements provided in BPL literature generally support the assumptions that the median BPL should:

- Increase with frequency
- Increase with depth inside the building
- Depend on the building material, type and geometry which might be interpreted as a variation with clutter type

However, there is a large range of median BPL measurement values reported across the literature in this area and a direct comparison across them is difficult to make due to different measurement set ups, test environments, frequencies of interest etc. between studies. Most of the studies studied showed an increase in building penetration loss with frequency, although in some cases these show only a small dependency. Others quote dependencies as high as around 10 dB/decade. While some of these differences may results from methodological issues, it seems clear that there is substantial genuine variation in frequency dependency (as well as absolute penetration loss) amongst individual buildings, as expected on physical grounds.

3. Use of SINR rather than RSRP to limit coverage

This section describes our investigation into the validity of using an SINR rather than an RSRP threshold as the cut-off for determining coverage area within the LTE model in the January 2012 consultation. A full description of this work, including reference sources for our findings, is given in the slide pack published as Annex B alongside this document.

3.1 Overview of issue raised

Within Ofcom's LTE technical model coverage is determined based on the simulated downlink SINR at user locations modelled across the cells within the network. The edge of coverage is determined by a minimum SINR threshold which is the higher of the minimum SINR to maintain the required downlink data rate for the scenario under investigation or a SINR cut-off that would be required to maintain basic control channel connectivity.

A stakeholder has raised concern that Ofcom's coverage modelling analysis is based on signal quality (SINR) and suggested that standard industry practice is to use signal strength (RSRP), as suggested by the cell selection procedure in the LTE specifications. It was also suggested that a minimum RSRP threshold of -122dBm should be used.

3.2 Our approach

In this study Real Wireless were asked to investigate:

- The requirements for coverage within the 3GPP LTE standards and how these relate to SINR and RSRP
- Whether standard industry practice in modelling LTE coverage tends to be based around SINR or RSRP or a mixture of these
- Whether there is any requirement within the 3GPP LTE standards or practical limit in real LTE networks that would support a minimum RSRP threshold of -122dBm

To achieve this we have we reviewed the 3GPP LTE standards, technical contributions presented at 3GPP meetings and standard LTE texts to understand the specified requirements for coverage and extract example coverage estimates and approaches from independent sources. We have also had informal discussions with planning tool vendors to add further insight on industry practice in this area.

In particular we have:

- Considered different approaches to analysing coverage of mobile broadband networks described in the open literature
- Considered the relevance of cell (re)selection to coverage (as we found that this is where an RSRP requirement was specified in the standards)
- Calculated how the Ofcom SINR cut-off might translate to a RSRP limit and compared this to the level suggested by the stakeholder
- Reviewed factors that might limit a minimum RSRP to the suggested level of -122dBm such as the parameters for defining RSRP thresholds for cell (re)selection within the 3GPP standards

3.3 Key findings

Our study in this area concludes that whilst we agree that network planning is sometimes based on RSRP alone, we generally see that coverage analyses are based on the signal quality required (i.e. SINR) to achieve a given service level target.

Upon review of the 3GPP standards, it was found that, while RSRP is a relevant parameter for cell selection, the standard does not prescribe an absolute RSRP threshold. Instead, it appears that the threshold is operator configurable over a wide range of values.

Our study highlights that a cell having sufficient RSRP to be 'suitable' for selection is no guarantee that it has sufficient quality to transfer data at a given rate. This is because RSRP is a measure of received power level rather than received signal quality. When considered against a fixed noise floor, RSRP can be viewed as a proxy to SNR at the receiver. Applying an RSRP threshold to determine coverage is therefore applicable only to 'noise limited' scenarios. However, real networks today can be interference as well as noise limited and applying a SINR threshold to determine coverage has the benefit over the RSRP approach of considering both of these.

