Wi4Net White Paper:

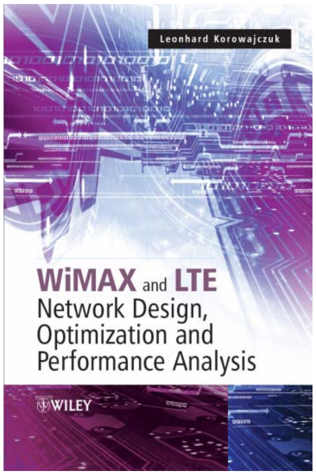
Throughput Considerations for Wireless Networks

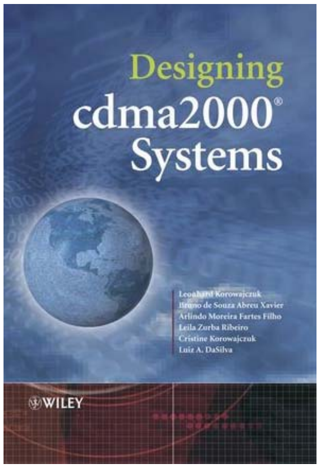
About us

CelPlan Technologies has been a worldwide leading provider of wireless network design, optimization and performance evaluation software for the last 18 years. We support all major technologies and have been pioneers in supporting broadband technologies, such as MMDS, LMDS and recently Wi-Fi, WiMAX and LTE.

Our services branch has designed hundreds of broadband networks for vendors and operators. Our list of customers includes Verizon, Sprint, Telefonica, Ericsson, Nokia-Siemens, Alcatel-Lucent, Redline and many others.

Our company has published books by renowned technical publishing house Wiley. We are under contract with them to publish a book on “LTE, WiMAX and Wi-Fi Network Design, Optimization and Performance Analysis”. We provide WiMAX Forum and WCA certified training worldwide for operators, vendors and consultants.





Our subsidiary Wi4Net has designed all its Public Safety deployments using CelPlan’s software and has been praised for it. Our deployed systems have been expanded several times without the need to re-configure previous deployments.

Wi4Net has been a pioneer in the 4.9 GHz field for Public Safety, having participated in the Long Beach trial in 2005. Wi4Net was also the first to certify a 4.9 GHz multi-band radio with the FCC. We were compelled to manufacture our own radios, as there were no radios available in the market that could address 4.9/5.9 GHz and perform in the challenging outdoor

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environment. We were the first one to offer 5, 10, 20 and 40 MHz channels, configurable in software.

Today, Wi4Net manufactures Wi-Fi 802.11a/g and 802.11n multi-band 4.9 GHz radios and integrates these in its advanced products, such as the FlexiVideo pole camera systems. Being technology agnostic, we choose the best solution for each application, including radios from other vendors.

Technologies and their claims

We have been experiencing a marketing war between technologies; first between CDMA and GSM and now, between WiMAX and LTE. The different entities involved, respectively WiMAX Forum and 3GPP, keep increasing their claims over time. IEEE responsible for the Wi-Fi specifications, followed a similar path. Vendors that seldom design networks, only amplify those claims.

Non-technical users and even many design engineers have difficulties to filter the facts and tend to keep in memory the top numbers. We have, as clients, small operators that have deployed networks based on those claims and today have to scrap their networks and re-design them completely.

We will try to analyze these claims and establish practical values that can be used as real guidelines for a network design. To do this we need to go a little bit into technicality, but we will make it understandable to everyone.

One can say that we can run a car at 200 miles per hour and that the same car can do 20 miles per gallon, but we should realize that both performances do not happen at the same time. Someone else can say that the same car can do 80 miles per gallon, omitting that the measurement should be done downhill only. Those types of claims extend to the wireless capacity world, so let’s analyze them under this light.

