Throughput Calculation for LTE TDD, FDD Systems and WiFi System

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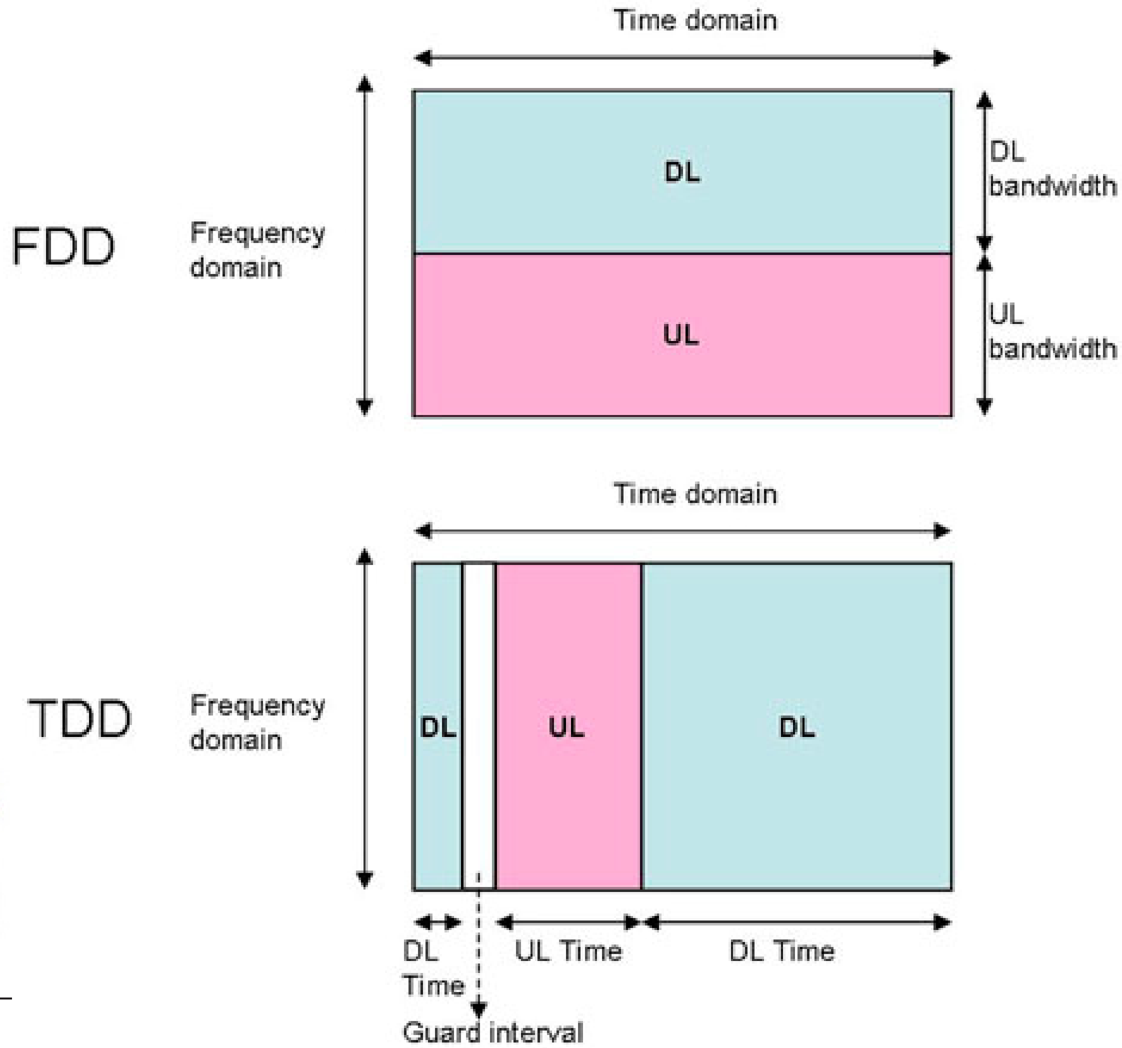
FDD & TDD

FDD

- ✓ Pair spectrum.
- ✓ GSM, cdma2000, WCDMA.
- ✓ Duplexer.

