The timing of the consumer and operator features available from HSPA and LTE

Produced by Real Wireless on behalf of Ofcom

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1 Scope of this Report

This report was commissioned by Ofcom in support of their forthcoming consultation on the auction of 2.6 GHz and 800 MHz spectrum.

The aim was to provide *factual data* relating to the relative opportunities to support future mobile broadband services between frequency bands of relevance to the consultation. It was not intended for us to interpret the data in terms of the relative merits of any particular set of spectrum holdings.

Two particular types of data were of interest:

- The current and likely future support for technical features within relevant standards
- The current and likely availability of devices supporting these features,

The frequency bands of interest are particularly:

- 800 MHz
- 900 MHz
- 1800 MHz
- 2.1 GHz
- 2.6 GHz

The scope of the consideration was restricted by Ofcom to networks and devices supporting the 3GPP HSPA and LTE mobile broadband specifications, including the evolutions of these specifications known as HSPA+ and LTE-Advanced.

Chapter 2 provides details of the evolution of features available in the 3GPP LTE and HSPA specifications and the extent to which these depend on the frequency band. Specifically, information has been gathered from latest 3GPP technical specifications and also from other technical publications that provide factual analysis of technology performance based on a specific set of features.

The chapter encompasses technology features such as bandwidth support, carrier aggregation, MIMO and combinations of these features supported by the various generations of 3GPP standard releases for both HSPA and LTE. In particular, the report highlights the benefits and performance of each technology based on the relevant release.

Chapter 3 provides details of the availability of devices supporting these features and frequency bands, based on publicly available information. It includes data regarding the number of devices that are commercially available today by frequency band and form factor type, such as handset, tablets, USB dongles, routers and embedded modules.

Chapter 4 summarises the outcome of a survey of device vendors and operators regarding the expected evolution of HSPA and LTE device availability over the next few years in European spectrum bands.

2 Technical features and evolutions of HSPA and LTE technologies

2.1 Introduction – Features available in 3GPP LTE and HSPA Specifications

This section considers the feature mixes that are available for each 3GPP release of the HSPA and LTE specifications. The benefits of these feature mixes are considered as follows:

- Consumer benefits in terms of improved service offerings
- Operator benefits in terms of improved network efficiency

The resulting feature and performance roadmaps per 3GPP release are then combined with device availability timescales to describe when the various feature mixes will be commercially available. Ultimately we aim to compare and contrast features and performance of 3G and LTE at any given point in time over the next few years.

The Third Generation Partnership Project (3GPP) is a collection of regional standards development organisations (SDOs), known as Organisational Partners, that come together in an appropriate environment to draft and produce informative technical reports and specifications that define 3GPP technologies, such HSPA and LTE. The Organisational Partner for Europe is the European Telecommunications and Standards Institute (ETSI). The reports and specifications are produced and published by the efforts of members and the support of the various SDOs so that new technology features and work items are delivered in an organised and timely manner. Formally, 3GPP produces *specifications* which are transposed by the SDOs into *standards*, but these terms are often used interchangeably.

3GPP has evolved since its inception in 1998 developing GSM, GPRS and EDGE technologies to the development of mobile systems supporting 3G technologies and beyond. The technical specifications are published on a regular basis to incorporate the latest technology features as they emerge. Therefore 3GPP creates Releases for the standards that, once frozen, offered a distinct set of features that would differentiate it from its earlier release. Table 2-1 provides a summary of freeze dates of each of the relevant 3GPP releases for both HSPA and LTE technology. After a standard has been frozen no further features can be added, but minor corrections and adjustments may be adopted, and it is typical for protocols to remain fluid for a period of 3 months after the freeze date.

3GPP Standard Release	Functional Freeze date
Release 5	March – June 2002
Release 6	December 2004 – March 2005
Release 7	December 2007
Release 8	December 2008
Release 9	December 2009
Release 10	March 2011
Release 11	September 2012 (expected)
Release 12	TBD

Table 2-1: 3GPP specification releases and associated freeze dates (based on [1])

2.2 Naming conventions used in this report

A mixture of technical and 'marketing' terms are used in the mobile industry to describe different generations and releases of mobile broadband technology. In this report we use the following terminology:

- **HSPA** refers to 3GPP specifications of the UTRAN (Universal Terrestrial Radio Access Network) with the addition of features to support High Speed Downlink Packet Access (HSDPA) from release onwards 5 and optionally High Speed Uplink Packet Access (HSUPA) from release 6 onwards.
- **HSPA+** is a marketing term which describes networks supporting additional features of HSPA such as 64QAM modulation support or MIMO antenna processing. These features are available in UE 2categories specified from release 7 onwards. It should be noted that not all release 7 UE categories contain HSPA+ features.
- **LTE** refers to the specifications for Evolved-UTRA(N) which were first published in release 8 to align with UTRAN releases at the same time
- **LTE-Advanced** refers to features included in release 10 and later releases of the E-UTRAN specifications, which enhance LTE performance to make it a suitable candidate for an IMT-Advanced technology according to the ITU-R3.

[1] http://www.3gpp.org/releases

[2] UE – User Equipment, the 3GPP generic term for a mobile device, whether a handset, USB modem, tablet or other form factor

[3] IMT-Advanced is often considered as a working definition of "4G" mobile technology (see http://www.itu.int/net/pressoffice/press_releases/2010/40.aspx). However, since 4G has also been used to refer to versions of HSPA+ and other technologies, we have largely avoided the ambiguities associated with that term in this report.

- In this report, **LTE** and **HSPA** refer to the overall technology streams, and where used **HSPA+** and **LTE-Adv** refer to the advanced feature sets.

2.3 Overview of HSPA and LTE and Associated technologies

HSPA and LTE are the names for the Radio Access Network (RAN) specifications produced by 3GPP. These RANs need to be partnered with a 'core network' which includes gateways for handling user traffic and control nodes for managing the network. HSPA can use the legacy core network which already supports GSM and earlier versions of 3G. LTE requires a new core network called the Enhanced Packet Core.

The EPC represents an evolved network architecture designed specifically to support IP (Internet Protocol) packet communications like those of the internet. The EPC also supports legacy RAN technologies, so once LTE and EPC are deployed, GSM and HSPA RANs can be migrated to this new core network and the legacy core network decommissioned to save costs. The new EPC core is based on IP, and so the same IP based routers and transport networks used for the internet can be used for mobile networks.

The '3G' RAN is called UTRAN (Universal Terrestrial Radio Access Network) and also UMTS (Universal Mobile Telephone System) and was designed to support 'circuit' connectivity such as voice and video conferencing. HSPA represents a set of additional features to improve handing of packet data. This included a shared downlink channel enabling rapid reallocation of resources between users as well as features such as improved adaptation to varying channel conditions.

The LTE RAN has been designed to support only packet-based communications, and so is anticipated to be more efficient at doing so than HSPA. On the other hand, circuit-like communications such as voice require additional complexity to be supported in LTE. Quality of service (QoS) features are described later which ensure delay sensitive traffic gets through in a timely fashion during periods of congestion.

UMTS and HSPA are based on a Wideband CDMA (Code Division Multiple Access) multiplexing scheme and operate on a fixed bandwidth carrier which occupies a single 5MHz spectrum block. LTE is based on an OFDM (Orthogonal Frequency Division Multiplexing) multiplexing scheme, which is well suited to packet based communication and support of MIMO (Multiple Input, Multiple Output) antenna configurations, enabling higher data rates and increased spectral efficiency. LTE's OFDM scheme also enables bandwidth flexibility, and can create waveforms to operate in spectrum allocations of 1.4, 3, 5, 10, 15 and 20MHz sizes, or pairs of bandwidths of this size to support uplink and downlink communication in frequency division duplex mode. This helps operators in re-farming small chunks of spectrum as well as efficiently using large blocks of up to 20MHz. Further bandwidth increases can be achieved with both HSPA and LTE by combining multiple carriers as described later.

The 3G RAN architecture includes both base stations and a Radio Network Controller (RNC). The latter co-ordinates radio resources across multiple base stations and manages handover. In LTE the RNC functionality has been integrated into the base station to make a 'flatter' network architecture with fewer nodes. Reducing the number of nodes in the path of user traffic also improves latency, and potentially helps reduce costs. Later releases of HSPA can also eliminate the RNC node, and base stations can connect directly to the gateway.

Overall, both HSPA and LTE and their associated core networks support similar features. HSPA represents a set of updates to the original '3G' design as requirements for cellular traffic have evolved from voice through to data. LTE has been designed from the start to support packet data communications, and aims to do so more efficiently and with improved performance for both consumers and operators. The remainder of this report looks at specific feature and performance differences between HSPA and LTE networks and devices.

The following section describes the different combinations of features that will be supported by different releases of the standard. We focus here on high-level features which significantly impact upon performance, such as MIMO and multicarrier support.

2.4 Bands and Bandwidths

2.4.1 Supported bands

Table 2-2 shows the bands of interest to this report which are supported by HSPA and LTE UEs and base stations, and the numbering conventions used in the standards.

Band, MHz	UTRA band	E-UTRA Band	Uplink band			Downlink band		
800 FDD	FDD XX	20	832 MHz	–	862 MHz	791 MHz	–	821 MHz
900 FDD	FDD VIII	8	880 MHz	–	915 MHz	925 MHz	–	960 MHz
1800 FDD	FDD III	3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz
2100 FDD	FDD I	1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz
2600 FDD	FDD VIII	7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz
3.5 FDD	FDD XXII	22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz
2.0 TDD	TDD (a)	34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz
2.6 TDD	TDD (d)	38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz

Table 2-2 Bands applicable to the UK and 3GPP numbering for UTRA and E-UTRA, Source: 3GPP 25.101[4], 25.102[5] , 36.101[6]

2.4.2 Release independence principle

Each new band requires different RF performance specifications. New bands are always being added, and so earlier releases of the specifications

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[4] "User Equipment (UE) radio transmission and reception (FDD)", 3GPP TS25.101

[5] "User Equipment (UE) radio transmission and reception (TDD)", 3GPP TS25.102

[6] "(E-UTRA); User Equipment (UE) radio transmission and reception"", 3GPP TS36.101 v10.4.1

may not include all bands. 3GPP support the principle of 'release independence', such that devices can be designed with functionality of an early release in a band added in a later release. Specifications 25.307[7] and 36.307[8] define which parts of the band-specific specifications from later releases apply for each previous release.

2.4.3 Support of wider bandwidth in HSPA

Operators can increase capacity by using bandwidths wider than the basic paired 2 x 5 MHz block to deploy multiple independent Node-Bs on different channels. However, the 3GPP specifications also include the following features to enable devices to combine multiple 5MHz channels to enhance user performance and spectral efficiency.

HSPA is fundamentally based on single carrier WCDMA which occupies a 5MHz channel bandwidth (2x5MHz for FDD). Wider operating bandwidths can be achieved with multi-carrier HSPA introduced in release 8. Early multi-carrier support is limited to 2 carriers in the same band. Later support extends to 8 carriers in different bands. Table 2-3 shows this roadmap in terms of 3GPP releases. Per-band support is not specified for the dual carrier feature, so it is assumed to be supported in all bands. For 4 and 8 carrier HSPA, permitted combinations are included in the specifications, as detailed later.

3GPP Release of UTRA (HSPA)	Bandwidth Support
Rel 99-7	Single 2x5 MHz carrier
Rel 8	Dual carrier for Downlink, but not combined with MIMO Carriers must be adjacent in same band. Dual carrier supported in all bands
Rel 9	10MHz Dual carrier for uplink Combination of downlink Dual Cell and 2x2 MIMO Dual band support for downlink: one carrier in each band
Rel 10	Multicarrier downlink up to 4 carriers across two bands . Limited band combinations supported
Later release proposals	Multicarrier support up to 8 carriers, limited band combinations.

Table 2-3 Roadmap for multicarrier support in UTRA stream (HSPA). Sources Holma[9], Qualcomm[10]

2.4.4 Support of wider bandwidths in LTE

LTE has flexible bandwidths from 1.4 to 20MHz, and multiples thereof up to 100MHz from release 10. Release 8 and 9 support 1.4, 3,5,10,15 and 20MHz in a single 'carrier'. Strictly speaking the OFDM scheme comprises

[7] "UTRA Requirements on UEs supporting a release-independent frequency band", 3GPP TS25.307

[8] "E-UTRA Requirements on UEs supporting a release-independent frequency band", 3GPP TS36.307

[9] "*LTE for UMTS, Evolution to LTE-Advanced*", H. Holma, A.Toskala, 2nd Ed, Wiley 2011

[10] "HSPA+ Advanced: Taking HSPA+ to the Next Level", Qualcomm, 25/1/2011, http://www.qualcomm.com/documents/hspa-advanced-taking-hspa-next-level

of many narrowband carriers, but for the purposes of discussion we consider their phase synchronised composite as a single carrier (“Component Carrier” in 3GPP terminology).

Carrier Aggregation is introduced in release 10 to combine up to 5 DL and 5 UL carriers in the same or different bands, providing up to 100MHz bandwidth. Figure 2-1 illustrates the support for wider bandwidths available in LTE. Notice that there are several different flavours of carrier aggregation depending on whether carriers are adjacent or not and whether they are the same or different bands.

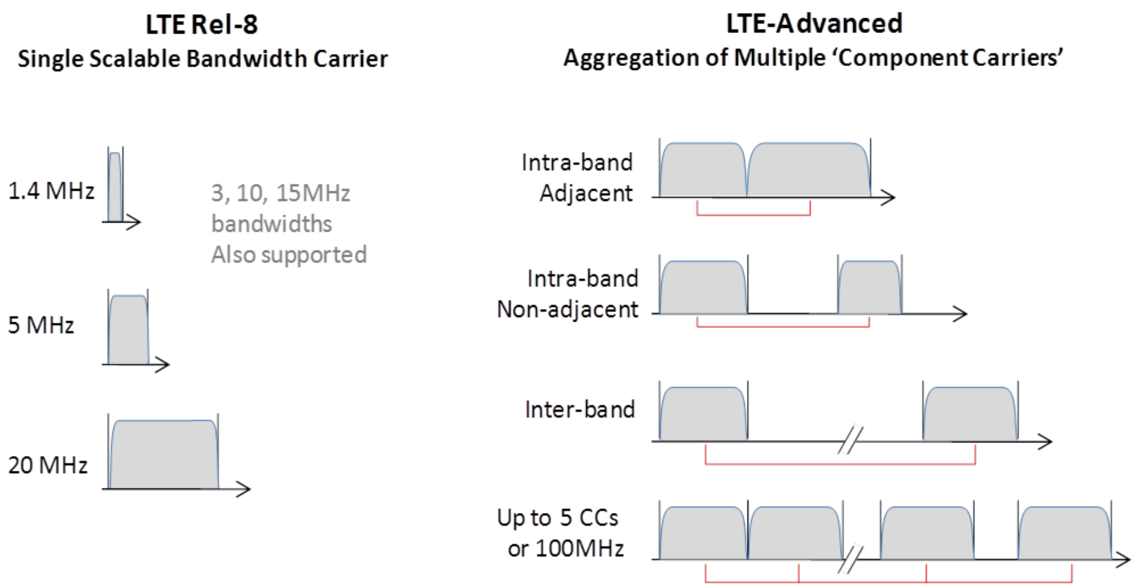

Figure 2-1 Flexible bandwidth and Multicarrier support in LTE

Table 2-4 shows that not all bandwidths are supported by all bands: 15MHz and 20MHz bandwidths are not supported in the UK’s 900MHz bands for example. Sub 5MHz bandwidths are only supported in 900MHz and 1800MHz bands.