Within this work we also show that Ofcom's minimum SINR assumptions in a noise only environment are commensurate with an RSRP threshold 5-6 dB lower than the equivalent RSRP threshold suggested by the stakeholder. However, we have found no evidence that this lower RSRP threshold could not be supported in real networks and our review of the 3GPP standards shows that this lower RSRP level is still within the range of RSRP values that can be signalled by the network.

Overall we conclude that Ofcom's SINR based approach is appropriate in analysing the coverage of a given data rate availability in both noise and interference limited networks.

4. Applying a minimum uplink throughput limitation to coverage

This section describes our investigation into the suggestion from a stakeholder that LTE coverage should be based on an uplink as well as downlink SINR threshold cut-off and that this uplink cut-off should be commensurate with a minimum uplink data rate to maintain connectivity. A full description of this work, including reference sources for our findings, is given in the slide pack published as Annex C alongside this document.

4.1 Overview of issue raised

As described in section 3.1, the LTE model used within the January 2012 consultation determines coverage based on applying a minimum downlink SINR threshold to the simulated SINR values found at user locations across cells within the network modelled.

A stakeholder response to the January 2012 consultation has challenged the reliance of the Ofcom model on a downlink SINR value and suggested that a minimum uplink throughput level is required to maintain essential uplink connectivity and should be included in Ofcom's coverage analysis.

The stakeholder also commented that the asymmetry of uplink and downlink data rates in LTE is too extreme to support TCP traffic.

4.2 Our approach

To provide background information on the issues raised by this stakeholder, Real Wireless was asked to investigate the following main areas:

- Whether the 3GPP standards placed any requirement on a minimum required uplink data rate to maintain a downlink connection
- Whether TCP requires a minimum uplink rate as a proportion of downlink traffic

4.3 Key findings

Our review of the 3GPP LTE standards has found no requirement for any uplink data traffic (as opposed to control traffic and signalling) to be supported to maintain the uplink connectivity required for a user availing of a purely downlink data service (as being modelling by the scenarios presented in the January 2012 consultation). A further investigation of LTE texts and 3GPP simulation results in this study also showed that LTE uplink control channels have been designed to ensure that similar ranges can be achieved for these as for downlink control channels. Therefore Ofcom's use of a minimum SINR cut-off based on the downlink SINR required to maintain connectivity should also ensure that the minimum uplink signal quality to maintain a connection is achieved.

Our review of TCP requirements for acknowledgement traffic on the uplink as a proportion of downlink traffic shows uplink rates between 0.5% and 11% of the downlink may be required, depending on the TCP-IP implementation. It is worth noting that acceptable uplink performance might not be determined solely by the acknowledgement traffic in all TCP applications.

5. Propagation at 2.6GHz

This section describes our review of propagation models appropriate for determining path loss above 1800MHz. A full description of this work, including reference sources for our findings, is given in the report published as Annex D alongside this document.

5.1 Overview of issue raised

A stakeholder response to the January 2012 consultation highlighted a disparity between Ofcom's description and implementation of the extended Hata propagation model. It was found that while this model was referenced as being from version 2 of the ECO SEAMCAT modelling tool it had actually been implemented in line with a description given in SEAMCAT version 1 documentation.

This issue impacts the path loss calculation above 2GHz.

5.2 Our approach

Within this study Real Wireless was asked to:

- Establish a foundation for the frequency dependence in the ECO extension of the COST231 Hata model above 2GHz in version 2 of the ECO SEAMCAT modelling tool
- Consider if this model is valid above 2GHz
- Make recommendations for propagation model enhancements if found to be necessary

To achieve these aims we:

- Reviewed relevant SEAMCAT documentation
- Carried out an extensive literature review of propagation models and measurements of path loss in the range between 1800MHz and 2600MHz
- Collated findings on the difference in path loss between 2600MHz and 1800MHz and the frequency gradient above 2GHz from these open literature sources and compared these against the equivalent values from the ECO extension of the COST 231 Hata model above 2GHz in the two versions of the SEAMCAT modelling tool under consideration by Ofcom

5.3 Key findings

Within this study we were unable to find the precise origin of the frequency dependence in the SEAMCAT version 2 model above 2 GHz.