TDD

- ✓ Un-pair spectrum.
- ✓ PHS, TD-SCDMA
- ✓ Switch.



FDD downlink peak data rates (64QAM)

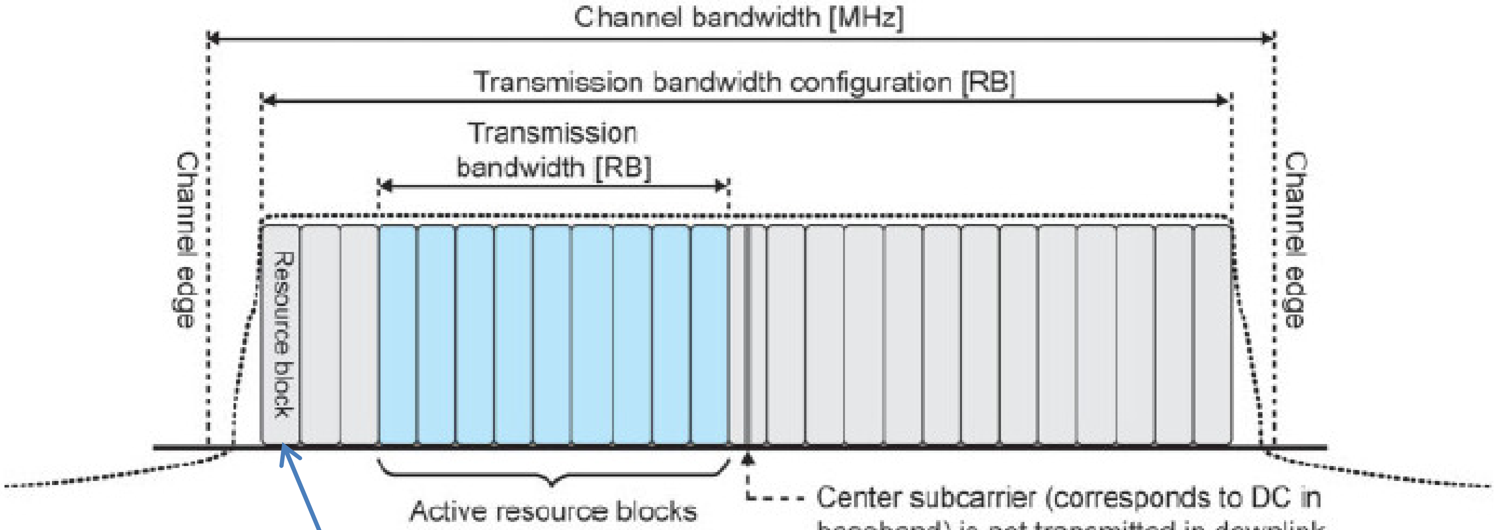
Antenna configuration	SISO	2x2 MIMO	4x4 MIMO
Peak data rate (Mbps)	100	172.8	326.4

FDD uplink peak data rates (single antenna)

Modulation depth	QPSK	16QAM	64QAM
Peak data rate (Mbps)	50	57.6	86.4

Table. LTE (FDD) downlink and uplink peak data rates.

Configurable Channel Bandwidth



- ✓ In CDMA systems, the transmission bandwidth is fixed and determined by the inverse of the chip rate.

- ✓ In OFDM systems, the subcarrier spacing is determined by the inverse of the FFT integration time. So number of subcarriers and transmission bandwidth can be determined independently. More flexibility.

Channel bandwidth (MHz)	1.4	3	5	10	15	20
Transmission bandwidth configuration (MHz)	1.08	2.7	4.5	9	13.5	18
Transmission bandwidth configuration (N_{RB}^{UL} or N_{RB}^{DL}) (RB)	6	15	25	50	75	100

Table. Transmission bandwidth configuration.