Receive sensitivity is also relaxed for the wider bandwidths in some bands as shown in Table 2-5. The sensitivity is the received power that is needed to achieve a throughput ≥95% maximum throughput with a QPSK test signal – and so represents a basic downlink connectivity. Lower sensitivity reduces the maximum path loss that can be tolerated by the downlink, and thus the maximum range of basic connectivity is reduced. Reduced UE sensitivity will impact edge of cell performance in a noise (coverage) limited network, but will have little or no impact to UEs in an interference (capacity) limited network.

Band, MHz	E-UTRA Band	Uplink band	Downlink band	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
800 FDD	20	832 MHz – 862 MHz	791 MHz – 821 MHz			Yes	Yes[1]	Yes[1]	Yes[1]
900 FDD	8	880 MHz – 915 MHz	925 MHz – 960 MHz	Yes	Yes	Yes	Yes[1]		
1800 FDD	3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]
2100 FDD	1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz			Yes	Yes	Yes	Yes
2600 FDD	7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz			Yes	Yes	Yes	Yes[1]
3.5 FDD	22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz			Yes	Yes	Yes[1]	Yes[1]
2.0 TDD	34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz			Yes	Yes	Yes	
2.6 TDD	38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz			Yes	Yes	Yes	Yes

Note [1]: bandwidth for which a relaxation of the specified UE receiver sensitivity requirement is allowed.

Table 2-4 LTE Bandwidth support per band, source 3GPP[11]

Band, MHz	E-UTRA Band	Uplink band	Downlink band	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
800 FDD	20	832 MHz – 862 MHz	791 MHz – 821 MHz			-97	-94	-91.2	-90
900 FDD	8	880 MHz – 915 MHz	925 MHz – 960 MHz	-102.2	-99.2	-97	-94		
1800 FDD	3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	-101.7	-98.7	-97	-94	-92.2	-91
2100 FDD	1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz			-100	-97	-95.2	-94
2600 FDD	7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz			-98	-95	-93.2	-92
3.5 FDD	22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz			-97	-94	-92.2	-91
2010 TDD	34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz			-100	-97	-95.2	-94
2600 TDD	38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz			-100	-97	-95.2	-94

Table 2-5 LTE UE Receive Sensitivity relaxations per band & bandwidth combination source 3GPP[12]

11 "(E-UTRA); User Equipment (UE) radio transmission and reception"", 3GPP TS36.101 v10.2.1"

12 "(E-UTRA); User Equipment (UE) radio transmission and reception"", 3GPP TS36.101 v10.2.1"

2.5 *Multicarrier Support*

2.5.1 Benefits of Multicarrier operation

A comparison of multicarrier vs. multiple single carrier transmission shows that the former can achieve higher performance. Figure 2-2 shows a result from 3GPP which shows Dual Carrier HSPA can support 25% more users per sector and at a 25% higher average user data rate. The explanation given by 3GPP is that DC-HSPA can better exploit multi user diversity gain at low loads, a technique where users are optimally scheduled according to their channel conditions.

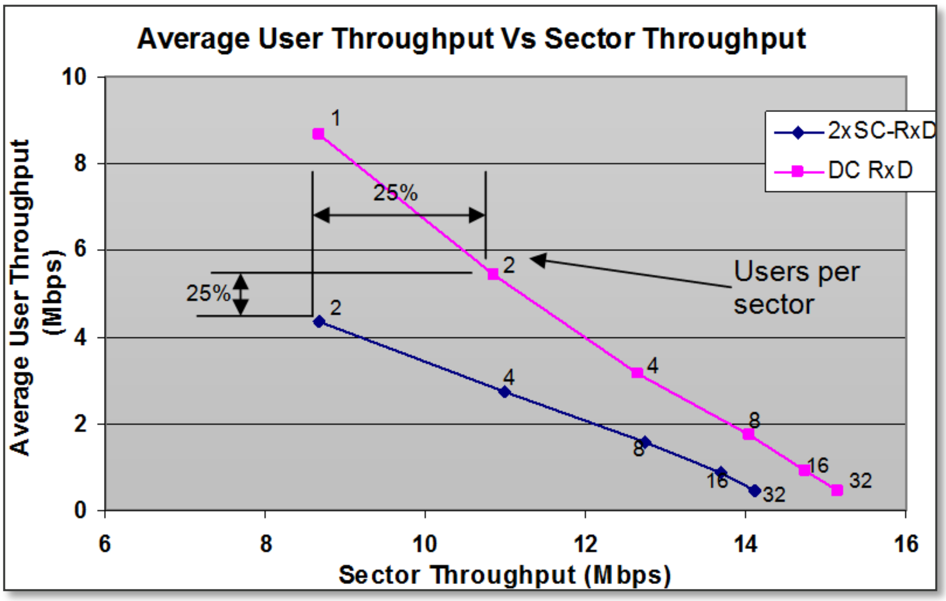

Figure 2-2 Comparison of Dual Carrier HSPA vs. 2 x Single Carrier HSPA. Source 3GPP[13]

[13] "Dual-Cell HSDPA operation", 3GPP TR 25.825 v1.0.0 May 2008

2.5.2 Consumer benefit of multicarrier support

Both HSPA and LTE users benefit from wider bandwidths, as this increases the maximum data rates that can be achieved, especially with light loads.

2.5.3 Operator benefits of multicarrier support

Wider bandwidths provide increased frequency domain scheduling gains, which increases spectral efficiency for the operator:

- HSPA being based on Wideband-CDMA does not natively support frequency domain scheduling like the OFDM based LTE. However, with dual carrier HSPA, some of the gains can be had. Dual carrier HSPA Channel Quality Indicator reports from UEs are used to select the best carrier, bringing some of the benefits of frequency domain scheduling. LTE achieves higher gains in this respect, as scheduling can occur per 180kHz 'resource block' rather than 5MHz carriers[14]
- Dual Carrier Uplink HSPA gains are lower than HSPA downlink. The HSPA uplink does not support the fast CQI reporting needed to support frequency domain scheduling over dual carrier [15], and thus gains will be lower than the downlink

2.6 Inter Band Carrier Aggregation Support

Support in release 10 specifications as of September 2011

Band		HSPA Multicarrier			LTE carrier Aggregation	
name	LTE (HSPA) Number	max carriers per band	dual band dual carrier	dual band multicarrier	CA intra band	CA inter band
800 FDD	20 (XX)	2	-	-	-	-
900 FDD	8 (VIII)	2	with I	I-3-VIII-1	-	-
1800 FDD	3 (III)	2	-	-	-	-
2100 FDD	1 (I)	3	with VIII	I-3-VIII-1	Yes	with band 5 only (non UK)
2600 FDD	7 (VII)	2	-	-	-	-

Note on HSPA nomenclature: Band (roman numerals) and number of carriers in that band (numbers) - so I-3-VIII-1 is up to 3 carriers in band I plus one carrier in band VIII.

Table 2-6 Multiband support for HSPA and LTE in September 2011 specifications. source 3GPP 36.101[16], 25.101[17]

[14] "LTE for UMTS, Evolution to LTE-Advanced", H. Holma, A.Toskala, 2nd Ed, Wiley 2011

[15] "LTE for UMTS, Evolution to LTE-Advanced", H. Holma, A.Toskala, 2nd Ed, Wiley 2011

[16] "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception", 3GPP TS36.101 v10.4.0 (2011-09)

Table 2-6 summarises support for inter-band carrier aggregation specified in Release 10, the most recent version of the LTE specification frozen at the time of writing. It shows that support is quite limited: Support in HSPA is limited to bands VIII (900MHz) and band I (2100MHz).

At the time of writing 3GPP LTE specifications did not describe support for any UK relevant Inter-band carrier aggregation. Since band specific support is not specified for (intra band) dual carrier, it is assumed to be supported by all bands.

2.7 Anticipated Additions to the specifications

Although current interband aggregation support is limited, 3GPP Work Items exist to add further multiband support to HSPA [[18],[19]]. Four Carrier support in HSDPA is described in [[20]], which gives the following UK relevant combinations for the release 11 timeframe:

- 2100 + 1800MHz
- 2100 + 900MHz (multiple carriers in both bands, whereas rel 10 supports only a single carrier in the 900 band)[21]

Note that due to the principle of release independence described earlier, it may be possible to back date future band combination additions to already frozen releases.

Eight Carrier HSDPA combinations are due to be presented to the RAN plenary meeting [22]in December 2011[23]

In LTE, Work Items exist to add many new inter band combinations. The two relevant to the UK are:

- Band 3 and Band 7 (UK 1800 MHz and 2600 MHz)[24]

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[17] "Universal Terrestrial Radio Access (UTRA); User Equipment (UE) radio transmission and reception, 3GPP TS25.101 v10.3.0 (2011-09)

[18] "3GPP work programme", http://www.3gpp.org/FTP/Specs/html-info/GanttChart-Level-2.htm#bm460007

[19] "Draft Report of 3GPP TSG RAN meeting #53 held in Fukuoka, Japan" Sep. 13 – 16, 201 http://goo.gl/ZbQXc

[20] "Downlink configurations for Four-carrier High Speed Download Packet Access (4C-HSDPA)" 3GPP TR 25.864 V10.0.0 (2011-07)

[21] "Downlink configurations for Four-carrier High Speed Download Packet Access (4C-HSDPA)" 3GPP TR 25.864 V10.0.0 (2011-07)

22 This is the formal meeting at which 3GPP decides on changes to RAN specifications.

[23] "Eight Carrier HSDPA, Report to TSG", RP-110997

[24] "Status Report to TSG, Core part: LTE-Advanced Carrier Aggregation of Band 3 and Band 7", RP-111204

- Band 20 and Band 7 (UK 800 MHz and 2600 MHz)[25]

The WI description anticipates completion of performance specs by March-May 2012[26]. "*Combinations will be introduced in a release independent manner*"[27], meaning that release 10 should be capable of the above combinations . Releases 8 and 9 do not support the carrier aggregation feature.

[25] "LTE Advanced Carrier Aggregation of Band 20 and Band 7", Orange, RP-110403

[26] "Work Item Description: LTE-Advanced Carrier Aggregation of Band 3 and Band 7", RP-110702

[27] "Consideration of Inter-band CA", R4-113416, July 2011

2.8 Combinations of MIMO, Modulation and Multicarrier Support

2.8.1 Timing of feature combinations requires an understanding of 'UE Categories'

3GPP standards define a number of UE categories which describe key capabilities of the device in terms of maximum data rate and support for key features such as MIMO, multicarrier and modulation. More advanced UE categories which introduce new features, or new combinations of previously released features become available in the later releases. Release 7 HSPA introduces a new category UE which supports MIMO. However, release 7 also introduces lower category UEs. Figure 2-3 illustrates the introduction of new UE categories by release.

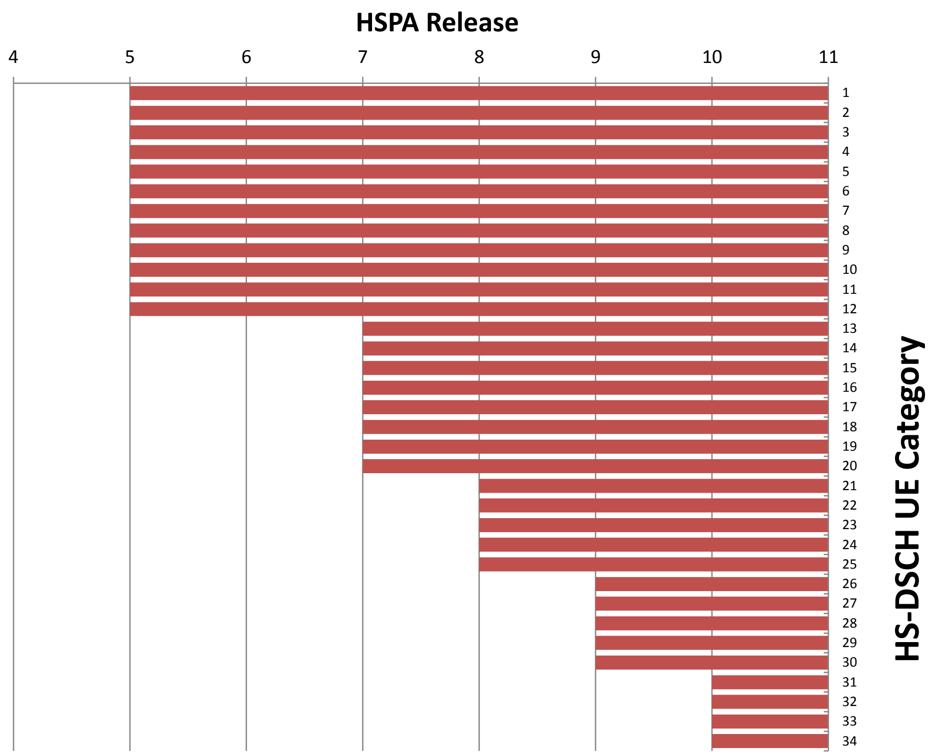

Figure 2-3 New categories are introduced in new releases, and old categories are still supported. Source, 3GPP 25.306[28]

The timing of device availability can be estimated as the publication of a given release plus some time for commercialisation, as described in Chapter 3. 3GPP UE Capability Specifications are 25.306[28] for HSPA and 36.306 for LTE[29].