Wi-Fi

Wi-Fi Is an OFDMA technology, that uses a non hierarchical per packet contention based access. The main reason for Wi-Fi’s success was its low cost and deployment ease. It was conceived for indoor deployments at homes and offices. It uses TDD (Time Division Duplex) and only one user (AP or client) can transmit at a time. When a user transmits it cannot listen, so if there is an access conflict (two entities trying to transmit at the same time), the transmission will continue until the end and then the entity will have to wait for an acknowledgement or wait until a timer expires to figure out that there was an issue and then re-send the message. This reduces significantly the useful throughput with an increase in the number of users.

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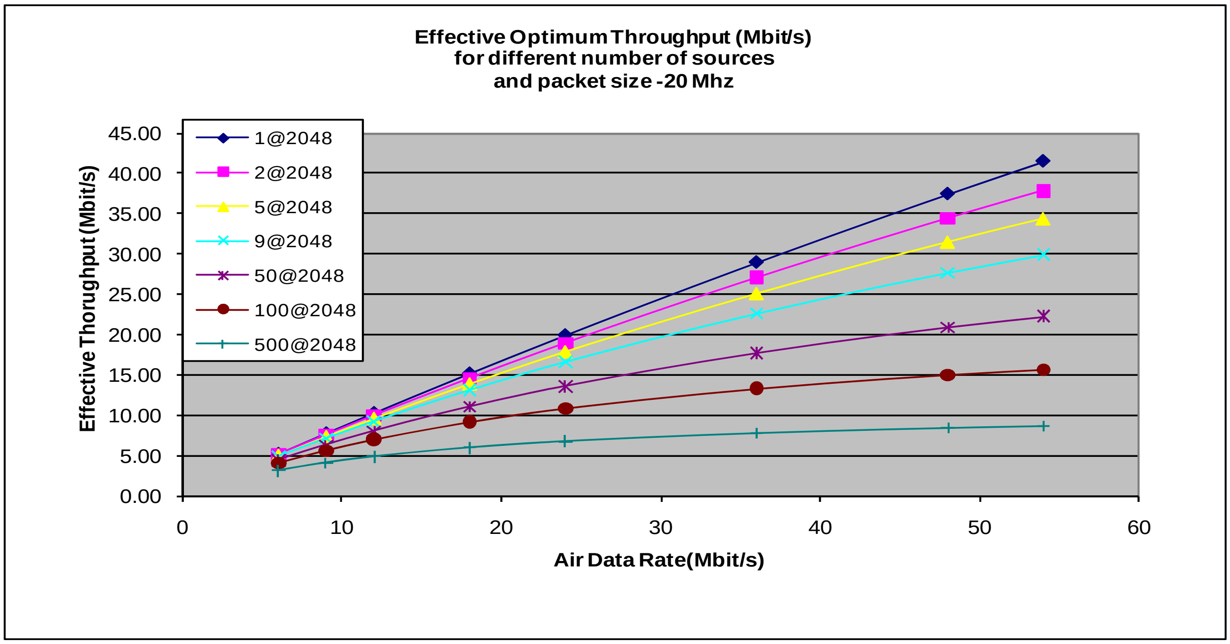
The graphs below show the optimum theoretical throughput of 802.11a for different configurations. The legend gives the number of clients and average packet size in bytes, so 5 @ 2048 means that 5 clients are sharing the air and sending 2048 bytes long packets.
The graph below shows a throughput of 40 Mbit/s for one client, when the highest (64QAM) modulation is used and 5 Mbit/s when the lowest one (QPSK) is used. This gives a maximum efficiency of 2 bit/Mhz. For 5 clients the accumulated throughput will be about 35 Mbit/s, or 7 Mbit/s per client.



The above graph is good only as a marketing tool, since we manipulated the parameters to get the maximum result. We considered packets sent only in one direction, adjusted the timings for a very short link (few meters), no interference was considered and the transmitted packets were maximized to the highest size of 2048 Bytes.

A more realistic scenario for a video transmission is shown in the next graph. We considered 75 % of the packets in one direction (from client to AP), a distance of 700 m, 10% of PER (Packet Error Rate) and an average packet size of 646 bytes. For 1 client we got 16 Mbit/s (0.8 bit/MHz), for 5 clients the best combined throughput is 10 Mbit/s (0.5 bit/MHz), while for 9 clients it is 7 Mbit/s (0.35 bit/MHz).