LTE symbol rate = 66.7μs, Δf = 1/ symbol rate = 15 kHz for each subcarrier.
In freq. domain 1 RE = 1 subcarrier, so 1 RB = 12 subcarriers = 180 kHz.

- ✓ In order to scale the development of equipment, UE categories have been defined to limit certain parameters.
- ✓ The most significant parameter is the supported data rates:

UE category	Peak downlink data rate (Mbps)	Number of downlink spatial layers	Peak uplink data rate (Mbps)	Number of uplink spatial layers	Support for 64QAM in uplink
Category 1	10.296	1	5.16	1	No
Category 2	51.024	2	25.456	1	No
Category 3	102.048	2	51.024	1	No
Category 4	150.752	2	51.024	1	No
Category 5	302.752	4	75.376	1	Yes
Category 6	301.504	2 or 4	51.024	1, 2, or 4	No
Category 7	301.504	2 or 4	10.2048	1, 2, or 4	No
Category 8	2998.56	8	149.776	8	Yes

Table. Peak data rates for UE categories.

Theoretical LTE Data Rate Calculation

- ✓ Question: Assume 20 MHz bandwidth (100 RB) and normal CP calculate data rate = ?

- ✓ Throughput ➔ symbols per second ➔bits per second.

- ✓ 1 RB = 1 time domain(1 slot = 0.5 ms = 7 OFDM symbols) x 1 freq. domain(12 subcarriers)
  = 7 x 12 x 2 = 168 symbols per ms
- ✓ 64 QAM = 2^6 QAM = 6 bits per symbol.
- ✓ 20 MHz(100 RB) = 16800 symbols per ms = 16,800,000 symbols per sec = 16.8 Msps.
- ✓ Throughput = data rate = 16.8 x 6 = 100.8 Mbps for single chain.

- ✓ LTE 4x4 MIMO (4T4R) 100.8 x 4 = 403.2 Mbps for DL.
- ✓ But there is 25% overhead use for controlling and signaling so 403.2 x 0.75 = 302.4 Mbps ~ 300 Mbps.
- ✓ For UL we have only one transmit chain at UE end so after 25% 100.8 x 0.75 = 75.6 Mbps ~ 75 Mbps.

- ✓ There is why we get the # of throughput 300 Mbps for DL and 75 Mbps for UL shown everywhere!!

$$\boxed{\text{LTE data rate} = \left[\frac{symbol}{\sec}\right]\cdot\left[\frac{bit}{symbol}\right]\cdot \#layers}$$

Downlink category	3GPP release	Downlink					
		Maximum number of DL-SCH transport block bits received within a TTI	(Mbit/s)	Maximum number of bits of a DL-SCH transport block received within a TTI	Total number of soft channel bits	Maximum number of supported layers for spatial multiplexing in DL	Support for 256QAM in DL
M1	Rel 13	1000	1	1000	25344	1	No
M2	Rel 14	4008	4	1000	73152	1	No
0	Rel 12	1000	1	1000	25344	1	No
1bis	Rel 14	10296	10	10296	250368	1	No
4	Rel 14	150752	150	75376	1827072	2	No
6	Rel 12	301504	301	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	3654144	2 or 4	No
7	Rel 12	301504	301	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	3654144	2 or 4	No
9	Rel 12	452256	452	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	5481216	2 or 4	No
10	Rel 12	452256	452	75376 (2 layers, 64QAM) 149776 (4 layers, 64QAM)	5481216	2 or 4	No
11	Rel 12	603008	603	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	7308288	2 or 4	Optional
12	Rel 12	603008	603	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	7308288	2 or 4	Optional
13	Rel 12	391632	391	97896 (2 layers, 256QAM) 195816 (4 layers, 256QAM)	3654144	2 or 4	Mandatory
14	Rel 12	3916560	3916	391656 (8 layers, 256QAM)	47431680	8	Mandatory
15	Rel 12	749856 - 798800	749 - 798	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	9744384	2 or 4	Optional
16	Rel 12	978960 - 1051360	978 - 1051	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	12789504	2 or 4	Optional

