17.1 DOWNLINK BIT RATES

- The Physical Downlink Shared Channel (PDSCH) is used to transfer application data. The throughput achieved by the PDSCH depends upon the:
  - the number of resource elements allocated to the PDSCH
  - the modulation scheme applied to each resource element
  - the quantity of redundancy included by physical layer processing
  - the use of multiple antenna transmission schemes
- The number of PDSCH resource elements depends upon the channel bandwidth and the choice between the normal and extended cyclic prefix. It also depends upon the overheads generated by the other physical channels and physical signals
- The modulation scheme and quantity of redundancy depend upon the RF channel conditions. UE experiencing good channel conditions are more likely to be allocated higher order modulation schemes with less redundancy
- Multiple antenna transmission schemes increase the throughput achieved by the PDSCH. 2×2 MIMO approximately doubles the peak throughput whereas 4×4 MIMO approximately quadruples the peak throughput. Reference signal overheads increase when using MIMO so the throughputs are less than double and quadruple the single antenna case
- The PDSCH is a shared channel so its throughput capability has to be shared between all users. Increasing the number of users reduces the throughput per user. Users experiencing poor channel conditions will reduce the total cell throughput
- Table 101 presents a set of theoretical absolute maximum physical layer throughputs which could be achieved if all resource elements were allocated to the PDSCH and the physical layer did not add any redundancy. These figures are not achievable in practice but provide a starting point from which to derive the maximum expected throughputs

	Channel Bandwidth	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
	Resource Blocks in the frequency domain	6	15	25	50	75	100
Normal Cyclic Prefix	OFDMA symbols per 1 ms	14					
	Modulation symbol rate (Msps)	1.0	2.5	4.2	8.4	12.6	16.8
	QPSK Bit Rate (Mbps)	2.0	5.0	8.4	16.8	25.2	33.6
	16QAM Bit Rate (Mbps)	4.0	10.1	16.8	33.6	50.4	67.2
	64QAM Bit Rate (Mbps)	6.1	15.1	25.2	50.4	75.6	100.8
	2×2 MIMO 64QAM Bit Rate (Mbps)	12.1	30.2	50.4	100.8	151.2	201.6
	4×4 MIMO 64QAM Bit Rate (Mbps)	24.2	60.5	100.8	201.6	302.4	403.2
Extended Cyclic Prefix	OFDMA symbols per 1 ms	12					
	Modulation symbol rate (Msps)	0.9	2.2	3.6	7.2	10.8	14.4
	QPSK Bit Rate (Mbps)	1.7	4.3	7.2	14.4	21.6	28.8
	16QAM Bit Rate (Mbps)	3.5	8.6	14.4	28.8	43.2	57.6
	64QAM Bit Rate (Mbps)	5.2	13.0	21.6	43.2	64.8	86.4
	2×2 MIMO 64QAM Bit Rate (Mbps)	10.4	25.9	43.2	86.4	129.6	172.8
	4×4 MIMO 64QAM Bit Rate (Mbps)	20.7	51.8	86.4	172.8	259.2	345.6

Table 101 – Absolute maximum physical layer throughputs if all resource elements were allocated to the PDSCH

- The throughputs within Table 101 have been generated by multiplying the modulation symbol rate by the number of bits per symbol. For example, the 20 MHz channel bandwidth has 100 Resource Blocks providing 1200 subcarriers in the frequency domain. When using the normal cyclic prefix there are 14 OFDMA symbols during each 1 ms subframe so the modulation symbol rate is given by 1200 × 14 / 0.001 = 16.8 Msps. The bit rate when using 64QAM is then given by 16.8 Msps × 6 bits per symbol = 100.8 Mbps
- The first step to deriving the maximum expected throughput is to remove the overheads generated by the other physical channels and physical signals, i.e. the PCFICH, PDCCH, PHICH, PBCH, Primary and Secondary Synchronisation Signals, and the Cell Specific Reference Signal. Table 102 presents a set of maximum physical layer throughputs with these overheads removed. The results still assume a coding rate of 1, i.e. the physical layer has not introduced any redundancy