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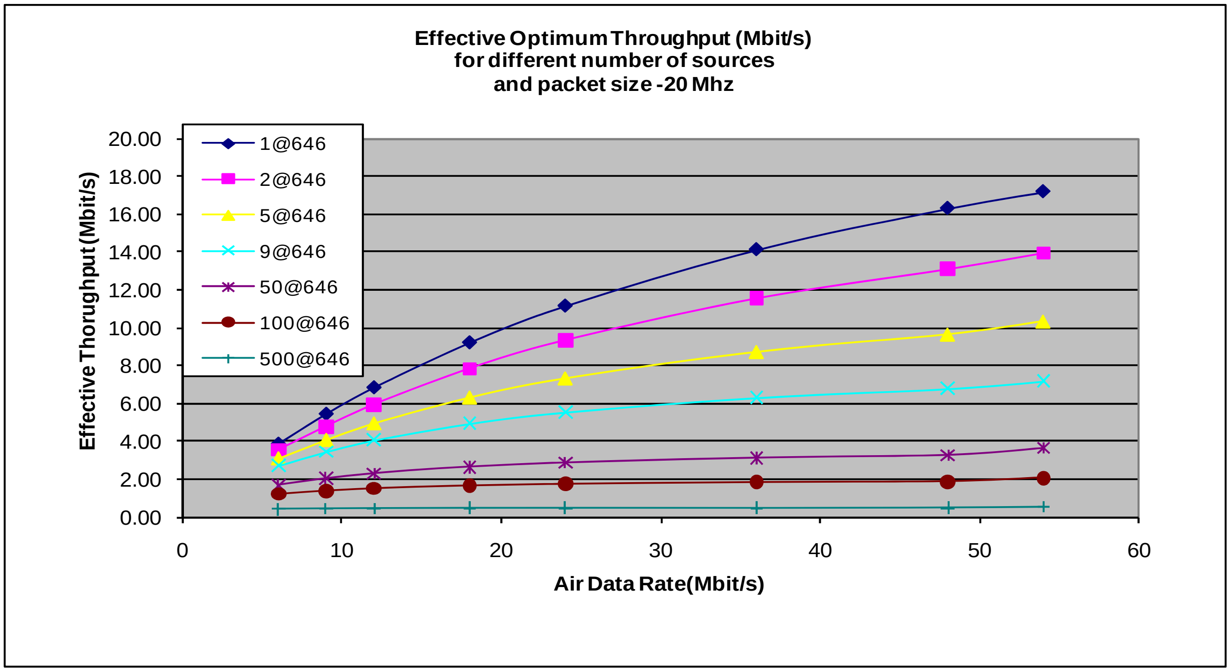

Furthermore, it should be noted that a 20 MHz channel compromises the frequency reuse in the 4.9 GHz band and will render a network non expandable. This bandwidth should be only be used in specific point to point connection, with highly directional antennas.

A cell based network should use preferably 5 MHz and 10 MHz, so the reuse factor is comparable to the cellular wireless networks reuse of 7.

The graph on the next page shows a more realistic throughput for a 10 MHz channel. For 10 users, we get a combined throughput of up to 6 Mbit/s. This results in 0.6 Mbit/s per client, as shown in the next graphs.