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[28] "UTRA User Equipment (UE) radio access capabilities", 3GPP TS 25.306

[29] "E-UTRA User Equipment (UE) radio access capabilities", 3GPP TS 36.306

2.8.2 HSPA Roadmap

Category	Release	Peak Rate	carriers	modulation	MIMO layers	codes	code rate
1	5	1.2	1	16 QAM	1	5	3/4
2	5	1.2	1	16 QAM	1	5	3/4
3	5	1.8	1	16 QAM	1	5	3/4
4	5	1.8	1	16 QAM	1	5	3/4
5	5	3.6	1	16 QAM	1	5	3/4
6	5	3.6	1	16 QAM	1	5	3/4
7	5	7.2	1	16 QAM	1	10	3/4
8	5	7.2	1	16 QAM	1	10	3/4
9	5	10.1	1	16 QAM	1	15	3/4
10	5	14	1	16 QAM	1	15	1/1
11	5	0.9	1	16 QAM	1	15	3/4
12	5	1.8	1	QPSK	1	15	5/6
13	7	17.6	1	64 QAM	1	15	1/1
14	7	21.1	1	64 QAM	1	15	5/6
15	7	23.4	1	16 QAM	2	15	1/1
16	7	28	1	16 QAM	2	15	5/6
17	7	23.4	1	64QAM or 2 layer MIMO		15	1/1
18	7	28	1	64QAM or 2 layer MIMO		15	1/1
19	8	35.3	1	64 QAM	2	15	5/6
20	8	42.2	1	64 QAM	2	15	1/1
21	8	23.4	2	16 QAM	1	15	5/6
22	8	28	2	16 QAM	1	15	1/1
23	8	35.3	2	64 QAM	1	15	5/6
24	8	42.2	2	64 QAM	1	15	1/1
25	9	46.8	2	16 QAM	2	15	5/6
26	9	55.9	2	16 QAM	2	15	1/1
27	9	70.6	2	64 QAM	2	15	5/6
28	9	84.4	2	64 QAM	2	15	1/1
29	10	63.3	3	16 QAM	1	15	1/1
30	10	126.6	3	16 QAM	2	15	1/1
31	10	84.4	4	64 QAM	1	15	1/1
32	10	168.8	4	64 QAM	2	15	1/1

Table 2-7 HSDPA UE Categories sources: 3GPP 25.306[[28]]

HSDPA - downlink

3GPP rel HSPA	Modulation Support	MIMO Layers	Multicarrier Support	Pk DL rate Mbps	reference
rel7	64QAM	1	1x5MHz	21	2
rel7	16QAM	2	1x5MHz	28	2
rel8	64QAM	2	1x5MHz	42	1
rel8	64QAM	1	2x5MHz	42	1
rel9	64QAM	2	2x5MHz	84	1
rel10	64QAM	2	4x5Mhz	168	1
rel11+	64QAM	2	8x5MHz	336	1,3
rel11+	64QAM	4	8x5MHz	672	3

HSUPA – Uplink

3GPP rel HSPA	Modulation Support	MIMO Layers	Multicarrier Support	Pk DL rate Mbps	reference
rel6		1	1x5MHz	5.76	2,4
rel7	16QAM	1	1x5MHz	11.5	2,4
rel9	16QAM	1	2x5MHz	23	1,3
rel11+	16QAM	2	2x5MHz	46	1
rel11+	64 QAM	2	2x5MHz	70	3

Table 2-8 HSDPA Downlink Feature Combination Roadmap sources: [1] Qualcomm[30], [2][31], [3] Nokia Siemens Networks[32], [4][33]

Table 2-7 lists all HSDPA UE categories and their associated feature combinations. It can be seen that each release supports a number of different configuration options. Although both MIMO and 64 QAM are introduced in release 7, they cannot be used together in release 8. Dual carrier first appears in release 8, but cannot be used in combination with MIMO until release 9. These combination limitations impact the peak rates than can be achieved for each release.

Table 2-8 provides a roadmap of the highest performing HSDPA and HSUPA category for each release of the standard. There are many more categories than shown, but this indicates the capability of the highest capability device at any given time. Unlike LTE, categories are independent for the uplink and downlink.

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[30] "HSPA+ Advanced: Taking HSPA+ to the Next Level" Qualcomm, 25/1/2011, http://www.qualcomm.com/documents/hspa-advanced-taking-hspa-next-level

[31] http://en.wikipedia.org/wiki/High-Speed_Downlink_Packet_Access

[32] Long Term HSPA Evolution Mobile broadband evolution beyond 3GPP Release 10, Nokia Siemens Networks, Dec 2010, www.nokiasiemensnetworks.com/.../HSPA_evolution_white_paper_low_res_141220.pdf

[33] http://en.wikipedia.org/wiki/High-Speed_Uplink_Packet_Access

The highest modulation, MIMO layers and carriers supported all have a significant impact on the peak data rate that can be achieved.

2.8.3 LTE Roadmap

Downlink

3GPP rel	Modulation	MIMO	Multicarrier	Pk DL rate	reference
	Support	Layers	Support	Mbps	
rel8	64QAM	1	1x20MHz	10	5
rel8	64QAM	2	1x20MHz	50	5
rel8	64QAM	2	1x20MHz	100	5
rel8	64QAM	2	1x20MHz	150	5
rel8	64QAM	4	1x20MHz	300	5
rel10	64QAM	8	5x20MHz	3,000	5

Uplink

3GPP rel	Modulation	MIMO	Multicarrier	Pk DL rate	reference
	Support	Support	Support	Mbps	
rel8	16QAM	1	1x20MHz	5	5
rel8	16QAM	1	1x20MHz	25	5
rel8	16QAM	1	1x20MHz	50	5
rel8	64QAM	1	1x20MHz	75	5
rel10	64QAM	2	2x20MHz	150	5
rel10	64QAM	4	5x20MHz	1,500	5

Table 2-9 LTE UE Categories, source 3GPP 36.306 [34], [5][35]

Table 2-9 summarises the highest performing LTE categories in each release. Unlike HSDPA and HSUPA, the UE category applies simultaneously to both DL and UL to limit the number of different combinations. Categories define number maximum throughputs per 'transport block', and overall throughput, and maximum number of MIMO layers. The highest data rates require simultaneous transmission of multiple transport blocks per 1ms Transmission Time Interval (TTI). These can be transmitted over a combination of different MIMO layers, or different 'component carriers', where carrier aggregation is implemented.

Multicarrier and MIMO support is therefore flexible, with some freedom left to the implementation. Maximum number of component carriers and layers signalled to the network by the UE. e.g. a cat 8 device achieves 3Gbps peak downlink rate with 10 simultaneous transmissions – which could be 5 x 20MHz carriers of 2 layer MIMO. Support of 64QAM is mandatory in the DL, but device dependent in the UL.

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[34] "E-UTRA User Equipment (UE) radio access capabilities", 3GPP TS 36.306

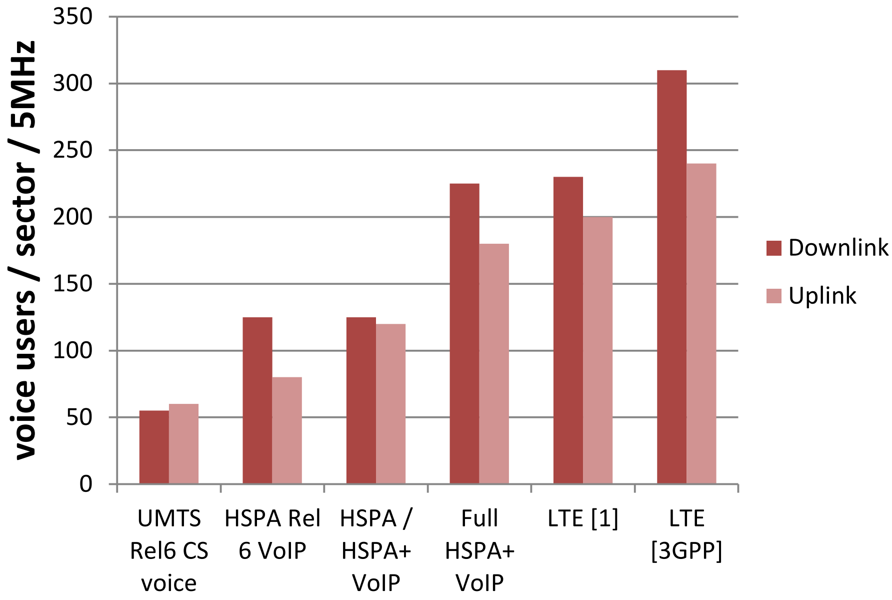
[35] "Proposal 8: UE categories for the Rel. 10 time frame", http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_62/Docs/R1-104944.zip

2.9 Voice Support

W-CDMA release 99 natively supports circuit switched (CS) voice over dedicated physical channels[36]. LTE is packet switched (PS) only and so voice must be supported over packet switching – Voice over IP (VoIP). HSPA+ rel8 supports both CS Voice over the High speed channels (over a CS core network), and VoIP (over the PS core).

“VoIP” is in principle supported by end user applications like Skype, but the industry is agreeing on native voice support based on IMS (IP Multimedia Subsystem)[37]. A GSMA Voice over LTE Initiative supported by 40 organisations in the mobile ecosystem has agreed on specifications for device and network-network interfaces, and is finalising roaming interfaces. The GSMA expects devices and services will appear late 2011 - early 2012.[38]

Figure 2-4 compares capacity of these different voice solutions in terms of maximum voice users per sector per 5MHz (assuming no data). Later releases provide higher capacity to the benefit of operators, who can support more calls with a given spectral and hardware resource.



Notes: The HSPA/HSPA+ result is based on a partial implementation of HSPA without MIMO or High order modulation LTE[1] is based on simulations by one vendor and LTE[3GPP] is based on an industry consensus, revealing the variation in the predictions

Figure 2-4 Voice Capacity for HSPA and LTE, source[39]

[36] "WCDMA for UMTS: HSPA Evolution and LTE", H.Holma, A.Toskala, Wiley, 2nd ed 2011

[37] “GSMA Leads Mobile Industry Towards a Single, Global Solution for Voice over LTE“ GSMA press Release

[38] Interview with GSMA on Voice over LTE http://www.youtube.com/watch?v=NEplrFb32rU

[39] “HSPA Performance and Evolution”, Tapia, Liu, Karimli, Feuerstein, Wiley 2009

2.10 Physical Layer Differences

2.10.1 Occupied bandwidth

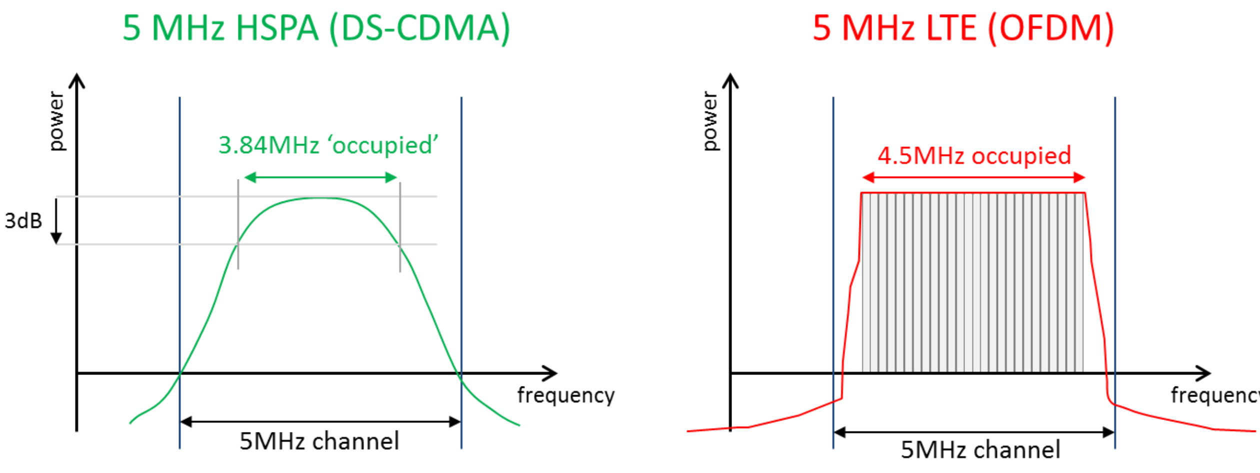


Figure 2-5 Occupied bandwidth in HSPA and LTE

Figure 2-5 compares the shape of the in channel spectrum for HSPA and LTE. HSPA uses a Direct Spread CDMA waveform with 3.84 Mchip/s, which is filtered to a spectral shape with a 3dB bandwidth of 3.84MHz. LTE uses an OFDM based multicarrier waveforms which occupies 4.5MHz when used in a 5MHz channel configuration. In both cases the 'unoccupied' bandwidth is needed as a roll-off region to ensure adequate protection for adjacent channels. Spectral efficiency calculations are based on the 5MHz channel bandwidth, and not the smaller 'occupied bandwidth'.

2.10.2 Loading and Stability

In Release-99 UMTS based on CDMA, resources are allocated to users by means of different spreading codes. As the network is loading, interference between the non-orthogonal codes and other cells requires increased transmit power. A theoretical limit is defined by 'pole capacity' where an additional user would require an infinite increase in transmit power from other users. In practice, as pole capacity is approached, the power increase required to maintain Eb/no targets gets larger and larger and the system becomes less stable. Call admission control is invoked at a certain loading level before the network becomes un stable.

HSPA uses codes with lower spreading factor of 16 compared to 128 or 256 used for voice bearers in rel.99[40]. This limits the number of users that can be simultaneously served, and so Time Division Multiplexing (TDM) is applied to on top of CDMA as loading increases [41]. With the CDMA based

[40] "Advanced receiver architectures for HSDPA and their performance benefits", Arunabha Ghosh and Richard A. Kobylinski, Texas Wireless Symposium 2005, https://www.utdallas.edu/~cpb021000/shared/pdfs/0000049.pdf

[41] "HSPA Performance and Evolution", Tapia, Liu, Karimli, Feuerstein, Wiley 2009

air interface, loading must be controlled both by limiting total power to maintain stability, and by Time Division Multiplexing of the High Speed Shared channels.

In the LTE downlink, the OFDM based air interface divides the available resources into a grid of orthogonal (frequency, time) units. These are shared out between users, so at higher loads, each user gets fewer resource units and consequently lower data rates. For very high loads, users data would need to be queued before resources become available for transmission. Hence higher loading results in increasing packet delays. QoS support in LTE can be used to ensure delay sensitive traffic (like voice) can jump ahead of delay tolerant traffic (like file transfer) in the queues, minimising the impact to user experience. Since resources in LTE are orthogonal, loading only increases packet delay and does not impact network stability as it does in CDMA. In practice, this might mean that LTE networks can be run 'hotter' than their HSPA equivalents.