		Channel Bandwidth	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Normal Cyclic Prefix	**1 PDCCH Sym.**	QPSK Bit Rate (Mbps)	-	4.4	7.4	14.9	22.4	29.9
		16QAM Bit Rate (Mbps)	-	8.8	14.8	29.8	44.8	59.8
		64QAM Bit Rate (Mbps)	-	13.2	22.2	44.7	67.1	89.7
		2×2 MIMO 64QAM Bit Rate (Mbps)	-	25.3	42.5	85.8	129.0	172.2
		4×4 MIMO 64QAM Bit Rate (Mbps)	-	47.7	80.3	161.9	243.4	325.0
	2 PDCCH Sym.	QPSK Bit Rate (Mbps)	1.5	4.0	6.8	13.7	20.6	27.5
		16QAM Bit Rate (Mbps)	3.1	8.1	13.6	27.4	41.2	55.0
		64QAM Bit Rate (Mbps)	4.6	12.1	20.4	41.1	61.8	82.5
		2×2 MIMO 64QAM Bit Rate (Mbps)	8.8	23.1	39.0	78.5	118.1	157.7
		4×4 MIMO 64QAM Bit Rate (Mbps)	17.2	44.8	75.5	152.4	229.2	306.0
	3 PDCCH Sym.	QPSK Bit Rate (Mbps)	1.4	3.7	6.2	12.5	18.8	25.1
		16QAM Bit Rate (Mbps)	2.8	7.3	12.4	25.0	37.6	50.2
		64QAM Bit Rate (Mbps)	4.2	11.0	18.6	37.4	56.4	75.3
		2×2 MIMO 64QAM Bit Rate (Mbps)	8.0	20.9	35.3	71.4	107.4	143.3
		4×4 MIMO 64QAM Bit Rate (Mbps)	15.4	40.5	68.3	137.9	207.4	277.0
	4 PDCCH Sym.	QPSK Bit Rate (Mbps)	1.3	-	-	-	-	-
		16QAM Bit Rate (Mbps)	2.5	-	-	-	-	-
		64QAM Bit Rate (Mbps)	3.8	-	-	-	-	-
		2×2 MIMO 64QAM Bit Rate (Mbps)	7.1	-	-	-	-	-
		4×4 MIMO 64QAM Bit Rate (Mbps)	13.7	-	-	-	-	-
Extended Cyclic Prefix	**1 PDCCH Sym.**	QPSK Bit Rate (Mbps)	-	3.7	6.2	12.5	18.8	25.1
		16QAM Bit Rate (Mbps)	-	7.3	12.4	25.0	37.6	50.2
		64QAM Bit Rate (Mbps)	-	11.0	18.6	37.5	56.4	75.3
		2×2 MIMO 64QAM Bit Rate (Mbps)	-	21.0	35.4	71.4	107.3	143.4
		4×4 MIMO 64QAM Bit Rate (Mbps)	-	39.1	66.0	133.2	200.4	267.5
	2 PDCCH Sym.	QPSK Bit Rate (Mbps)	1.3	3.3	5.6	11.3	17.0	22.7
		16QAM Bit Rate (Mbps)	2.5	6.6	11.2	22.6	34.0	45.4
		64QAM Bit Rate (Mbps)	3.8	9.9	16.8	33.9	51.0	68.1
		2×2 MIMO 64QAM Bit Rate (Mbps)	7.1	18.8	31.8	64.2	96.6	128.9
		4×4 MIMO 64QAM Bit Rate (Mbps)	13.8	36.2	61.2	123.6	186.1	248.5
	3 PDCCH Sym.	QPSK Bit Rate (Mbps)	1.1	3.0	5.0	10.1	15.2	20.3
		16QAM Bit Rate (Mbps)	2.2	5.9	10.0	20.2	30.4	40.6
		64QAM Bit Rate (Mbps)	3.3	8.9	15.0	30.3	45.6	60.9
		2×2 MIMO 64QAM Bit Rate (Mbps)	6.3	16.6	28.2	56.9	85.8	114.6
		4×4 MIMO 64QAM Bit Rate (Mbps)	12.0	31.9	54.0	109.2	164.3	219.5
	4 PDCCH Sym.	QPSK Bit Rate (Mbps)	1.0	-	-	-	-	-
		16QAM Bit Rate (Mbps)	2.0	-	-	-	-	-
		64QAM Bit Rate (Mbps)	3.0	-	-	-	-	-
		2×2 MIMO 64QAM Bit Rate (Mbps)	5.7	-	-	-	-	-
		4×4 MIMO 64QAM Bit Rate (Mbps)	10.9	-	-	-	-	-

Table 102 – Maximum physical layer throughputs based upon resource elements available to the PDSCH (coding rate = 1, no re-transmissions, no SRB, paging nor SIB overheads, no protocol stack overheads)