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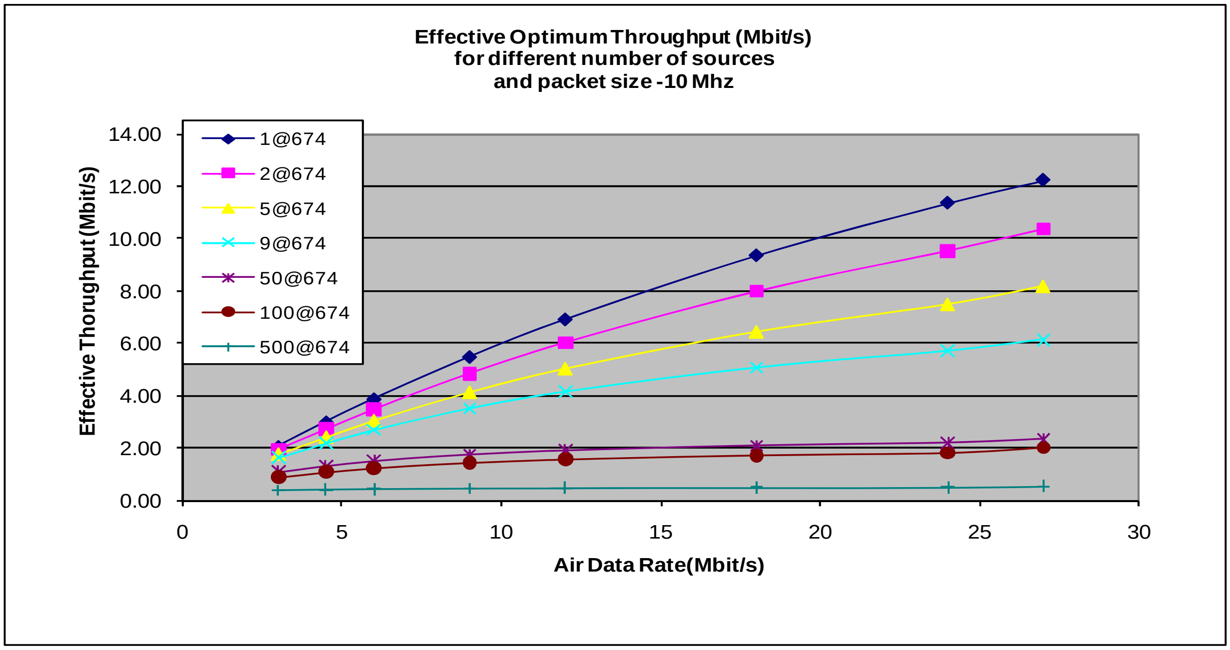