2.10.3 Delay spread and system bandwidth, and the use of equalisers in HSPA

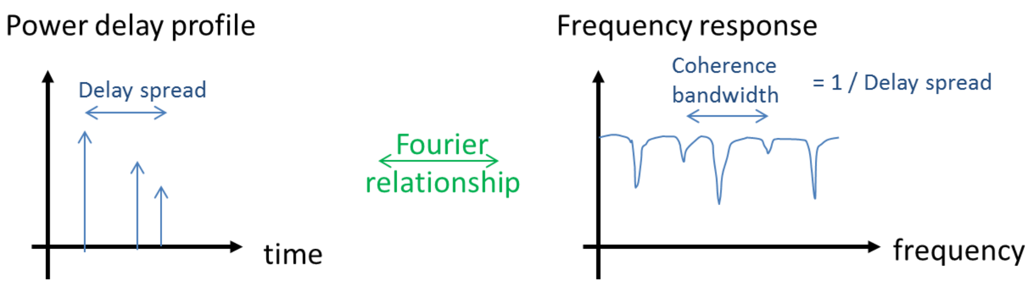


Figure 2-6 Key concepts for wireless channels

Multipath propagation in mobile access channels results in echoes of the signal arriving at different time intervals as shown in Figure 2-6. The second moment of the resulting 'power delay profile' is the delay spread of the channel. Multipath results in frequency selective fading in the frequency domain.

Early CDMA uses a Rake receiver to track multiple components. However such receivers do not work well with the low spreading factor HSPA in channels with large delay spread[42]. Their inability to resolve multipath results in a loss of orthogonally between codes. More modern HSDPA receivers are based on an equaliser technique which compensates for the

[42] "Advanced receiver architectures for HSDPA and their performance benefits", Arunabha Ghosh and Richard A. Kobylinski, Texas Wireless Symposium 2005, https://www.utdallas.edu/~cpb021000/shared/pdfs/0000049.pdf

frequency response to improve orthogonally, which has a corresponding improvement to signal quality as shown in Figure 2-7. According to [[43]],

"Today, most (if not all) of the HSDPA devices include an equaliser" (2009)

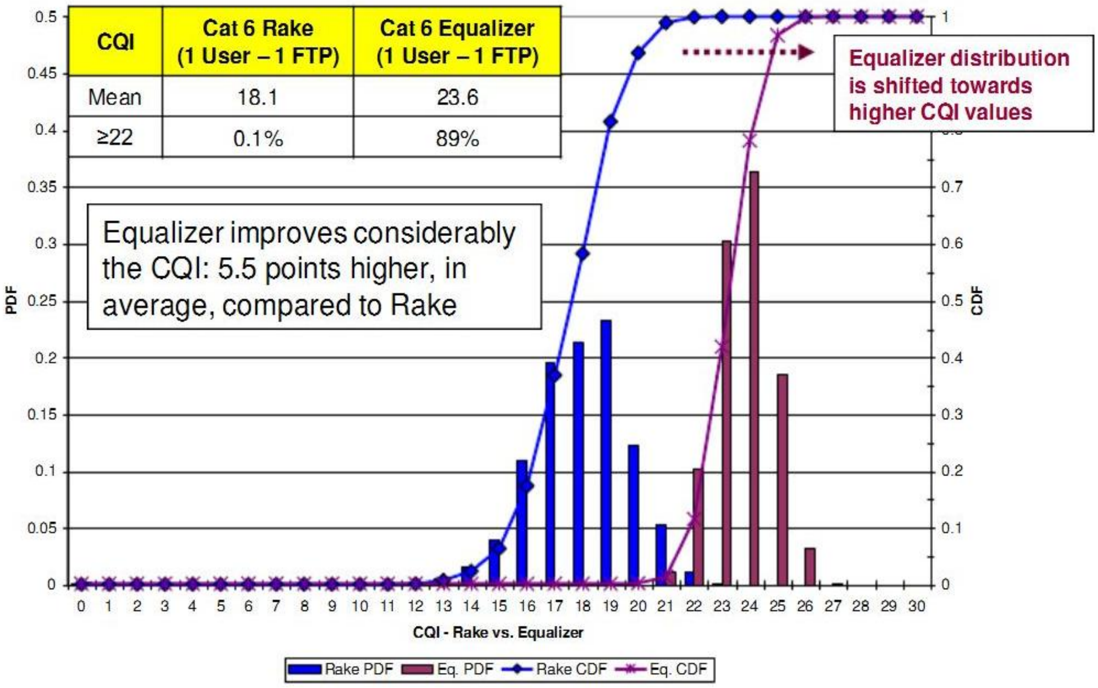


Figure 2-7 Benefit of Equalisers for HSDPA. Source: Qualcomm[44]

2.10.4 Frequency diversity

The power delay profile and frequency response of a channel are related to each other by the Fourier transform, as illustrated in Figure 2-6. Impulses or echoes in the time domain correspond to repeating cancellation nulls in the frequency domain. The repetition interval of these nulls is the coherence bandwidth which is equal to 1/delay spread. 'Wideband' systems such as CDMA and LTE are ones where the channel bandwidth is wider than the coherence bandwidth of the radio environment it operates in. Frequency diversity can be achieved where the system bandwidth is wider than the coherence bandwidth:

$$\text{Diversity order} \propto \frac{\text{system bandwidth}}{\text{coherence bandwidth}} = \text{system bandwidth} \times \text{delay spread}$$

HSPA mitigates frequency selective fading by spreading user data over a wide bandwidth LTE with a single user per cell can use Forward Error

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[43] "*HSPA Performance and Evolution*", Tapia, Liu, Karimli, Feuerstein, Wiley 2009, p242

[44] "*Examining HSDPA Performance In A Live Network*", Qualcomm, *10 March 2009,* http://www.scribd.com/doc/55329322/HSPA-Qualcomm-Workshop-2

Correction across a bandwidth wide transmission to mitigate the frequency selective fades. LTE with multiple users per cell can use frequency selective scheduling to exploit frequency diversity of the channel.

The wider system bandwidths of 10-20MHz available with LTE mean that a greater degree of frequency diversity can be achieved compared to the 5MHz carrier of HSPA. This is mitigated to some extent by multicarrier HSPA, although scheduling is per 5MHz carrier, and is much coarser than the scheduling per 180 kHz resource block in LTE.

2.11 QoS Support

Quality of Service support means that different traffic types can be prioritised during times of congestion. This means that delay sensitive traffic like voice and gaming can 'jump the queue' ahead of delay tolerant traffic like file transfer. Mechanisms to enable such prioritisation need to be implemented on an end to end basis, including the LTE Radio access network, the transport network (backhaul), and the core. A policy and charging function in the core network also needs to be aware of QoS assignments, deciding which UEs' traffic flows can be prioritised and assigning an appropriate charge.

QoS support exists for HSPA networks, providing 4 traffic classes each with 13 QoS attributes which specify bit rates, error rates, maximum transfer delays etc. The result is a complex implementation which in practice is not fully used[45].

QoS support is greatly simplified in the Enhanced Packet System (which comprises the LTE RAN and Enhanced Packet Core). Packets belonging to different data flows are 'tagged' with a QCI (Quality Class Indicator) label which is read by queue prioritisation functions throughout the network. Only 9 different QCI labels are specified, which reduces complexity compared to the many QoS parameters in HSPA. Table 2-10 outlines the nine QoS Classes supported EPS, and their associated QoS parameters. Packets in a particular flow need only to have the QCI label, and do not need to carry information about their QoS requirements. All the nodes throughout the network are pre-programmed to prioritise the labelled packets in such a way to meet delay and packet loss targets.

[45] "SAE and the Evolved Packet Core", M. Olsson et al, Academic Press 2009, pp164

Table 2-10: LTE QoS classes and recommended QoS Parameters[46]

QCI	Resource Type	Priority	Packet Delay Budget[47]	Packet Error Loss Rate	Example Services
1		2	100 ms	10^{-2}	Conversational Voice
2	GBR	4	150 ms	10^{-3}	Conversational Video (Live Streaming)
3		3	50 ms	10^{-3}	Real Time Gaming
4		5	300 ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
5		1	100 ms	10^{-6}	IMS Signalling
6	Non-GBR	6	300 ms	10^{-6}	Video (Buffered Streaming), TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100 ms	10^{-3}	Voice, Video (Live Streaming), Interactive Gaming
8		8	300 ms	10^{-6}	Video (Buffered Streaming), TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		9			

2.12 Performance roadmaps

Having introduced the features and combination thereof, this section now considers the performance that can be achieved. For each aspect we consider:

- Benefits for user: generally a better experience of the network
- Benefits for the operator: generally increased efficiency, which in turn reduces cost

In some cases there is a tradeoff between the consumer and operator benefit. Increased network performance could mean better performance for a given number of users, OR the same performance could be achieved with less network equipment.

2.12.1 Peak rates

Higher peak rates enable faster page download, faster filling of buffers for streaming content etc. Operators/device vendors can advertise peak rates to attract consumers to devices or network. MIMO and High Order Modulation increase link spectral efficiency when conditions allow, representing better exploitation of the environment.

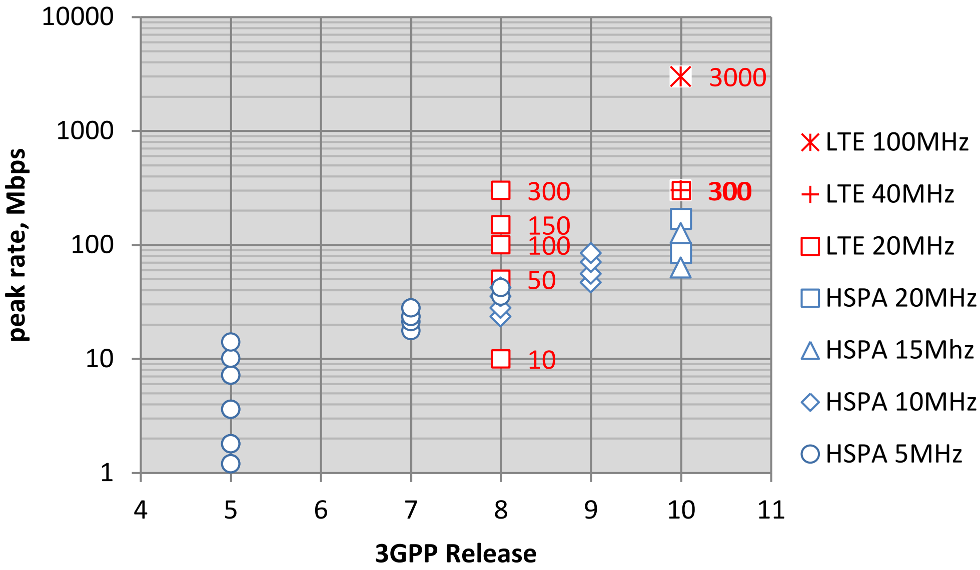
Figure 2-8 plots LTE and HSPA peak rates by release, showing that for a given release, the span of peak rates offered by LTE devices is higher than those of HSPA devices. Part of the reason why LTE achieves higher peak rates than HSPA is thanks to the wider channel bandwidths and degree of

[46] 3GPP TS 23.203, table 6.1.7

[47] The radio interface accounts for all but 20ms of this budget

carrier aggregation possible. However, this is also in part to the higher *link* spectral efficiencies possible, shown in Figure 2-9. This is perhaps a more fair comparison of the two technologies, and shows that LTE only achieves higher efficiency when 4 layer MIMO is used, which is not supported by HSPA. Note that LTE can also support 8 layer MIMO but in practice integrating this many antennas into a device is challenging[48].

Table 2-11 summarises the peak rate roadmap resulting from feature combinations per 3GPP release for both HSDPA and LTE.



Assumes 4 layer MIMO for LTE devices with 300Mbps or greater. 1 or 2 layer MIMO for all others according to the standards

[48] *Note that the category 8 LTE device is assumed to have 4 layer MIMO and operate in 100MHz spectrum. In theory this device could also operate in 50MHz with 8 layer MIMO, and would achieve twice the spectral efficiency of 60b/s/Hz*

Figure 2-8 LTE and HSPA peak rate roadmap, source: 3GPP[49], [50], Real Wireless analysis

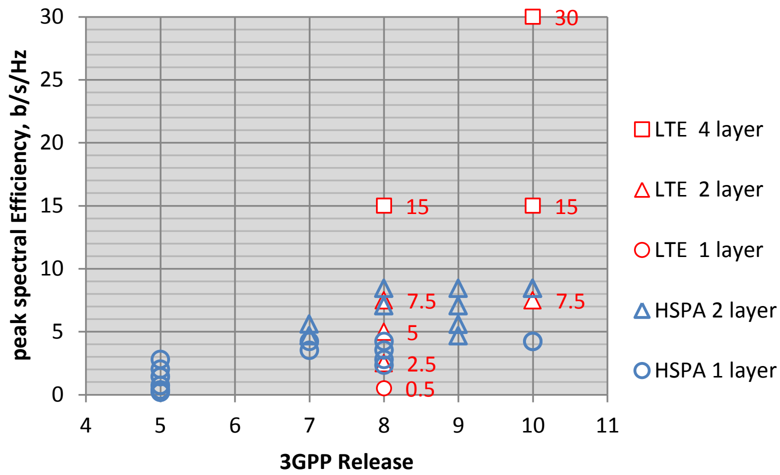


Figure 2-9 Peak Link Spectral Efficiency

3GPP Release (Freeze date)	HSPA		LTE	
	Peak rates	**Description of spectrum and technology required (bandwidth, UK-specific bands, antennas)**	**Peak rates**	**Description of spectrum and technology required (bandwidth, UK-specific bands, antennas)**
Rel 5-6 (Jun 02 – Mar 05)	14 Mbps	5 MHz, 2100 MHz, single antenna	N/A	N/A
Rel 7 (Dec 07)	28 Mbps	5 MHz, 2600, 2100, 1800 or 900 MHz, 64 QAM or 2 layer MIMO	N/A	N/A
Rel 8 (Dec 08)	42 Mbps	2 x 5 MHz, 2100, 2600, 1800 or 900 MHz., Dual carrier or 2 layer MIMO	300 Mbps	1.4 – 20MHz, 2100, 2600, 900MHz (up to 10MHz) 2 and 4 layer MIMO
Rel 9 (Dec 09)	84 Mbps	2 x 5 MHz, 2100, 2600, 1800, 900 or 800 MHz, 2 layer MIMO	300 Mbps	1.4 – 20MHz, 800, 2100, 2600, 900MHz (up to 10MHz) Up to 4 layer MIMO
Rel 10 (Mar 11)	169 Mbps	4x5 MHz, 3500, 2100, 2600, 1800, 900, 800 (including 1 x 5 MHz @ 900 & 3 x 5 MHz in 2100 MHz), 2 layer MIMO	3 Gbps	Up to 5 x 20MHz. 800, 2100, 2600, 3500 900MHz (up to 10MHz) up to 8 layer MIMO

Table 2-11 Roadmap for peak rate support in HSPA and LTE. Source: Real Wireless based on 3GPP

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[49] "UE Radio Access capabilities", 3GPP TS25.306

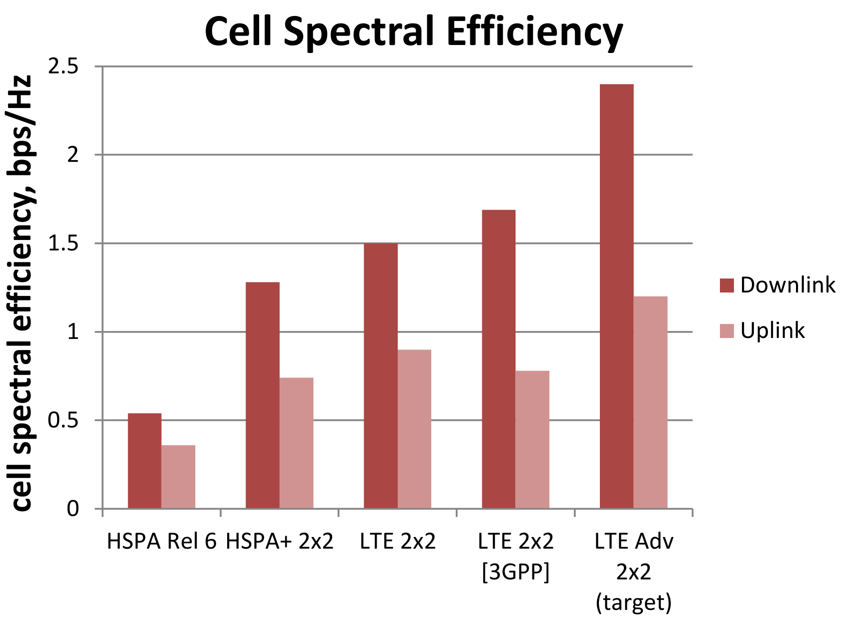
[50] "E-UTRA User Equipment (UE) radio access capabilities", 3GPP TS 36.306, v 10.1.0, 2011-03

2.12.2 Cell Spectral Efficiency

Whilst peak rates indicate the 'top speed' of the technologies, they are only achieved with the right conditions where there is only one device being served by a cell, and that device has excellent channel conditions (high signal quality and rich scattering where needed to provide orthogonal MIMO layers).