In terms of the validity of this model, Figure 1 presents our findings of frequency gradients and mean path loss differences between 2600 MHz and 1800 MHz from open literature reviewed during this study and compares these against the two SEAMCAT model versions considered. Where these studies have not specifically examined frequencies above 2GHz or are limited to a number of frequency measurement points these are indicated on the x axis. It should be noted that these studies target a range of different environments and assumptions and as such are not direct like for like comparisons. However, this figure gives a good idea of the range of frequency gradients that are supported by existing literature

and where the Seamcat model lies within these. This figure and the more detailed analysis in the report show that:

- Neither SEAMCAT approach taken alone appears to be representative of the expected difference in path loss from measurements.
- The frequency dependence in measurements occupies an intermediate value between the two SEAMCAT cases.
- Measurements vary significantly in the range 15-35 dB/decade over the relevant frequency range, with 25 dB/decade being an approximate mean level across these.

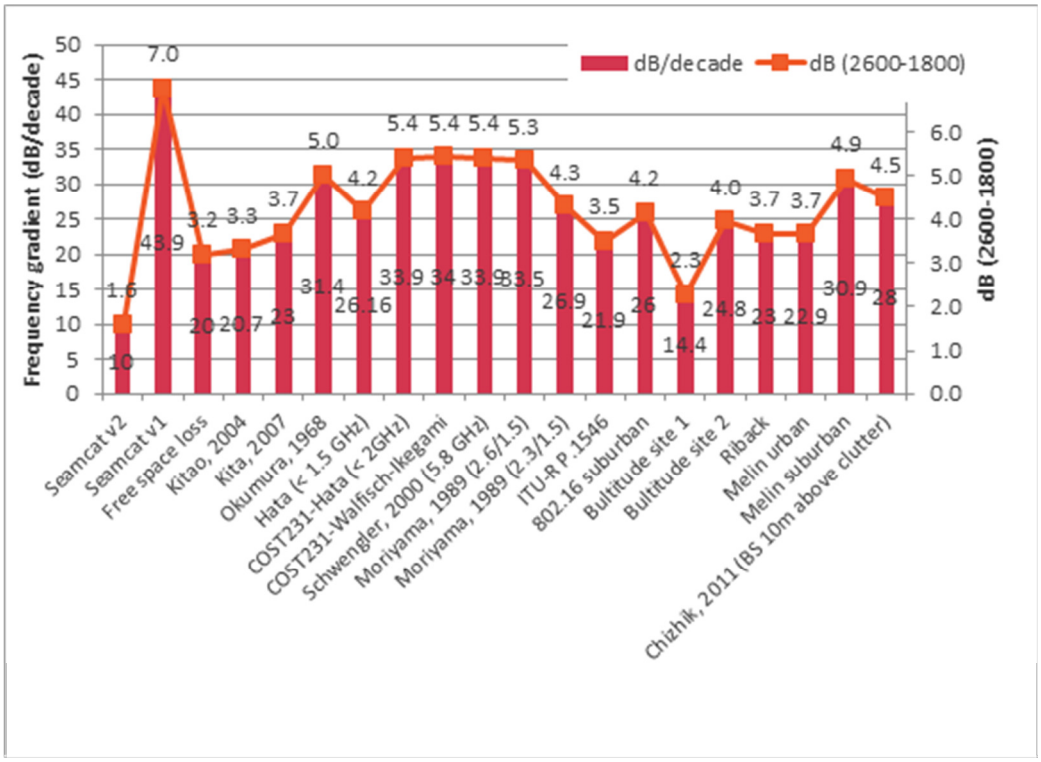

Figure 1: Summary of frequency gradients and mean path loss difference between 2600 MHz and 1800 MHz found in open literature reviewed and compared against the SEAMCAT model versions

These findings suggest Ofcom should modify the propagation model employed at 2.6 GHz to have between 2.3 and 5.5 dB (with a central value around 4 dB) greater loss at 2.6 GHz than 1.8 GHz, but should not place too much weight on the specific value adopted, given the variabilities which are not captured by the standard models. A more detailed model could be used to capture some of these variabilities. This more detailed model would assign a path loss which depends on base station height relative to clutter type, but it is anticipated that this might involve a departure from the models widely employed in regulatory circles and would require further research to confirm whether this is the case.