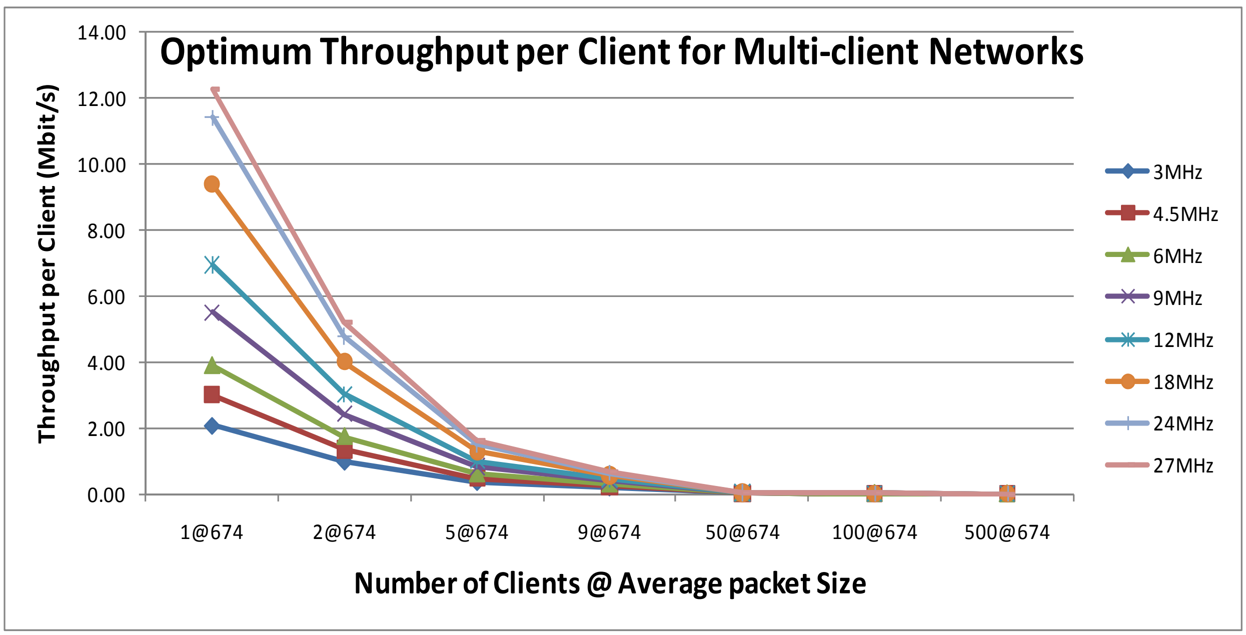

The above throughputs represent the maximum throughput in the air. They have to be discounted by the FEC (Forward Error Code) which will yield between 80 and 50% of the above throughput, plus the wireless protocol (MAC) which will consume another 5%. The best actual throughput available for the applications is between 75% and 45% of the one shown in the graphs. Summarizing:

- For 10 clients sending 674 bytes video packets uplink on a 10 MHz channel, each one will get a best case throughput of 0.45 Mbps, but most likely something around 0.3 Mbps.

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The above throughputs were calculated for optimum conditions, but an RF channel is subject to fading and this can reduce significantly the throughput.

Wi4Net was one of the first companies to approach this issue by designing a Front End stage that provided transmit diversity, by transmitting in two antennas simultaneously. About 15% of our deployments use this feature.

This feature was incorporated into the MIMO (or intelligent antenna algorithms) specification of 802.11n, plus some additional options. The MIMO used algorithms are:

- Receive Diversity
- Transmit diversity
- Space-Time Block Coding
- Spatial multiplexing
- Transmit Beamforming (not commercially implemented in 802.11n)

Intelligent antenna systems do not increase capacity per se; they only reduce the effect of fading. The exception is the Spatial Multiplexing that claims doubling the capacity, if the antennas transmissions are totally uncorrelated. In real life this does not happen, as some correlation always exists, and the increase in capacity varies between -10% to +25%.

How does 802.11n claim 600 Mbps

- **Claim 1**: 802.11 throughput is 54 Mbit/s

  Reality: This is the air interface throughput, applies only to 64QAM and requires 20 MHz bandwidth. It does not consider an obligatory FEC code, which by itself can reduce the throughput by 50%, or conflicts between clients.

  In real life the 54 Mbps result for 10 clients in an accumulated throughput of 4.5 Mbit/s and even this throughput applies only to 20% of the customers in a real network.

- **Claim 2**: Throughput goes from 54 Mbit/s to 58.5 Mbit/s by using more sub-carriers (802.11a has 48 sub-carriers, but 802.11n has 52).

  Reality: The increase in carries happens only for 40MHz channels.

- **Claim 3**: Throughput goes from 58.5 Mbps to 65 Mbps due to an additional FEC code in 802.11n of 5/6, compared to ¾ for 802.11a.

  Reality: The error correction overhead was not considered in the 54 Mbps assumption to start with. Besides, this lesser code will apply to even more restricted locations.

- **Claim 4**: Throughput will boost to 72.2 Mbps by reducing the guard interval from 800 ns (802.11a) to 400 ns (802.11n)

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Reality: This reduces the multipath spread to 100 m only, which is acceptable for indoor, but is not realistic for outdoor environments.

- **Claim 5:** Capacity doubles to 150 Mbps, due to 40 MHz channels

  Reality: Although Wi4Net supports 40 MHz channels since the 1995, it does not have a single deployment using them, as it eats all spectrum and stops expansions.

- **Claim 6**: Capacity jumps to 600 Mbps, by using MIMO, as capacity double with each added antenna.

  Reality: This is the most outrageous claim. It ignores completely that the paths to the different antennas are never completely uncorrelated and that paths interfere with each other. Complete antenna non-correlation is only achievable in a lab using cables and channel simulators to interconnect the antennas. Real life implementations will result in a -10% to 20% throughput increase.