Cell spectral efficiency is a better indicator of the capacity of a technology in 'real world' loaded conditions. The units of bits per second per Hz per cell provide a benefit (bits per second) normalised to the cost (Hz of spectral resource and 'cell' representing a sector antenna and associated hardware)

Higher efficiency means reduced costs for operators to deliver a given level of service. Figure 2-10 compares cell spectral efficiencies for the various HSPA and LTE releases with comparable 2x2 antenna configurations.



Note: LTE and LTE [3GPP] represent a single vendor view and an industry consensus view, respectively, which illustrates the degree of alignment in results

Figure 2-10 Cell Spectral Efficiency, sources: Tapia [51], 3GPP[52]

Results in Figure 2-10 are obtained from simulations representing fully utilised large networks with many cells and many active devices continuously transferring data in each cell. The actual spectral efficiency achieved in practice will be limited by the availability and penetration of devices, the utilisation of the spectrum and the characteristics of traffic that consumers demand. Figure 2-11 indicates how spectral efficiency taking into account these factors and the device capability mix used by consumers at any given time, given assumptions regarding device availability

[51] "HSPA Performance and Evolution", Tapia, Liu, Karimli, Feuerstein, Wiley 2009

[52] LTE Adv Target from "Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced) (Release 10)", 3GPP 36.913 v10.0.0, March 2011

documented in a previous study for Ofcom. Clearly this lags behind the most recently specified feature sets.

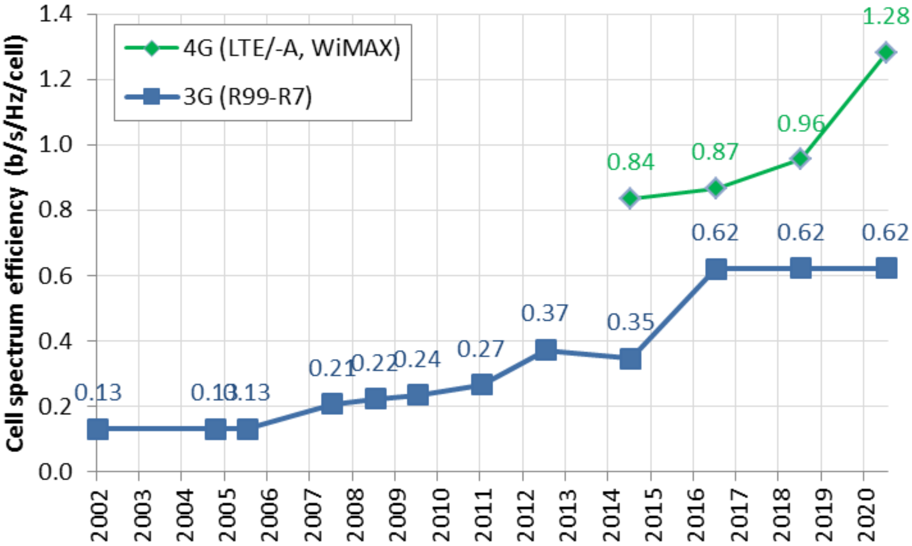


Figure 2-11 Cell Spectral Efficiency Evolution, Source Real Wireless[53]

2.12.3 Latency

There are several metrics which combine to make up overall latency as illustrated in Table 2-12.

Connection setup time is the time for a UE in idle mode (i.e registered but with no connection) to get to active mode (set up uplink and DL connections) ready to transmit IP packets. The consumer benefit of a lower connection setup time is a faster connection time gives rise to a sense of an 'always on' experience. The first web page in a session will appear sooner. The operator benefit of fast connection times mean idle connections can be dropped sooner to conserve resources without significant impact to user experience. This helps mitigate inefficiency of maintaining connectivity for 'chatty' applications.

Air interface latency and TTI are underlying metrics which impact U-plane latency, but in themselves are not directly experienced by consumers or operators. Air interface latency is the time for a single message to traverse the air interface. It is principally limited by the Transmission Time Interval (TTI). Benefits of low latency here are faster adaptation of the air interface to changing channel conditions, so better performance for high speed UEs. It also enables a faster reacting Hybrid ARQ mechanism, improving the trade-off between energy efficiency (rely heavily on re-transmissions), and latency (get it right first time). The shorter TTI therefore gives more flexibility of QoS mechanisms in the RAN to transport packets according to their Quality Class, described elsewhere. Air interface latency also contributes to user plane latency. One HSDPA test showed air interface comprised 81% of total end-end latency[55].

[53] Source: "*Ofcom 4G Capacity Gains*", Real Wireless December 2010

	HSPA (r6)	HSPA+ (r7)	LTE (r8)	LTE-Adv (r10)
Connection setup time	<1s [54]	<100ms [55]	<100ms[55]	target < 50ms[56]
Air interface (RTT)	~80ms [55]	<30ms [55]	<10ms[55]	<10ms[56]
Transmission Time Interval	2ms[54]	2ms[54]	1ms[57]	1ms[57]
End-End U-Plane (RTT)	**~100ms[55]**	**<25ms[58]**	**<25ms[59]**	**target: less than rel 8[56]**

Table 2-12 Latency Metrics for HSPA and LTE

U-plane latency is the time for the smallest unit of data to traverse from the UE modem to the edge of the core network. The consumer benefit of low latency is that connections react sooner to inputs, giving better experience of interactive tasks such as gaming, surfing, voice and video and cloud services. The Operator benefit of lower latency is that it enables a better service offering to attract consumers. An example can be found on Verizon Wireless' website for LTE[60].

2.13 Coverage

HSPA and LTE are both constrained by the same regulatory limits for EIRP, however there are differences which mean LTE can achieve a given data rate with a slightly higher path loss, and thus has a coverage advantage.

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[54] "LTE for UMTS, Evolution to LTE-Advanced", H. Holma, A.Toskala, 2nd Ed, Wiley 2011, p520

[55] "HSPA Performance and Evolution", Tapia, Liu, Karimli, Feuerstein, Wiley 2009

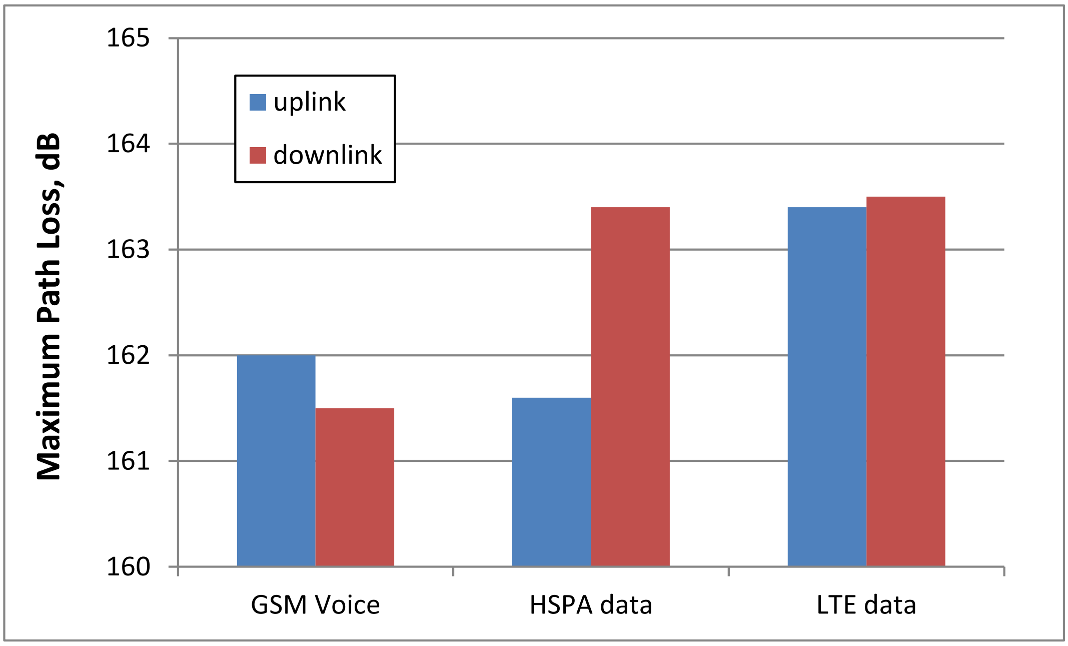
[56] "Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced)", 3GPP document TR 36.913 v10.0.0

[57] "*LTE the UMTS Long Term Evolution*", S. Sesia, I Toufik, M. Baker, Wiley 2009

[58] Real Wireless estimate based on air interface latency comprising 80% of air interface, as seen in [55], p120

[59] "*Latest results from the LTE/SAE Trial Initiative*", February 2009 http://www.lstiforum.org/file/news/Latest_LSTI_Results_Feb09_v1.pdf

[60] Verizon LTE website markets LTE with low user plane latency as "LTE Response Time is over 2x faster" http://network4g.verizonwireless.com/#/whatis4g



Assumes data service of 1Mbps download and 64Kbps upload

Figure 2-12 Maximum allowable Path Loss for GSM, HSPA and LTE. Source[61]

Figure 2-12 shows a summary of maximum allowable path losses based on detailed link budgets. Considering a data service of 1Mbps downlink and 64kbps uplink, the maximum path loss for LTE is within 0.1dB for uplink and downlink. This service is typical of a file download, where a small uplink bandwidth is needed for to send acknowledgements for received packets on the downlink. Assuming similar path loss on the downlink and uplink frequencies, the LTE service would likely fail on both uplink and downlink at similar ranges. Higher downlink data rates would likely result in downlink range limiting, and lower downlink rates, uplink limiting.

HSPA, has more imbalance, and such a service would likely be limited by downlink range. GSM provides a symmetrical voice service and is also balanced for UL and DL. In this analysis, LTE has a 1.8 dB uplink link budget advantage over HSPA. Figure 2-13 shows that this corresponds to a 23% increase in range for unobstructed ‘free space’ propagation labelled r^2. In a “r^4” propagation environment typical of a partially obstructed path over rooftops, 1.8dB corresponds to a range increase of 11%.

[61] *“LTE for UMTS: Evolution to LTE Advanced”*, Harri Holma, Antti Toskala, 2nd ed., Wiley 2010

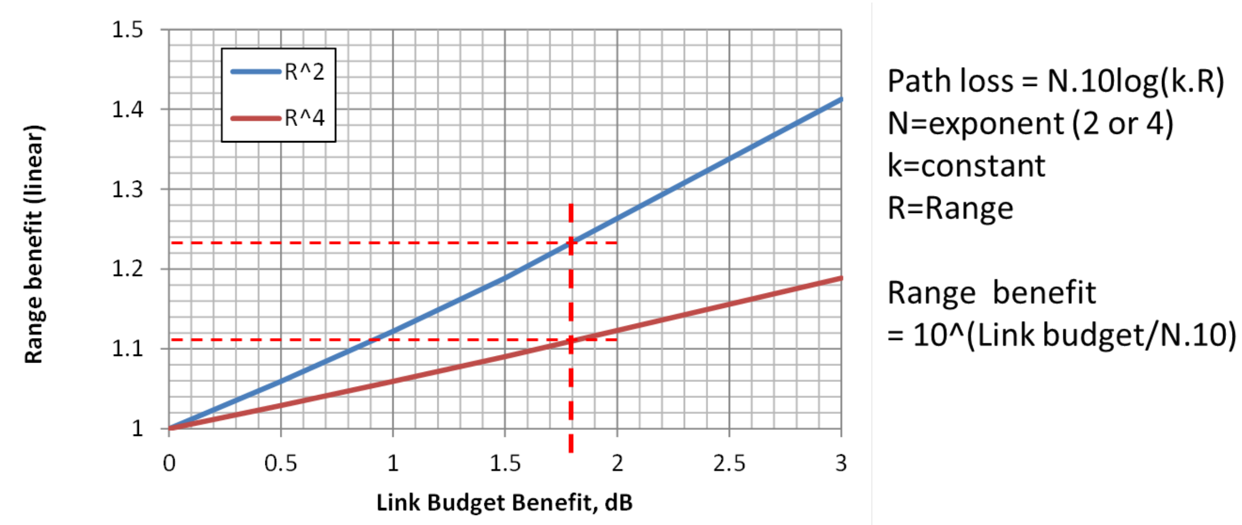


Figure 2-13 Range benefit (theoretical) for a given link budget benefit

2.14 Summary of HSPA vs. LTE performance

	Benefits of better performance		Technology			
Aspect	**Consumer**	**Operator**	**HSPA Rel 5-6**	**HSPA+ Rel 7-10**	**LTE Rel 8-9**	**LTE-Adv Rel 10**
Peak Rate	faster downloads	better service offering	14	up to 168 Mbps	300Mbps (4x4 MIMO)	up to 3Gbps
Cell Spectral Efficiency (DL)	potentially better QoS	more efficient use of spectrum and equipment	0.54 bps/Hz	1.28 bps/Hz	1.5 bps/Hz	2.4 bps/Hz
Coverage (UL)	Service available in more places	Wider site spacing, or higher coverage %	1.8dB UL link budget advantage for LTE corresponds to 11% greater range for r^4 propagation			
User plane Latency	Improves interactivity	better service offering	~100ms	<25ms	<25ms	< LTE rel 8
Connection setup time	feels 'always on'	drop idle connections sooner more efficient for chatty applications	~1s	<100ms	<100ms	<50ms
Carrier Bandwidths	wider BW improves data rates	Wider bandwidths more efficient than multiple individual ones	5MHz	5MHz	1.4,3,5,10,15,20 MHz	
Multicarrier support			1	2,3 or 4 x 5MHz	1	up to 5x20MHz
Bands supported for carrier aggregation			none	2100 (x3) + 900 (x1)	none	none
Voice support	should make no difference	PS enables higher efficiencies and ultimately can drop the CS core	CS	CS&PS	PS only	PS only
Voice capacity	should make no difference	more efficient use of spectrum and equipment	80	180	240	N/A

Table 2-13 Comparison of key performance criteria for HSPA and LTE

Table 2-13 summarises the key performance aspects described and gives figures for HSPA, HSPA+, LTE and LTE Advanced. In several areas, HSPA+ has similar performance to release 8 LTE. However the potential for wider bandwidths and more MIMO layers enables LTE-Advanced to promise significant improvements over previous generations.