MSM8998 Overview

10 nm premium-tier chip with integrated modem and AP

$$20\text{MHz}(100\text{RB}) = 16.8 \text{ Msps}$$

$$16.8 \times 6(64\text{ QAM}) \times 0.75 = 75.6 \text{ Mbps} \approx 75.376 \text{ Mbps (TBS table)}$$

$$16.8 \times 8(256\text{ QAM}) \times 0.75 = 100.8 \text{ Mbps} \approx 97.896 \text{ Mbps (TBS table)}$$

Modem

- Sixth-generation LTE modem, Rel-12 Cat 16 up to 1 Gbps, 4x DL CA (80 MHz CA across four bands), 256-QAM DL, 8 × 4 DL MIMO with CA, LTE-U/LAA, LWA

MSM8998/APQ8098 Variants

Product	Variants	Description
MSM8998	-1-AB	10 layers, 4xDLCA, CDMA
	-2-AB	10 layers, 4xDLCA, no CDMA
	-3-AB	6 layers, 3xDLCA, CDMA
	-4-AB	6 layers, 3xDLCA, no CDMA
	-5-AB	8 layers, 4xDLCA, CDMA
	-6-AB	8 layers, 4xDLCA, no CDMA
APQ8098	-1-AA	AP only, no modem

Layers are referred to by the number of data streams transmitted to the UE (handset) to process.
For example,
MSM8998-1-AB supports up to 10 layers with a theoretical maximum throughput of 1 Gbps;
MSM8998-5-AB supports up to 8 layers with a theoretical throughput of 800 Mbps.

$$20\text{MHz}(100\text{RB}) = 16.8 \text{ Msps}$$

$$16.8 \times 6 (64 \text{ QAM}) \times 0.75 = 75.6 \text{ Mbps} \approx 75.376 \text{ Mbps (TBS table)}$$

$$16.8 \times 8 (256 \text{ QAM}) \times 0.75 = 100.8 \text{ Mbps} \approx 97.896 \text{ Mbps (TBS table)}$$

$\therefore$ theoretical maximum throughput : $100.8 \times 10 \approx 1$ Gbps 醬來的~

Multiple Configurations for Layers

Layers	4xDLCA	3xDLCA	2xDLCA
10	4×4, 2×2, 2×2, 2×2 MIMO *MSM8998-1/-2*	4×4, 4×4, 2×2 MIMO *MSM8998-1/-2*	
8	2×2, 2×2, 2×2, 2×2 MIMO *MSM8998-5/-6*	4×4, 2×2, 2×2 MIMO *MSM8998-5/-6*	4×4, 4×4 MIMO *MSM8998-5/-6*
6		2×2, 2×2, 2×2 MIMO *MSM8998-3/-4*	4×4, 2×2 MIMO *MSM8998-3/-4*

Use 3GPP Spec. 36.213 for Throughput Calculation

- ✓ Coding rate described the efficiency of the particular modulation scheme.
- ✓ Example: 16 QAM with 0.5 coding rate means its can only carry 2 information bits.

- ✓ The combination of the modulation and coding rate is called Modulation Coding Scheme (MCS).

- ✓ Example: 100 RBs MCS Index = 28, the TBS = 75376, assume 4x4 MIMO so the peak data rate = 75376 x 4 = 301.5 Mbps.

The other ways:
lookup table called TBS table (Transport Block Size table) find throughput.