A practical throughput improvement reached with 802.11n in real systems is about 10 to 20% above the one reached by 802.11a with transmit diversity. Wi4Net analyses each deployment and chooses the best solution for each connection, whether it being 802.11a, 802.11n, 802.16d, 802.16e or microwave.

Other Solutions

There are 3 Wi-Fi chip vendors (in market participation order): Atheros, Intel and Broadcom. All those vendors provide the basic hardware design and the software. Vendors can do very little to differentiate themselves.

Vendor additions refer to parameter optimization for outdoor environment, additional frequency support and routing features. The majority of the claims are marketing based.
We believe that a design should be done using real performance values, which can be easily calculated from the theory and considering the real field environment.

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WiMAX

WiMAX was conceived to eliminate 802.11 shortcomings and designed to be an outdoor/indoor system. It is a hierarchical system, in which access to the air is controlled by the Base Station. Each client is dynamically allocated time slots where it can send and receive data. The advantage of this solution is that the throughput is not reduced with the number of clients, unless saturation is reached. WiMAX provides in a 10 MHz channel up to 23 Mbps (Up + Down), although claims go up to 140 Mbps. The uplink throughput considered for a design should be around 16 Mbps, which results in a 1.6 Mbps per user (against 0.3 Mbit/s using Wi-Fi).

Until recently WiMAX cost was not competitive for Public Safety deployments, but more recently it has become a viable possibility. Wi4Net partnered with Alvarion, one of the most prominent companies in this segment, and is offering its most advanced solution BreezeMAX Extreme 5000.

Design Tools

Wi4Net uses the most advanced toolset in the market, CelPlanner Suite. This allows us to consider all the effects involved in a wireless network design, like: multipath, interference, noise, antenna patterns, propagation factors and so on.

Examples of the configuration screens for Wi-Fi are shown on the next pages.