Table 2-14 summarises key performance aspects comparing LTE with HSPA for a given release. Freeze dates per release are taken from 3GPP and lag time to commercial and mass adoption dates based on Real Wireless and Informa analysis.

3GPP Release		Rel 5-6	Rel 8	Rel 9	Rel 10
Standards Freeze		**Jun 02**	**Dec 08**	**Dec 09**	**Mar 11**
UK Commercial		**Jun 03**	**Jan 13**	**Jul 14**	**Jan 16**
Mass adoption		**May 04**	**Jan 15**	**Jul 16**	**Jan 18**
Peak Rates	HSPA	14 Mbps	42Mbps	84 Mbps	169 Mbps
	LTE	-	300 Mbps	300 Mbps	3 Gbps
Capacity (Cell Spectral Efficiency)	HSPA	0.54 bps/Hz	1.28 bps / Hz		
	LTE (2x2)	-	1.5 bps/Hz	1.5 bps/Hz	2.4 bps/Hz
User Plane Latency	HSPA	~100ms	<25ms		
	LTE	-	<25ms	<25ms	<LTE Rel 8
Connection Setup time	HSPA	~1s	<100ms		
	LTE	-	<100ms	<100ms	<50ms
Carrier Bandwidth and multicarrier support	HSPA	5MHz x 1	5MHz x 2	5MHz x 2	5MHz x 4
	LTE	-	1.4-20MHz x 1	1.4-20MHz x 1	1.4-20MHz x 5

Table 2-14 Comparison of key performance criteria for LTE and HSPA by Release. Sources for dates: 3GPP[62], Real Wireless[63], Informa[64]

[62] 3GPP Work plan (incl rel 12) http://www.3gpp.org/ftp/Information/WORK_PLAN/Description_Releases/

[63] "4G Capacity Gains", Real Wireless, January 2011, http://stakeholders.ofcom.org.uk/market-data-research/technology-research/2011/4G-Capacity-Gains/

[64] "Future of Mobile Networks Report", Informa, Media and Telecoms, 2010

3 Commercial device availability and frequency band support

3.1 Introduction

The following section investigates the commercial availability of HSPA and LTE devices and the frequency bands they support with a particular focus on the European harmonised bands and devices likely to be available for use in the UK. The section presents two perspectives relating to device availability:

- Public announcements of products available on the market
- Research on unannounced product roadmaps

The first part of this section specifies the number and types of devices supported in each of the frequency bands of interest, thus providing a status of the device market as of the present day.

The second part of this section provides a brief overview of research conducted by Rethink Research on product roadmaps for devices and the bands to be supported in future as captured from a variety of vendors and operators.

3.2 HSPA and LTE devices available in current and upcoming UK frequency bands

Penetration and proliferation of mobile devices on operators' networks has seen significant growth[65] in the last few years with the emergence of mobile broadband USB modems, smartphones and tablet PCs. The technology, features and functionality has also evolved from 'quad band' phones to devices now supporting a greater number of licensed mobile bands, including:

- 700 MHz
- 800 MHz
- 900 MHz
- 1800 MHz
- 1900 MHz (US for roaming)
- 2100 MHz
- 2600 MHz

USB modems were a key driver behind the increase in uptake of mobile broadband services and applications along with the deployment and upgrade to the UK's 3G networks to HSPA. The 2100 MHz band was the first frequency band to support HSPA technology in the UK and early devices required only a single band to support this in uptake.

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[65] Cisco VNI 2011 http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

In 2009 the 900 MHz and 1800 MHz bands became liberalised and HSPA devices across Europe began to support 900 MHz. This has led to an increase in the number of devices supporting both HSPA and LTE technologies in the last 18 months. The following sections identify the number devices commercially available across each of the spectrum bands listed above and the types of form factor for HSPA and LTE technologies.

The Global Mobile Suppliers Association (GSA) provides regular updates of global mobile broadband network deployments in both HSPA and LTE technologies. The following section captures the latest device availability that support mobile frequency bands used or due for release in the UK.

This section presents each band in ascending order of frequency, providing factual data on the number of devices and the frequencies they support and the different form factors that are available on the market.

Mobile devices typically take different forms and those providing a choice to consumers mainly fall into five core categories, these include:

- Handsets/Smartphones
- Tablets
- USB modems
- Embedded modules (Laptops/Netbooks)
- Routers

However, other form factors are also considered in this section that form part of the wider ecosystems and these include:

- PEM (PC Express Mini) cards
- Chipset modules (for phones, tablets and other consumer devices)

3.3 Timeline for LTE device availability

Since February 2011 there have been approximately 70 new devices released for LTE in the form factors listed above. The total number of LTE-enabled user devices now available is 197 (As of end October 2011). These devices span all standard frequency bands from 700 MHz to 2600 MHz. A breakdown of the devices now available per frequency band is given below[66]:

- 700 MHz (US Digital Dividend) 106 devices
- 800 MHz (EU Digital Dividend, Band 20) 42 devices
- 900 MHz (Band 8) 5 devices (June '11)
- 1800 MHz (Band 3) 41 devices
- 2600 MHz (Band 7) 52 devices
- 800/1800/2600 MHz 32 devices
- AWS (Band 4) 35 devices

It is noted that out of these devices 118 also support HSPA and 135 support the 800, 1800 MHz and 2600 MHz bands.

Multiband devices, particularly USB modems, have increased the speed of device development and release on to the market. It typically takes two to

[66] GSA, Status of the LTE Ecosystem October 28, 2011

three years from standards freeze to devices becoming commercially available and another three years for mass deployment. Figure 3-1 provide a view of the expected time between standards publication (corresponding to the 'freeze dates' specified in Chapter 2), commercial launch and availability to 50 million subscribers globally [67] .

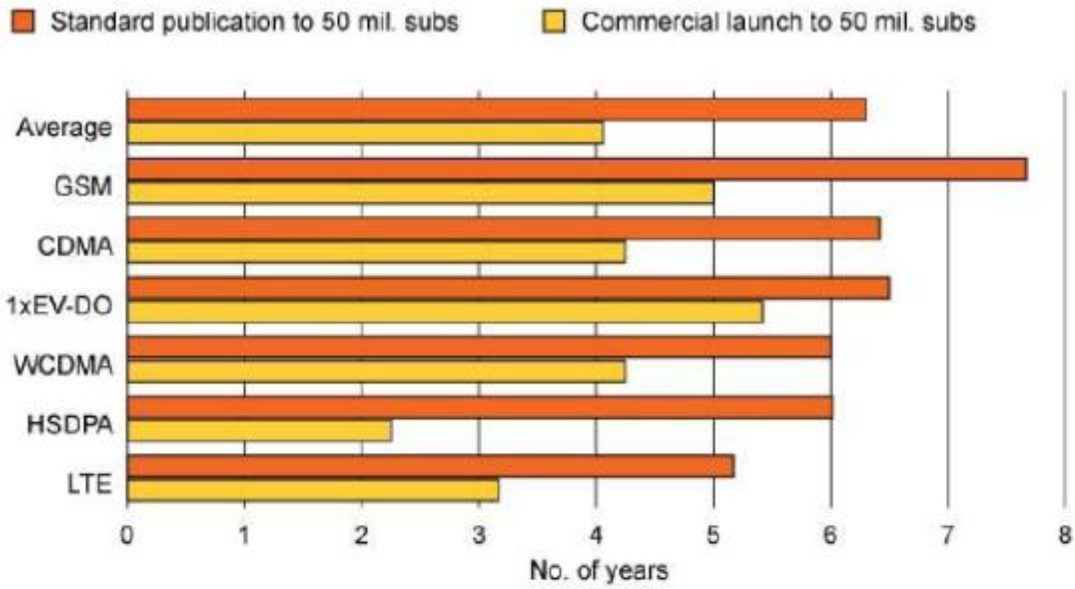

Figure 3-1 Mobile system years to reach 50 million subscribers (Source: Informa Telecoms and Media[67])

The first smartphone devices which support the European spectrum bands for LTE 800 MHz, 1800 MHz and 2600 MHz frequency bands have recently come to market. The Samsung Galaxy S II LTE[68] handset and the Samsung Galaxy Tab 8.9[68] tablet are now available on the market and meet the 3GPP Release 8 specification for LTE.

3.4 HSPA and LTE mobile device availability

3.4.1 800 MHz HSPA devices

There is one device available which supports HSPA at 800 MHz which is a PC Mini Express Card[69]. Besides this device no further published information was found on devices which support HSPA in this band.

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[67] Future of Mobile Telecoms, Informa Telecoms and Media, 2010

[68] Samsung Mobile Press August 2011 http://www.samsungmobilepress.com/2011/08/28/Samsung-speeds-up-the-Smarter-Life-with-LTE-versions-of-the-GALAXY-S-II-and-GALAXY-Tab-8.9

[69] Qualcomm, http://www.qualcomm.com/documents/files/gobi-3000-product-sheet.pdf

Commercial investment from vendors, device development and support in the 800 MHz band has been predominantly focused on LTE technology.

3.4.2 800 MHz LTE devices

There is significant vendor support for LTE devices in the 800 MHz band with 42 commercially available in several form factor types including chipsets, dongles, phones, tablets and routers. 36 of the devices also support other frequency bands including 1800 MHz and 2600 MHz.

Particular LTE 800 devices include:

- A baseband processor, the Altair FourGee 3100[70] is a baseband processor which can be incorporated into handsets, dongles and other consumer electronic devices.
- Samsung and ZTE have produced tablets and smartphones that can operate on the 800 MHz band and the 1800 MHz and 2600 MHz bands. The Samsung Galaxy S2 LTE and ZTE V5L are two example handsets and the Samsung Galaxy Tab 8.9 and ZTE V11L are two example tablets. These devices also fall back to HSPA as part of the dual mode and form the first devices of this type supported in the band.
- Nokia's LTE-capable multi-mode multi-band Internet USB Modem RD-3 has been commonly used in recent 800 MHz trials such as the first test call conducted in Finland[71].

3.4.3 900 MHz HSPA devices

Devices that support this band are growing rapidly. They usually also support the 2100 MHz band as increasing number of operators begin to deploy 3G in the 900 MHz spectrum.

The following example commercial 900 MHz HSPA deployments have been sourced from GSA Mobile Broadband Global Update and Evolution June 2011[72]. Devices used in these deployments support at least 3GPP Release 6 with some operators, notably 3 in Sweden, supporting HSPA Release 8 with DC-HSPA.

- Cell C South Africa HSPA+ Rel 7 using ZTE equipment
- Elisa Finland HSPA
- Faroese Telecom Faroe Islands HSPA+
- CSL Hong Kong HSPA
- Vodafone Romania HSPA+
- Three in Sweden HSPA+ (84 Mbps)
- AIS Thailand HSPA

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[70] Source: Altair, http://www.altair-semi.com/3gpp-lte-baseband-processor-fourgee-3100

[71] Nokia Siemens, http://www.nokiasiemensnetworks.com/news-events/press-room/press-releases/nsn-and-nokia-conduct-first-lte-call-at-800-mhz)

- O2 UK – Multiple UK cities

The number of devices supporting HSPA in this band has grown to 663[72] including: Apple iPhone 4 and 4S, iPad2, Samsung Galaxy S, Blackberry Playbook, Nokia N8, HTC HD7 etc.

There were 182 HSPA+ 900 MHz devices as at Spring 2011 including BandRich PR40 series pocket router, Novatel Wireless USB modem Ovation MC545 capable of supporting 42 Mbps.

addition, there is a growing number of device form factors becoming available in this band apart from standard handsets which include USB dongles, smartphones, tablets, embedded laptops, netbooks, e-readers etc.

3.4.4 900 MHz LTE devices

Reports suggest [72] operators are focusing on WCDMA/HSPA/HSPA+ deployments in the 900 MHz band.

However, Value Partners[73], forecast a timeline for mass market adoption of LTE900 over the next 5 to 10 years. LTE chipsets being developed are beginning to support 900 MHz, such as those from Infineon, ST Ericsson, Altair. Some example trials of LTE use in the 900 MHz band include, Cosmote in Greece and Magyar Telecom in Hungary who are each testing and trialling LTE technology[74]. Additionally, Cell C[75] in South Africa are conducting LTE trials in existing 900 MHz spectrum

3.4.5 1800 MHz HSPA devices

There are no commercially available HSPA devices that support the 1800 MHz band on the market at present. One UMTS/HSPA 1800 trial network has been identified in France, Orange have trialled HSPA in the 1800 MHz band using Ericsson BTS and Qualcomm devices[76].

The trial commenced in November 2010 using a Qualcomm RTR 8600 chipset which supports DC-HSPA, LTE, EDGE and GPS.

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[72] GSM/3G Market Update GSA, Oct 11
http://www.gsacom.com/downloads/pdf/UMTS900_information_paper_281011.php4

[73] Mobile data trends and the implications for telecom operators, Value partners Vietnam, June 2011 http://www.valuepartners.com/VP_pubbl_pdf/PDF_Comunicati/Media%20e%20Eventi/2011/value-partners-Mobile-data-trends-and-the-implications-for-telecom-operators-Jenna-Hanoi.pdf)

[74] GSA October 2010 GSM/3G technology market update

[75] ITWeb, June 2011 http://www.itweb.co.za/index.php?option=com_content&view=article&id=44719:sas-lte-commitments-lag&catid=44)

[76] http://www.lightreading.com/document.asp?doc_id=195338

3.4.6 1800 MHz LTE devices

The most recent report (November 2011) from the GSA "Embracing the 1800MHz opportunity: Driving mobile forward with LTE in the 1800MHz band[77]" provides some insights and contributions from operators and vendors that are involved with trials and deployments of LTE in the 1800 MHz band.