1 TTI (=1ms) so
1 TTI = 1000 bps.

Table 7.1.7.1-1: Modulation and TBS index table for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	TBS Index I_{TBS}
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	4	9
11	4	10
12	4	11
13	4	12
14	4	13
15	4	14
16	4	15
17	6	15
18	6	16
19	6	17
20	6	18
21	6	19
22	6	20
23	6	21
24	6	22
25	6	23
26	6	24
27	6	25
28	6	26
29	2	reserved
30	4	
31	6	

Table 7.1.7.2.1-1: Transport block size table (dimension 27×110)

I_{TBS}	N_{PRB}									
	91	92	93	94	95	96	97	98	99	100
4	6456	6456	6712	6712	6712	6968	6968	6968	6968	7224
5	7992	7992	8248	8248	8248	8504	8504	8760	8760	8760
6	9528	9528	9528	9912	9912	9912	10296	10296	10296	10296
7	11064	11448	11448	11448	11448	11832	11832	11832	12216	12216
8	12576	12960	12960	12960	13536	13536	13536	13536	14112	14112
9	14112	14688	14688	14688	15264	15264	15264	15264	15840	15840
10	15840	16416	16416	16416	16992	16992	16992	16992	17568	17568
11	18336	18336	19080	19080	19080	19080	19848	19848	19848	19848
12	20616	21384	21384	21384	21384	22152	22152	22152	22920	22920
13	23688	23688	23688	24496	24496	24496	25456	25456	25456	25456
14	26416	26416	26416	27376	27376	27376	28336	28336	28336	28336
15	28336	28336	28336	29296	29296	29296	29296	30576	30576	30576
16	29296	30576	30576	30576	30576	31704	31704	31704	31704	32856
17	32856	32856	34008	34008	34008	35160	35160	35160	35160	36696
18	36696	36696	36696	37888	37888	37888	37888	39232	39232	39232
19	39232	39232	40576	40576	40576	40576	42368	42368	42368	43816
20	42368	42368	43816	43816	43816	45352	45352	45352	46888	46888
21	45352	46888	46888	46888	46888	48936	48936	48936	48936	51024
22	48936	48936	51024	51024	51024	51024	52752	52752	52752	55056
23	52752	52752	52752	55056	55056	55056	55056	57336	57336	57336
24	55056	57336	57336	57336	57336	59256	59256	59256	61664	61664
25	57336	59256	59256	59256	61664	61664	61664	61664	63776	63776
26	66592	68808	68808	68808	71112	71112	71112	73712	73712	75376

http://www.3gpp.org/ftp/Specs/archive/36_series/36.213/

DL/UL Throughput calculation for LTE FDD

- ✓ BW = 20 MHz
- ✓ Multiplexing scheme = FDD
- ✓ UE category = Cat 3
- ✓ Modulation supported =
  per Cat 3 TBS index 26 for DL (75376 for 100 RBs) and 21 for UL (51024 for 100 RBs)

- ✓ Throughput = # of Chains x TB size.

DL throughput = 2 x 75376 = 150.752 Mbps.
UL throughput = 1 x 51024 = 51.024 Mbps.

UE category	Peak downlink data rate (Mbps)	Number of downlink spatial layers	Peak uplink data rate (Mbps)	Number of uplink spatial layers	Support for 64QAM in uplink
Category 1	10.296	1	5.16	1	No
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Category 3	102.048	2	51.024	1	No
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Category 8	2998.56	8	149.776	8	Yes

Good website: http://niviuk.free.fr/ue_category.php

DL/UL Throughput calculation for LTE TDD

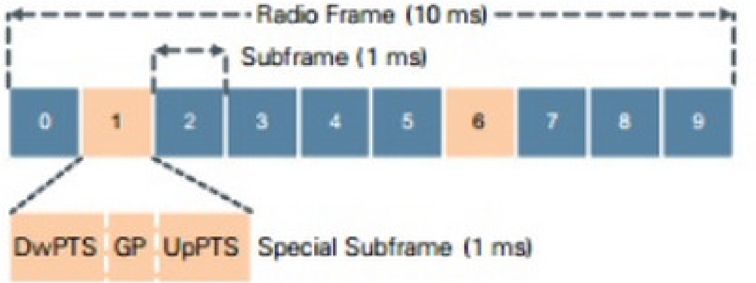

Table. LTE TDD frame configuration.