- Table 102 illustrates the relatively significant impact of the number of OFDMA symbols allocated to the PDCCH, PCFICH and PHICH. These physical channels can be allocated 2, 3 or 4 symbols when using the 1.4 MHz channel bandwidth, and 1, 2 or 3 symbols when using the other channel bandwidths. In practise, the number of allocated symbols depends upon the quantity of traffic loading the cell. There will be a requirement for an increased number of symbols as the traffic increases, i.e. the maximum throughput capability will decrease as the traffic and associated overheads increase
- The figures in Table 102 are significantly less than those in Table 101. For example, the maximum throughput associated with the 20 MHz channel bandwidth, the normal cyclic prefix and 4×4 MIMO decreases from 403 Mbps to 325, 306 or 277 Mbps (depending upon the number of symbols allocated to the PDCCH, PCFICH and PHICH). This demonstrates the impact of the overheads generated by the physical channels and physical signals which do not transfer any application data
- Redundancy added by the physical layer further reduces the throughputs measured at the top of the physical layer. The PDSCH uses a combination of rate 1/3 Turbo coding and rate matching to generate redundancy. In general, the quantity of redundancy is large when UE experience poor channel conditions and small when UE experience good channel conditions
- Figure 80 illustrates an example link adaptation strategy which defines the physical layer coding rate as a function of the channel conditions and modulation scheme. The coding rate reflects the quantity of redundancy added by the physical layer. A low coding rate indicates a large quantity of redundancy while a high coding rate reflects a small quantity of redundancy. A coding rate of 1 corresponds to no redundancy

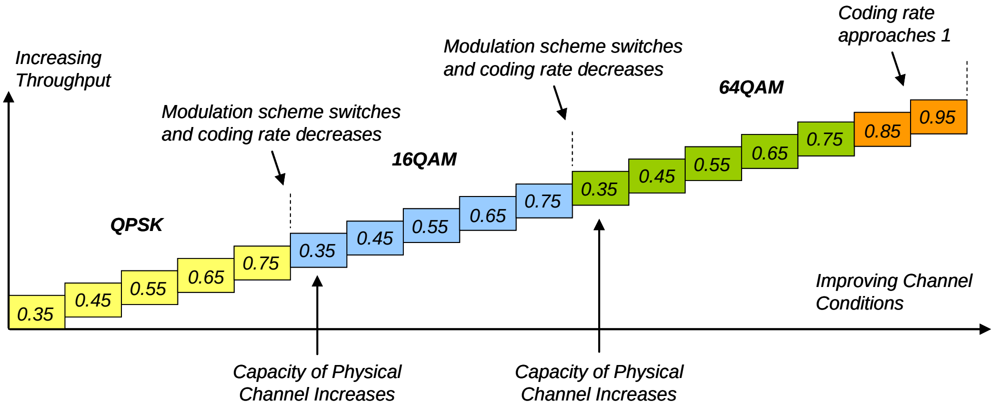

Figure 80 – Physical layer coding rate as a function of channel conditions and modulation scheme

- QPSK and a low coding rate are associated with poor channel conditions. Link adaptation allocates larger transport block sizes as the channel conditions improve but the modulation scheme is kept as QPSK. This forces the quantity of redundancy to decrease (and the coding rate to increase), i.e. larger quantities of data are transferred without increasing the capacity of the physical channel
- In this example, the modulation scheme is switched from QPSK to 16QAM once the channel conditions have improved sufficiently to allow the coding rate to increase to 0.75. Switching the modulation scheme increases the capacity of the physical channel so the quantity of redundancy can be increased. Link adaptation then continues to allocate larger transport block sizes as the channel conditions improve. The modulation scheme is switched from 16QAM to 64QAM once the channel conditions have improved sufficiently to allow the coding rate to again reach 0.75
- Once 64QAM has been allocated, link adaptation continues to allocate larger transport block sizes as the channel conditions improve. In this case, there is no option to switch to a higher order modulation scheme once the coding rate reaches 0.75. Instead, link adaptation continues to allocate larger transport block sizes and the coding rate approaches 1
- System Information Blocks (SIB), paging messages and RRC signalling are transferred using the PDSCH. This reduces the PDSCH capacity available for application data. The overhead generated by the SIB, paging messages and RRC signalling will depend upon the quantity of traffic loading the cell but is likely to be relatively small, i.e. less than 100 kbps
- Re-transmissions reduce the higher layer throughputs. Hybrid Automatic Repeat Request (HARQ) re-transmissions from the MAC layer reduce the throughputs measured from above the MAC layer. Automatic Repeat Request (ARQ) re-transmissions from the RLC layer reduce the throughputs measured from above the RLC layer. Likewise TCP re-transmissions reduce the throughput measured from above the TCP layer
- Protocol stack headers also reduce the higher layer throughputs. The MAC, RLC, PDCP and IP layers add headers to the application data. The PDCP layer provides header compression for IP data streams so is able to reduce the impact of the IP header. The TCP layer also adds its own header when using TCP applications