The report highlights the growing interest and opportunities for LTE1800 stating 23 firm deployment commitments from global operators. In addition, there are 6 LTE1800 networks commercially launched in Europe.

There is vendor support for 41 LTE devices currently which include a mixture of form factors such as chipsets, routers, tablets, dongles and phones. The majority of these devices fall back to HSPA/HSPA+ and in some cases support DC-HSPA+.The majority of the devices supporting this band also support other frequency bands such as 800 and 2600 MHz for LTE.

Samsung and ZTE have produced tablets and smartphones that can operate on the 1800 MHz band (and the 800 MHz and 2600 MHz bands). The Samsung Galaxy S2 LTE and ZTE V5L are two example handsets and the Samsung Galaxy Tab 8.9 and ZTE V11L are two example tablets that are commercially available. These devices also fall back to HSPA as part of the dual mode and form the first devices of this type supported in the band.

3.4.7 2100 MHz HSPA devices

The 2100 MHz band is one of the most widely supported bands for mobile devices. This is based on the number of operator deployments of networks in this band with over 166 operators across Europe (including approximately 20 UMTS900 deployments in Europe) who have deployed HSPA networks. The GSA reported[78] around 3227 HSPA devices are now commercially available from over 264 suppliers with 2457 HSPA devices operating in this band.

All mobile operators in the UK have deployed HSPA in their 2100 MHz networks with maximum DL speeds of at least 7.2 Mbps. According to a GSA market analysis[79] 3 and O2 have already deployed HSPA+ with O2's network reaching maximum download speeds of 42 Mbps.

The types of devices found on the market include USB dongles, smartphones, embedded laptops, data cards and routers including personal MiFi. Around 25% growth in devices available took place between September 2010 and September 2011.

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[77] Embracing the 1800MHz opportunity: Driving mobile forward with LTE in the 1800MHz band, GSA, November 2011, http://www.gsacom.com/news/gsa_342.php4

[78] GSA Mobile broadband market update and outlook for GSM, WCDMA-HSPA/HSPA+ and LTE, September 2011, http://www.gsacom.com/downloads/pdf/GSA_Global_mobile_market_update_and_outlook_220911.php4

[79] GSA, GSM/3G market/technology update April 2011 http://www.gsacom.com/downloads/pdf/global_ehspa_network_commitments_080411.php4)

3.4.8 2100 MHz LTE devices

There is currently no evidence of any European countries supporting LTE in this band. The contrary evidence from the GSA and GSMA suggests that European countries are predominantly planning to deploy LTE in new spectrum such as 2.6 GHz rather than 2100 MHz [80]

However, NTT DoCoMo has deployed LTE in the Japanese version of this band and some analysts suggest this should be the global roaming band for LTE[81]. European operators are focusing on enhancing services in 2.1 GHz spectrum to HSPA+ and DC-HSPA+ including Spain, Sweden, Italy and Portugal[82].

3.1.1 2600 MHz HSPA devices

The 2600 MHz band was originally designated as the ‘3G expansion band’ by the ITU configured with (3G) systems in mind. However, there is little evidence of HSPA being deployed in the 2600 MHz band. Operators holding fresh 2600 MHz spectrum have either already deployed LTE or are planning to deploy LTE[83] in future.

The 3GPP standards do support HSPA at 2600 MHz but no commercially available devices that offer HSPA in this band have been found at present.

3.1.2 2600 MHz FDD LTE devices

In Europe, the 2600 MHz band was the first to have LTE technology deployed by Teliasonera in Sweden at the end of 2009. A single mode/band USB modem (Samsung GT-B3710 USB modem[84]) was the only device available at launch to access the network. There are currently (Oct 2011) 52 devices that support the 2600 MHz band according to the GSA report[85] from numerous vendors including, ZTE, Samsung, BandRich and Huawei.

Device types include, embedded modules, tablets, phones, PC Cards, notebooks, routers, and USB dongles. More than 50% of the devices support multiple bands including 800 MHz and 1800 MHz and also support other technologies such as HSPA/HSPA+.

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[80] GSMA http://www.gsmamobilebroadband.com/networks/ and GSA Mobile broadband market update and evolution http://www.gsacom.com/downloads/pdf/GSA_MBB_Update_May_2011.php4)

[81] Maravedis Research UK 2011 http://www.mobileslte.org/wp-content/uploads/2011/02/Top-100-LTE-Anbieter-2011.pdf

[82] GSA GSM/3G market/technology update April 2011 http://www.gsacom.com/downloads/pdf/global_ehspa_network_commitments_080411.php4

[83] GSA, GSM and 3G market and technology update April 2011, http://www.gsacom.com/downloads/pdf/global_ehspa_network_commitments_080411.php4

[84] Samsung USB modem http://www.samsung.com/us/aboutsamsung/news/newsIrRead.do?news_ctgry=irnewsrelease&news_seq=15946

The GSA June 2011 report revealed ZTE[85] were the only vendor to offer a tablet and phone in this frequency band and Samsung is the only company to offer a notebook in this frequency band and IP Wireless offering a PC Card. However, since the June 2011 report Samsung has released the Galaxy S II and the Galaxy Tab 8.9 to widen the choice of vendor handsets and tablets in this band.

The device ecosystem in this band has been developing rapidly over the last 18 months both in terms of multi band support and multi-mode support. The Samsung GT-B3710, for example, was the first USB modem commercially released in 2009, which later evolved to GT-B 3730 in late 2010 which supported both LTE and HSPA+ technologies.

There were 9 live commercial networks in Europe and 4 trial networks as of June 2011 which included:

Commercial networks in Europe:

- Austria (2)
- Sweden (2)
- Finland (2)
- Estonia
- Denmark
- Norway

Trial networks in Europe:

- France
- Italy
- Germany
- UK

3.4.9 2600 MHz TD-LTE devices and TD-LTE in general

China Mobile leads the development of TD-LTE with the recent completion of a pilot network in September 2011[86].

There are 16 TD-LTE trials currently underway outside of China including:

- Australia
- Denmark
- France
- Germany
- India
- Ireland
- Malaysia (2)
- Japan
- Oman

[85] GSA, GSA LTE ecosystem report June 2011 http://www.gsacom.com/downloads/pdf/GSA_LTE_ecosystem_report_June_2011_130611.php4

[86] http://www.rethink-wireless.com/2011/11/16/softbank-china-mobile-tout-td-lte-progress.htm

- Poland
- Russia
- Taiwan
- USA

In Europe specifically, trials have been taking place in Spain, Sweden and Germany:

- Vodafone Spain has been conducting TD-LTE trials in their 2600 MHz spectrum achieving DL speeds of 60 Mbps and UL speeds of 25 Mbps[87]
- Hi3G in Sweden is planning to deploy a dual mode TDD/FDD LTE network at 2600 MHz with support from ZTE[88]
- E-Plus[89] in Germany launched a TD-LTE field trial in their 2.6 GHz spectrum in Q1 of 2011. This trials is being supported by ZTE and China Mobile

Numerous chipset vendors are conducting interoperability testing to establish co-existence between different products including:

- Altair Semiconductors[90] has developed a chipset for this band suitable for use in USB dongles, data cards and handsets
- Device manufacturers are discussing device roadmaps at the Global TD-LTE Initiative (GTI) [91]
- Huawei demonstrated TD-LTE at Shanghai World Expo using HiSilicon TD-LTE chipset[92]
- In 2010 Motorola showcased its TD-LTE USB dongle supporting both 2300 and 2600 MHz[93]
- Nokia also support both 2300 and 2600 MHz devices within their product portfolios[96]
- Apple is readying a TD-LTE phone for China Mobile[94]. However, this is for China Mobile's 2.3 GHz network and cannot be used in the 2.6 GHz band

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87 4G Trends, April'11 http://www.4gtrends.com/articles/30180/lte-reported-speeds-present-a-confused-and-confusi/

88 Fierce Broadband Wireless, March '11 http://www.fiercebroadbandwireless.com/story/swedens-hi3g-ups-ante-lte-game-dual-mode-tddfdd-network/2011-03-31

89 ZTE , Feb '11 http://wwwen.zte.com.cn/en/press_center/news/201102/t20110217_220157.html

90 Altair Semiconductors http://www.altair-semi.com/altair-semiconductor-unveils-td-lte-reference-design-wireless-terminal-manufacturers

91 Global TD-LTE Initiative www.lte-tdd.org

92 Huawei The LTE Dream is Coming True http://www.tessco.com/yts/partner/manufacturer_list/vendors/huawei/pdf/huawe_lte_brochure.pdf

93 Mobile underground info http://www.mobileunderground.info/showthread.php?t=9329&page=1

Two independent analyses have also forecast the deployment and growth of TD-LTE in the next 2 to 3 years:

- HSBC[95] believes TD-LTE will be a commercial standard in 2-3 years with FDD and TDD baseband chipsets integrated in 1-2 years as of 2011
- Ovum[96] forecasts 89 million TD-LTE connections by 2015 with main deployments in China, India and Russia

3.4.10 3500 MHz LTE devices

3GPP Release 10, frozen in March 2011, included support for the 3.5 GHz band for LTE and HSPA. 3GPP TR 37.801[97] is a new work Item that incorporated UMTS/LTE technology in the 3500 MHz band and a frequency band arrangement to allow support for both FDD and TDD operation.Given general trends[98], devices supporting this band could be available 12-18 months after standards. However, no specific evidence of vendors developing 3500 MHz LTE devices was found.

3.5 Summary of mobile device availability for LTE and HSPA

The summary in Table 3-1 shows a snapshot of the specific device types across each of the frequency bands used in Europe as of June 2011. The trend in terms of number of devices supported across all frequencies shows the top three bands supported are the 800, 1800 and 2600 MHz:

- 26 devices supported in 2600 MHz
- 19 devices supported in 800 MHz
- 17 devices supported in 1800 MHz

In terms of form factor, USB modems and routers are the two leading device types emerging on the market that support all three frequency

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[94] GSM Arena ,May 2011
http://www.gsmarena.com/apple_is_prepping_a_tdlte_capable_iphone_for_china_mobile-news-2672.php

[95] HSBC http://www.research.hsbc.com/midas/Res/RDV?p=pdf&key=JzvnUIUvcR&n=293267.PDF

[96] Global Opportunities for TDD LTE, Ovum, Feb 2011 Global TD-LTE Initiative www.lte-tdd.org

[97] 3GPP TR 37.801 3rd Generation Partnership Project; Technical Specification Group Radio Access Networks;

UMTS-LTE 3500 MHz Work Item Technical Report (Release 10)

[98] 4G Americas LTE Devices Today and Tomorrow, 4G World 2010, Karthik Arumugam October 2010

bands. There are currently two smartphones and two tablets that support these frequency bands.

Band	Total number of devices	No. of USB modems	No. of Phones	No. of module	No. of Routers	No. of PC Cards	No. of Notebooks	No. of tablets
800 MHz	19	9	1	2	6	0	0	1
900 MHz	5	1	0	2	2	0	0	0
1800 MHz	17	10	1	2	3	0	0	1
2100 MHz	8	3	0	3	2	0	0	0
2600 MHz (FDD)	26	13	1	3	4	1	2	1
2600 MHz (TDD)	5	1	0	2	1	1	0	0
3500 MHz	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 3-1 Summary of device types per band and form factor as of June 2011

Band	Total number of devices
800 MHz	42 (Oct ’11)
900 MHz	5 (June ’11)
1800 MHz	41 (Oct ’11)
2100 MHz	8 (June ’11)
2600 MHz (FDD)	52 (Oct ’11)
2600 MHz (TDD)	17 (Oct ’11)
3500 MHz	N/A

Table 3-2 Summary of device types per band October 2011 (excluding form factor)

Since June 2011 there has been a rapid increase in the number of devices available. In the case of 2600 MHz, the number of devices has now doubled since June 2011 which now supports this band. In the case of both the 800 MHz and 1800 MHz, more than double the number of devices are now available, compared to June 2011. The rankings in terms of number of devices supported by band include:

- 52 devices supported in 2600 MHz
- 42 devices supported in 800 MHz
- 41 devices supported in 1800 MHz

3.6 Summary of devices by frequency band and technology

HSPA 2600 MHz band summary

- No evidence of 2.6 GHz devices found

HSPA 2100 MHz band summary

- 3071 HSPA devices from 262 suppliers
- 2318 HSPA devices operate in this band
- Device types include USB dongles, smartphones, embedded laptops, data cards and routers including personal MiFi

HSPA 1800 MHz band summary

- 1 UMTS/HSPA 1800 trial network identified in France
- No commercial services found

HSPA 900 MHz band summary

- 32 Global and 20 European UMTS900 commercial networks in operation as of June 2011
- 663 HSPA devices available for use in this band which includes: Apple iPhone 4, iPad2, Samsung Galaxy S, Blackberry Playbook, Nokia N8, HTC HD7 etc
- 45 DC-HSPA+ devices available from Spring 2011 including BandRich PR40 series pocket router, Novatel Wireless USB modem Ovation MC545 capable of supporting 42 Mbps
- Number of UMTS900-HSPA user devices launched has almost doubled in past year
- O2 has upgraded to HSPA+ in 2011 delivering speeds up to 21 Mbps

HSPA 800 MHz band summary

- 1 device from Qualcomm PC Mini Express Card was found
- No commercial services found

LTE 3500 MHz band summary

- There are currently no commercially available devices supported in this band, but standards supporting the band were published in March 2011.

LTE 2600 MHz band summary

- Currently supports the largest selection and mix of commercial devices with 52 FDD and 17 TDD in total including USB modems, tablets and handsets
- More than 19 out of 69 devices support multi-frequency
- More than 20 out of 69 devices support multi-mode with a mixture of HSPA, HSPA+ and DC-HSPA+

LTE 2100 MHz band

- Currently supports a collection of 8 different devices
- 6 out of the 8 devices support multi-frequency
- All devices support multi-mode with a mixture of HSPA, HSPA+ and DC-HSPA+

LTE 1800 MHz band summary

- Supports a well-established mix of devices with a total of 41 different devices including dongles, tablets and handsets
- All devices support multi frequency
- More than 15 out of the 41 devices support multi-mode with a mixture of HSPA, HSPA+ and DC-HSPA+

LTE 900 MHz band summary

- Currently supports 5 devices with a small mix of modules, routers and USB modems
- All devices support multi frequency
- All devices support multi-mode with a mixture of HSPA, HSPA+ and DC-HSPA+

LTE 800 MHz band summary

- Currently supports a growing mix of devices with a total 42 different devices including dongles, tablets and handsets
- More than 13 out of the 42 devices support multi frequency
- More than 10 out of the 42 devices support multi-mode with a mixture of HSPA, HSPA+ and DC-HSPA+

4 Expected future evolution of device support

Rethink Research has spoken to 39 device manufacturers and 23 global mobile operators including subsidiaries of all major market players. The focus of the research was to determine the expected roadmap of device availability over the next few years, as distinct from their current public announcements. The data presented below relates specifically to forecast devices intended specifically for the EU market.