UL/DL Configuration	Period (ms)	Subframe 0	1	2	3	4	5	6	7	8	9
0		D	S	U	U	U	D	S	U	U	U
1	5	D	S	U	U	D	D	S	U	U	D
2		D	S	U	D	D	D	S	U	D	D
3		D	S	U	U	U	D	D	D	D	D
4	10	D	S	U	U	D	D	D	D	D	D
5		D	S	U	D	D	D	D	D	D	D
6	5	D	S	U	U	U	D	S	U	U	D

Table. Special subframe configuration.

DwPTS/GP/UpPTS length (OFDM symbols)						
Format	Normal CP			Extended CP		
	DwPTS	GP	UpPTS	DwPTS	GP	UpPTS
0	3	10		3	8	1
1	9	4		8	3	
2	10	3	1	9	2	
3	11	2		10	1	
4	12	1		3	7	2
5	3	9		8	2	
6	9	3	2	9	1	
7	10	2		-	-	-
8	11	1		-	-	-

- ✓ BW = 20 MHz
- ✓ Multiplexing scheme = TDD
- ✓ UE category = Cat 3
- ✓ Modulation supported = per Cat 3 TBS index 26 for DL (75376 for 100 RBs) and 21 for UL (51024 for 100 RBs)

- ✓ TDD frame configuration 2 (D-6, S-2 and U-2)
- ✓ Special subframe configuration 7 (DwPTS-10, GP-2 and UpPTS-2)

- ✓ DL Throughput = # of Chains x TB size x (DL Subframe + DwPTS in SSF)
- ✓ UL Throughput = # of Chains x TB size x (UL Subframe + UpPTS in SSF)

- ✓ DL Throughput = 2 x 75376 x (6/10 + (2/10) (10/14)) = 112 Mbps.
- ✓ UL Throughput = 1 x 51024 x (2/10 + (2/10) (2/14)) = 11.7 Mbps.

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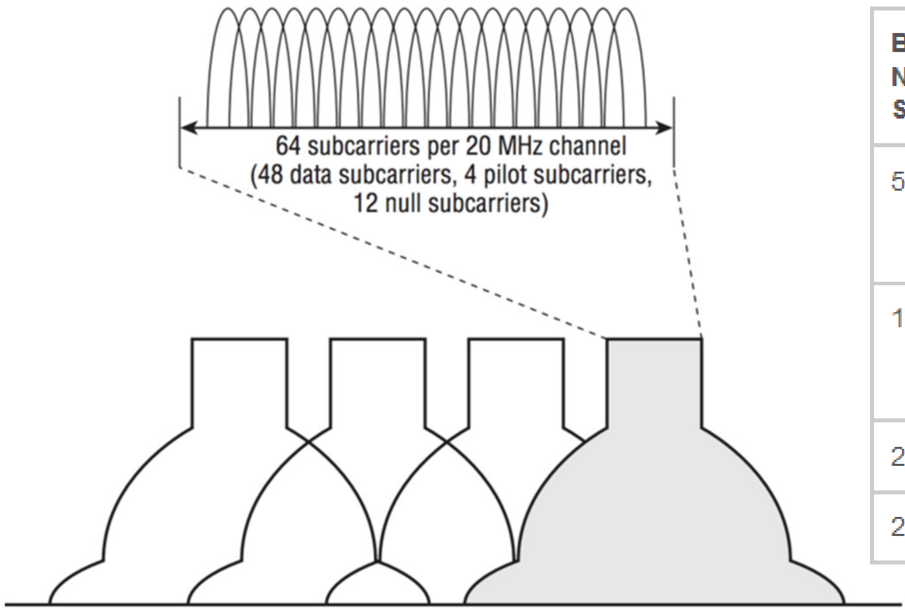
WiFi Throughput Calculation

Wi-Fi OFDM channelization and Thruput calculation

- ✓ Each 20 MHz channel, whether it's 802.11a/g/n/ac, is composed of 64 subcarriers spaced ***312.5 kHz*** apart.
- ✓ This spacing is chosen because we use 64-point FFT sampling.
- ✓ 802.11a/g use 48 subcarriers for data, 4 for pilot, and 12 as null subcarriers.
- ✓ 802.11n/ac use 52 subcarriers for data, 4 for pilot, and 8 as null.