6. Appropriate loading and overhead assumptions on LTE networks

This section summarises our investigation into issues raised by stakeholders around the loading and overhead assumptions used in Ofcom's LTE technical model. A full description of this work, including reference sources for our findings, is given in the slide pack published as Annex E alongside this document.

6.1 Overview of issue raised

Within Ofcom's LTE technical model used in the January 2012 consultation Ofcom make the following assumptions in terms of loading and overheads on the downlink:

- Cell loading of 85% (i.e. a maximum 85% of resources will be available to the Physical Downlink Shared Channel (PDSCH) and related control channels to allow a user to achieve a target throughput)
- A 20% overhead is assumed on the downlink which is commensurate with the Physical Downlink Control Channel (PDCCH) occupying 2 symbols

In the responses received to the consultation a stakeholder questioned whether 85% cell loading was suitable for evaluation of a coverage obligation. It was also commented that 20% loading has been agreed elsewhere and in previous studies but this is understood to be a network loading level rather than a cell loading level. We understand (since completing this study) that the specific reference was in the context of the coverage obligation rather than the competition assessment. The 20% overhead assumption was also challenged given that the maximum 3 symbols of PDCCH would result in a 30% overhead.

6.2 Our approach

Within this investigation Real Wireless were asked to consider the following questions:

- Is 85% loading too high to give a decent user experience?
- Is 20% an appropriate level of overhead, especially given the number of symbols needed for PDCCH in heavily loaded cells?

To address these we have taken the following approach:

- Clarified the background to the issues being raised by the stakeholders and in particular looked at:
  - How loading relates to user experience
  - What constitutes overheads on an LTE downlink and how they vary
- Examined sources of the calculation of overhead from open literature and previous Real Wireless studies
- Examined how other studies treat loading levels, including 3GPP contributions, books, papers and vendor presentations
- Compared our findings on typical loading and overhead assumptions from other sources with those applied in Ofcom's LTE model

6.3 Key findings

Our key findings in this study can be split into the two questions originally posed:

1. **Is 85% loading too high to give a decent user experience? –** We found that 3GPP simulations assume 100% uplink and downlink loading levels. Therefore the Ofcom assumed level of 85% does not seem excessive. While there is a link between loading and user experience it is difficult to quantify this and the stakeholder had not provided any specific evidence on the level of performance degradation which would be encountered. On the point that a loading level of 20% was previously agreed we would highlight that this is a network loading level and understand (since completing this study) that this comment was in the context of the coverage obligation rather than the competition assessment. Within our study we show that 85% cell loading is reasonably consistent with a 20% network loading level in a lightly loaded network given that not all cells will be active simultaneously.

2. **Is 20% an appropriate level of overhead, especially given the number of symbols needed for PDCCH in heavily loaded cells?** – We confirmed that the 20% loading level assumed by Ofcom is consistent with the PDCCH occupying 2 symbols and that if 3 symbols of PDCCH were required, 30% would be a more appropriate downlink overhead assumption. However, we would highlight that the number of symbols occupied by the PDCCH is not directly a function of loading per se but of the number of connected mode users in the cell, which might still be small even in a heavily utilised cell. For example, a single user achieving the peak rate would only attract the lower downlink overhead of 2 symbols for the PDCCH. Overall we found that either case could be relevant depending on the scenario being modelled. A 3GPP source for LTE spectrum efficiency evaluations has made the assumption that the PDCCH would occupy three symbols.