★ Table 103 presents a set of example application throughputs assuming physical layer coding rates of 0.75 and 0.95. The coding rate of 0.95 is only shown for the 64QAM modulation scheme to remain consistent with the link adaptation strategy shown in Figure 80. Table 103 assumes the normal cyclic prefix, a 10 % re-retransmission rate and an additional 5 % overhead generated by a combination of the SIB, paging, RRC signalling and protocol stack headers

		Coding Rate	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
1 PDCCH Symbol	QPSK Bit Rate (Mbps)	0.75	-	2.8	4.7	9.6	14.4	19.2
	16QAM Bit Rate (Mbps)	0.75	-	5.6	9.5	19.1	28.7	38.3
	64QAM Bit Rate (Mbps)	0.75	-	8.5	14.2	28.7	43.0	57.5
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.75	-	16.2	27.3	55.0	82.7	110.4
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.75	-	30.6	51.5	103.8	156.1	208.4
	64QAM Bit Rate (Mbps)	0.95	-	10.7	18.0	36.3	54.5	72.9
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.95	-	20.5	34.5	69.7	104.8	139.9
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.95	-	38.7	65.2	131.5	197.7	264.0
2 PDCCH Symbols	QPSK Bit Rate (Mbps)	0.75	1.0	2.6	4.4	8.8	13.2	17.6
	16QAM Bit Rate (Mbps)	0.75	2.0	5.2	8.7	17.6	26.4	35.3
	64QAM Bit Rate (Mbps)	0.75	2.9	7.8	13.1	26.4	39.6	52.9
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.75	5.6	14.8	25.0	50.3	75.7	101.1
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.75	11.0	28.7	48.4	97.7	147.0	196.2
	64QAM Bit Rate (Mbps)	0.95	3.7	9.8	16.6	33.4	50.2	67.0
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.95	7.1	18.8	31.7	63.8	95.9	128.1
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.95	14.0	36.4	61.3	123.8	186.2	248.5
3 PDCCH Symbols	QPSK Bit Rate (Mbps)	0.75	0.9	2.4	4.0	8.0	12.1	16.1
	16QAM Bit Rate (Mbps)	0.75	1.8	4.7	8.0	16.0	24.1	32.2
	64QAM Bit Rate (Mbps)	0.75	2.7	7.1	11.9	24.0	36.2	48.3
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.75	5.1	13.4	22.6	45.8	68.9	91.9
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.75	9.9	26.0	43.8	88.4	133.0	177.6
	64QAM Bit Rate (Mbps)	0.95	3.4	8.9	15.1	30.4	45.8	61.2
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.95	6.5	17.0	28.7	58.0	87.2	116.4
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.95	12.5	32.9	55.5	112.0	168.5	225.0
4 PDCCH Symbols	QPSK Bit Rate (Mbps)	0.75	0.8	-	-	-	-	-
	16QAM Bit Rate (Mbps)	0.75	1.6	-	-	-	-	-
	64QAM Bit Rate (Mbps)	0.75	2.4	-	-	-	-	-
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.75	4.6	-	-	-	-	-
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.75	8.8	-	-	-	-	-
	64QAM Bit Rate (Mbps)	0.95	3.1	-	-	-	-	-
	2×2 MIMO 64QAM Bit Rate (Mbps)	0.95	5.8	-	-	-	-	-
	4×4 MIMO 64QAM Bit Rate (Mbps)	0.95	11.1	-	-	-	-	-

Table 103 – Application layer throughputs based upon resource elements available to the PDSCH (normal cyclic prefix, 10% re-transmissions, 5% additional overheads)

★ These throughput figures are comparable to those provided by UMTS High Speed Packet Access (HSPA) when making similar assumptions for both technologies. For example, UMTS HSPA with a 5 MHz channel bandwidth and 64QAM can achieve an application layer throughput of approximately 18 Mbps. LTE offers the same throughput capability when using 5 MHz and 64QAM if a single OFDMA symbol is allocated to the PDCCH, PCFICH and PHICH. Similar comparisons can be made when MIMO is applied to HSPA, and when HSPA is allocated 2 or 4 RF carriers to generate effective UMTS channel bandwidths of 10 or 20 MHz