Bandwidth (as Number of Data Subcarriers)	×	Number of Spatial Streams	×	Data Bits per Subcarrier	÷	Time per OFDM Symbol	=	PHY Data Rate (bps)
56 (20 MHz)		1 to 4		Up to 5/6 × log2(64) = 5		3.6 microseconds (short guard interval)		
108 (40 MHz)						4 microseconds (long guard interval)		
234 (80 MHz)		5 to 8		Up to 5/6 × log2(256) ≈ 6.67				
2 × 234 (160 MHz)								

- ✓ A standard Wi-Fi symbol is 4μs, composed of ***3.2 μs IFFT*** (useful symbol duration) and 0.8μs long guard interval. (or using total symbol time is 3.6μs and 0.4μs for short guard interval).
- ✓ So, "subcarrier spacing is equal to the reciprocal of symbol time." Let's examine:
  - Subcarrier spacing = 312.5 kHz.
  - Useful symbol duration = 3.2μs IFFT.
  - Reciprocal = 1 cycle / 0.0000032 sec = 312,500 cycles/sec = 312.5 kHz
- ✓ Since IFFT is used for modulation the spacing of the subcarriers is such that at the frequency where we evaluate the received signal (the center frequency of each subcarrier) all other signals are zero. And this in turn drives the duration of the useful symbol time and is the reason why we use 3.2μs IFFT.

WiFi Thruput calculation using excel

Bandwidth (as Number of Data Subcarriers)	×	Number of Spatial Streams	×	Data Bits per Subcarrier	÷	Time per OFDM Symbol	=	PHY Data Rate (bps)
56 (20 MHz)		1 to 4		Up to 5/6 × log2(64) = 5		3.6 microseconds (short guard interval)		
108 (40 MHz)						4 microseconds (long guard interval)		
234 (80 MHz)		5 to 8		Up to 5/6 × log2(256) ≈ 6.67				
2 × 234 (160 MHz)								

Physical Layer	802.11ac						
Bandwidth [MHz]	160						
Number of data subcarriers [#]	468						
Number of spatial streams [#]	8						
Modulation	256 QAM	**BPSK**	**QPSK**	**16 QAM**	**64 QAM**	**256 QAM**	**1024 QAM**
Number of bits per symbol [bits]	8	1	2	4	6	8	10
Coding rate	5/6	**1/2**	**2/3**	**3/4**	**5/6**	**note: 5/6 on 64 QAM not available in 802.11g**	
Data bits per subcarrier [bits]	6.67	0.50	0.67	0.75	0.83		
Guard interval duration [µs]	0.4	**0.40**	**0.80**	**1.60**			
Guard interval type	400 ns GI	400 ns GI	800 ns GI	1600 ns GI			
Symbol duration [µs]	3.2	**3.20**	**6.40**	**12.80**			
Symbol duration type	3200 ns	3200 ns	6400 ns	12800 ns			
Time per OFDM symbol [µs]	3.6						
PHY Data Rate [Mbps]	6,933.33						
Throughput [Mbps]	4,853						

$$\text{WiFi data rate} = \left[\frac{symbol}{\sec}\right]\cdot\left[\frac{subcarriers}{symbol}\right]\cdot\cdot\left[\frac{bit}{subcarriers}\right]\cdot \#\,spatial\ \ streams$$

$$= \left[\frac{symbol}{\sec}\right]\cdot\left[\frac{subcarriers}{symbol}\right]\cdot\left[coding\ \ rate\cdot\frac{bit}{subcarriers}\right]\cdot \#\,spatial\ \ streams$$

$$= \frac{1}{3.6\mu s}\cdot 468\cdot\frac{5}{6}\cdot 8\cdot 8 = 6933.33\text{ Mbps}$$

Thank you for your attention