7. Smart scheduling assumptions

This section summarises a study to investigate the availability and benefits of state of the art smart scheduling techniques in LTE networks and how these match the assumed benefits from these techniques in Ofcom's LTE technical model. A full description of this work, including reference sources for our findings, is given in the slide pack published as Annex F alongside this document.

7.1 Overview of issue raised

Smart scheduling techniques in LTE relate to 'intelligently' scheduling, in terms of time and frequency, the resources available across users in a network to minimise interference and the impact of channel impairments.

Within Ofcom's LTE technical model used in the January 2012 consultation, Ofcom has assumed some benefits of smart scheduling. These include user throughput gains due to frequency selective scheduling and improved channel reuse at light loads due to 'intelligent' scheduling.

As smart scheduling helps reduce interference it tends to move network performance towards being noise rather than interference limited. In noise limited networks the coverage benefits of low frequency spectrum become more apparent and so it is important that assumptions in this area are realistic.

7.2 Our approach

Within this study Ofcom wished to understand how well their smart scheduling assumptions in their LTE model aligned with the state of the art and planned evolution of this technique in commercially available products. In particular Real Wireless was asked to investigate the following question:

"Based on vendor inputs on the commercial availability and benefits of smart scheduling will operators be able to match the performance anticipated by Ofcom modelling in the early years of LTE rollout?"

Within this study we note that, although the 3GPP standards specify signalling to support scheduling, the exact details of scheduling algorithms are left to vendors to implement. As such we did not expect to find a standardised, clear cut answer from the 3GPP standards on the implementation and benefits of smart scheduling. With this in mind we approached this study as follows:

- A review of the 3GPP standards to understand support for smart scheduling provided across the various releases
- A literature survey to understand both standardised and vendor specific aspects of smart scheduling and claimed benefits
- Vendor interviews at Mobile World Congress and individually provided inputs on timing of commercial availability

7.3 Key findings

From our review of the 3GPP LTE standards in this study we found that smart scheduling is possible in a basic form in release 8 of LTE, although additional support is added to LTE-A (Release 10) to enhance performance. In particular we found that:

- Release 8 supports frequency selective scheduling which helps mitigate interference
- Release 10 supports dynamic Inter Cell Interference Cancellation (ICIC) and Co-ordinated Multi-point (CoMP) techniques which provide benefits to cell edge user throughput

In terms of timescales, our study found that although release 10 User Equipment (UEs) are likely to be available from late 2013, it may be 2016 or later before these become dominant in the device mix and the benefits of LTE-Advanced based scheduling techniques can be realised.

Overall we have found that Ofcom's assumed 'intelligent' scheduling benefit at low loads aligns well with the low gains found in commercial deployments of release 8 LTE networks with ICIC. We also found that their assumed gains for frequency domain scheduling are well aligned with commercial figures.

As the assumptions made by Ofcom are appropriate for release 8 LTE they will be applicable for the first few years of rollout up to around 2016. However, the assumptions may result in an underestimate of user throughput for release 10 infrastructure and UEs which are likely to dominate after this time.

List of Acronyms

2G	Second generation systems e.g. GSM, IS-95
3G	Third generation mobile systems, e.g. UMTS
3GPP	Third generation partnership project
4G	Fourth generation mobile systems e.g. LTE, WiMax
BPL	Building propagation loss
CoMP	Co-ordinated Multi-Point techniques
ECO	European Communications Office
GSM	Global system for mobile communication
ICIC	Inter Cell Interference Cancellation
ITU-R	International Telecommunications Union – Radiocommunications sector
LOS	Line of sight
LTE	Long term evolution of mobile systems
LTE-A	LTE Advanced
MNO	Mobile network operator
NLOS	Non line of sight
PCS	Personal Communications Service
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
RB	Resource Block
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
UE	User Equipment
UMTS	Universal mobile terrestrial system

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