Notably, the 1800MHz band has moved significantly up the LTE development priority list for about three-quarters of vendors, motivated by EU decisions and pressure from individual carriers especially Orange and Telstra (Australia).

In the 2.6GHz band there is greater short term focus on data-only devices compared to lower bands. Handset development and launch plans are lagging those of data-only devices by only 11-13 months, far shorter than in other technologies, and the shortest lags are in 800MHz.

There is little interest in LTE-only consumer devices except for 2.6GHz dongles/data cards. Support for both LTE and DC HSPA+ is limited in the first wave of devices, but is already firmly on the development roadmap for 2013 and after.

Consensus among device vendors is that DC HSPA+ will be the volume driver for the next three years in Europe, but LTE will drive the high margin, high profile launches because of its urban profile in many countries. DC HSPA+ has been promoted in the development priorities amid rising interest in EU and other regions.

Initial choice of launch device profile will depend in part on committed operator support in terms of volume and subsidy (cf. Verizon in USA). The figures below summarise the findings from the work carried out by Rethink Research.

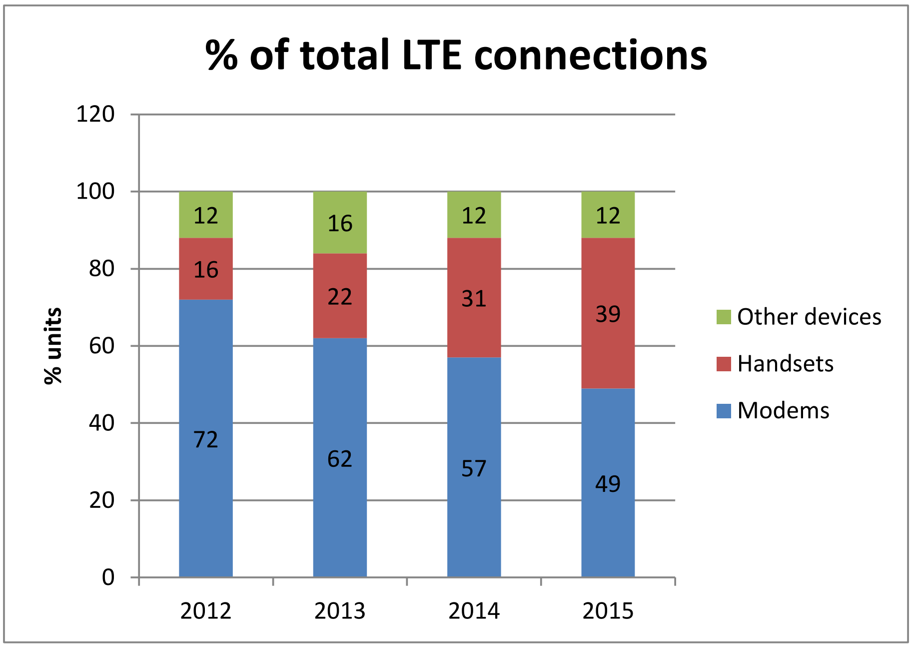

Figure 4-1 Percentage of total LTE connections

Figure 4-1 shows the evolution of handsets growth relative to USB modems and other devices. More than 50% increase in handset growth is forecast over a three year period from 2012 to 2015 with proportion of USB modems shrinking by less than 30% over the same period.

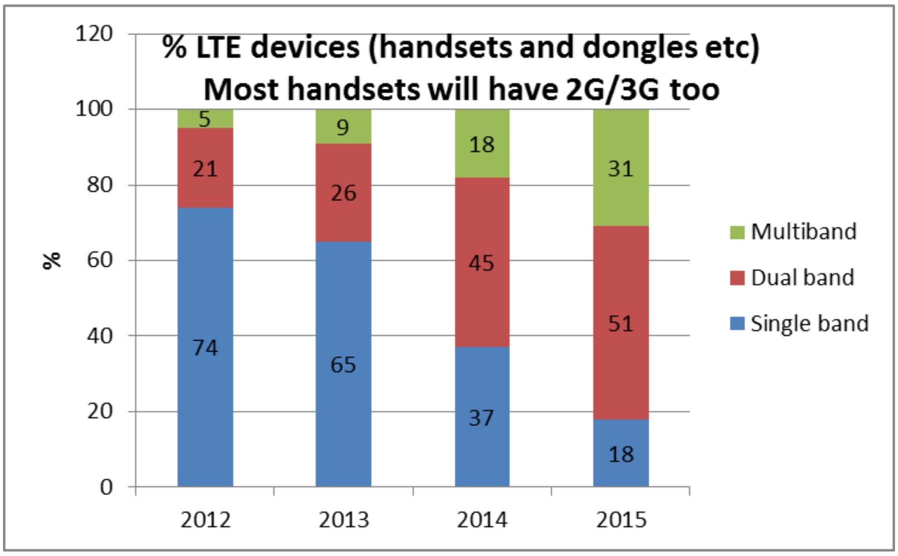

Figure 4-2 Percentage of LTE devices

Figure 4-2 shows the evolution of devices supporting more than one band over a four year period. Rrapid growth is predicted to come from dual band devices increasing by 2.5 times over the period.

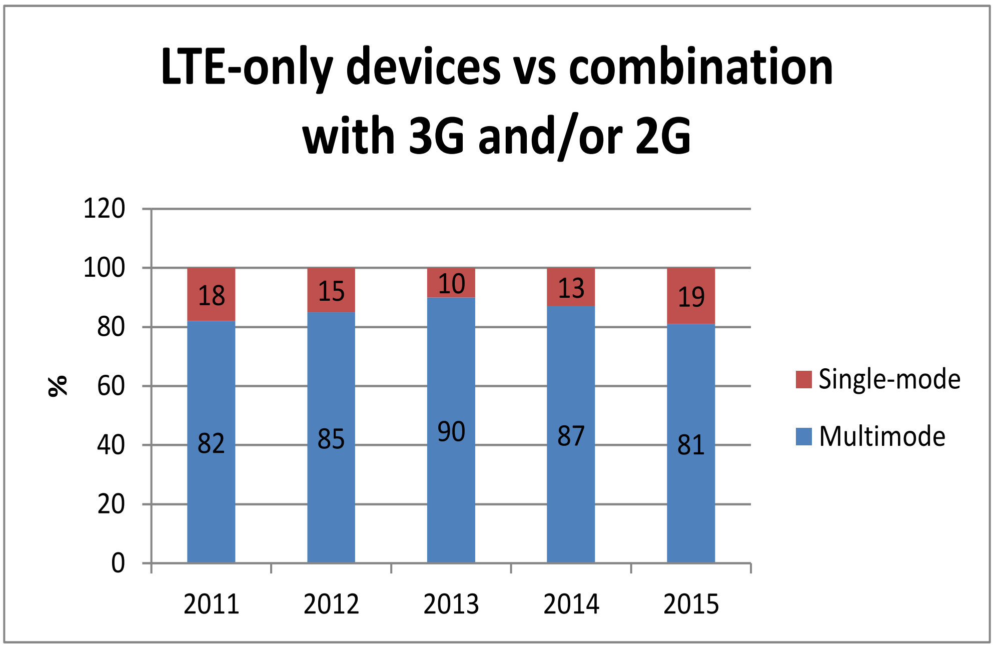

Figure 4-3 LTE-only devices vs. combination with 3G and/or 2G

Figure 4-3 shows the evolution of devices supporting more than one mode over five year period. The starting point is shows multimode devices are the majority with a peak of multimode devices in 2013 and shrinking to a lower proportion as more single mode devices begin to become available after 2013.

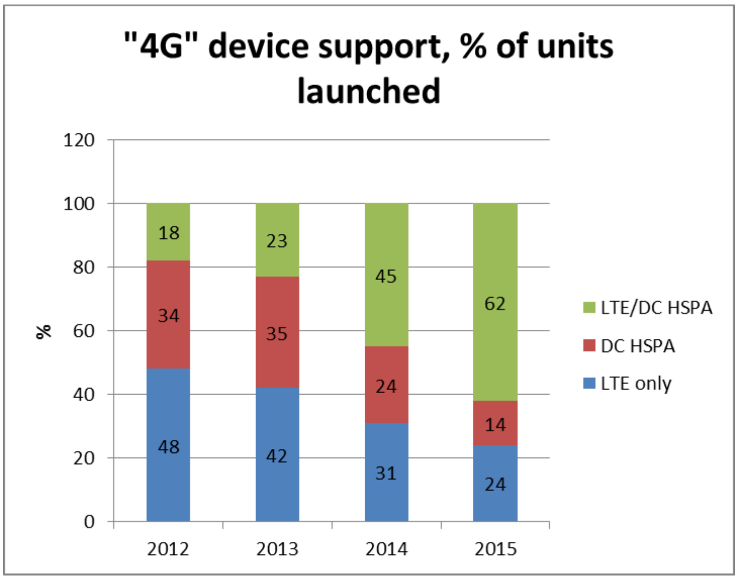

Figure 4-4 Percentage of 4G device support

Figure 4-4 shows the evolution of devices supporting the mix of modes between HSPA and LTE or both over four year period. The trend shows that growth in dual mode HSPA/LTE devices will be the dominant feature of devices by 2015 compared to DC HSPA only or LTE only devices.

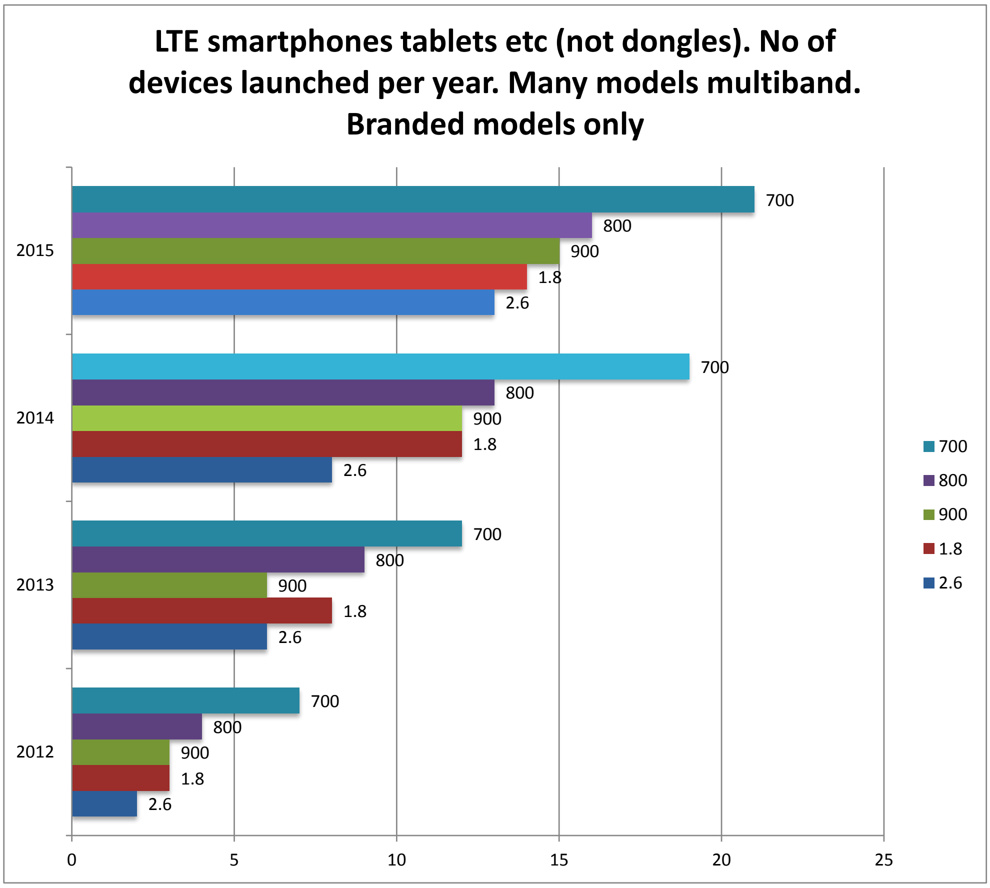

Figure 4-5 LTE smartphones and tablets launched per frequency band per year

Figure 4-5 shows a forecast of the evolution of devices supporting mix of the five popular mobile bands launched per year. The number of devices launched in the 700 MHz is greatest in each year due to the launch of LTE in the 700 MHz band in the US in 2009/2010. The trend of devices launched per band is led by the 800 MHz, 900 MHz and 1800 MHz bands. The 2600 MHz band has the lowest number of devices launched per year in comparison to those other bands.

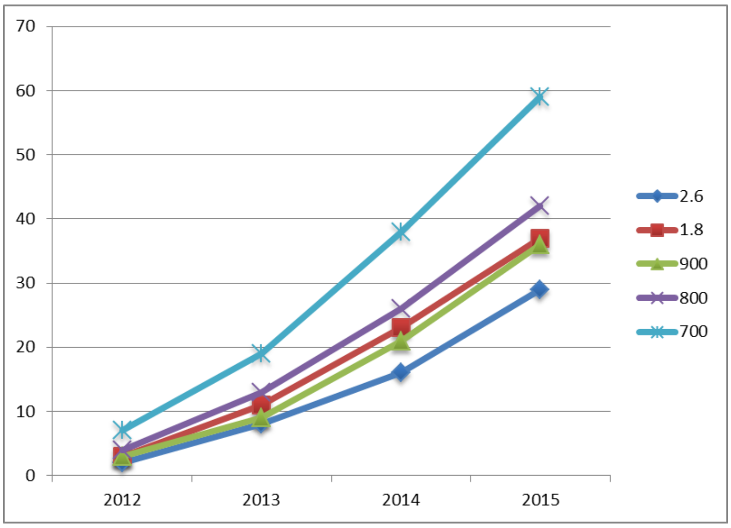

Figure 4-6 Cumulative device launches from 2012

Figure 4-6 shows the cumulative device launch across each of the five mobile bands which shows between 30 - 40 devices available across the 800 MHz, 900 MHz, 1800 MHz and 2600 MHz bands by 2015.