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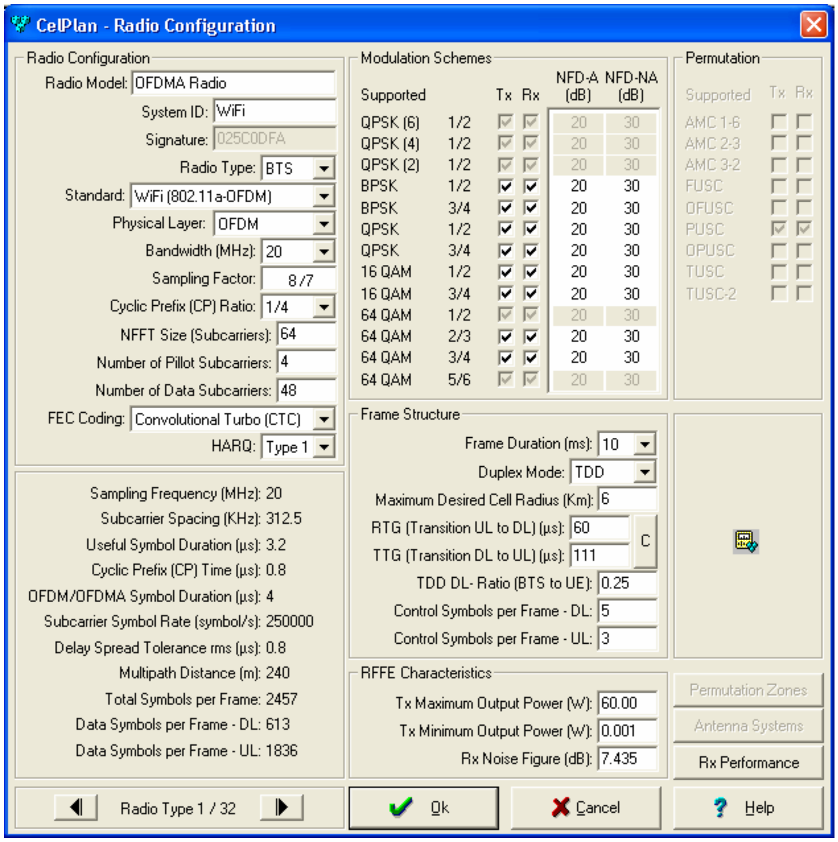
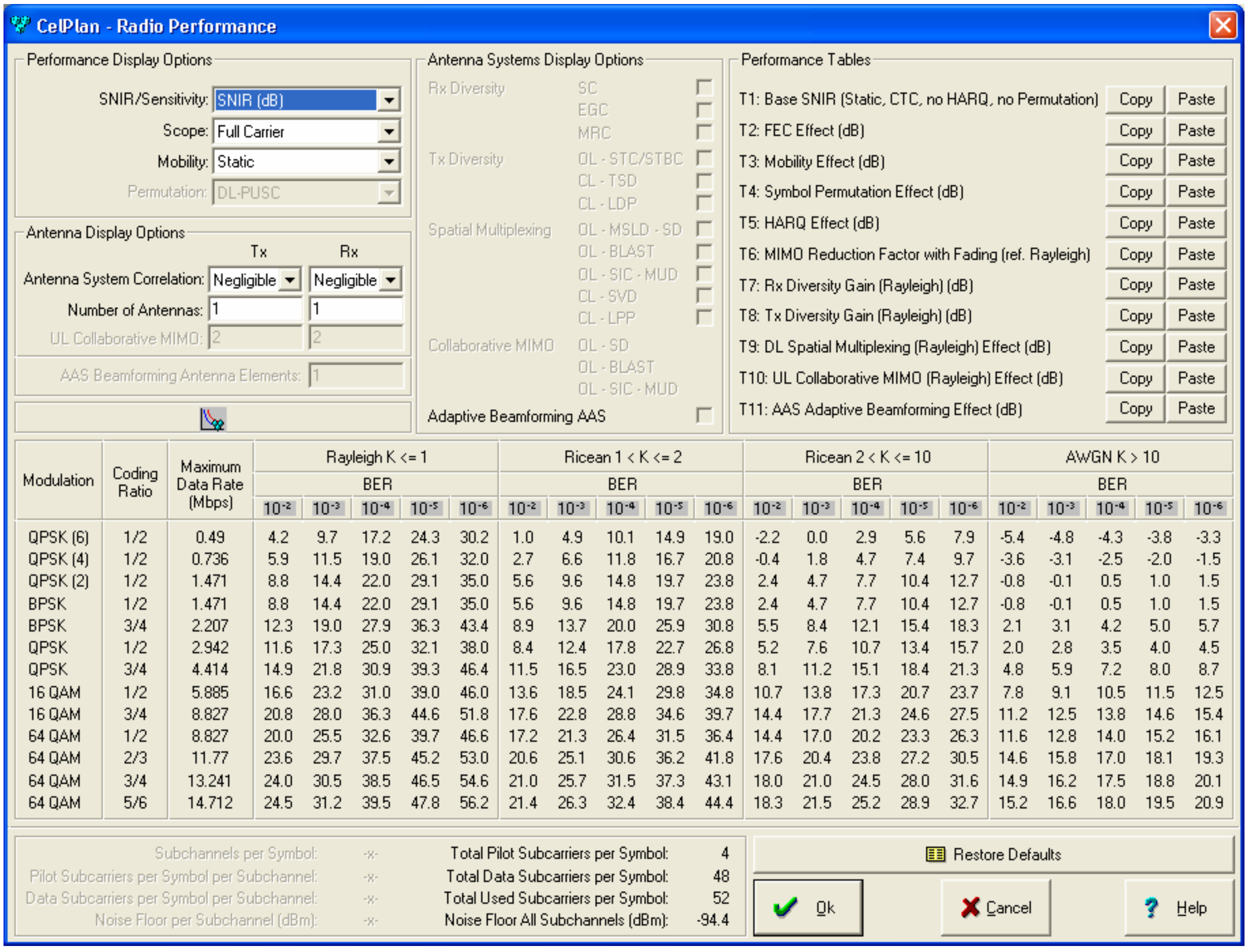
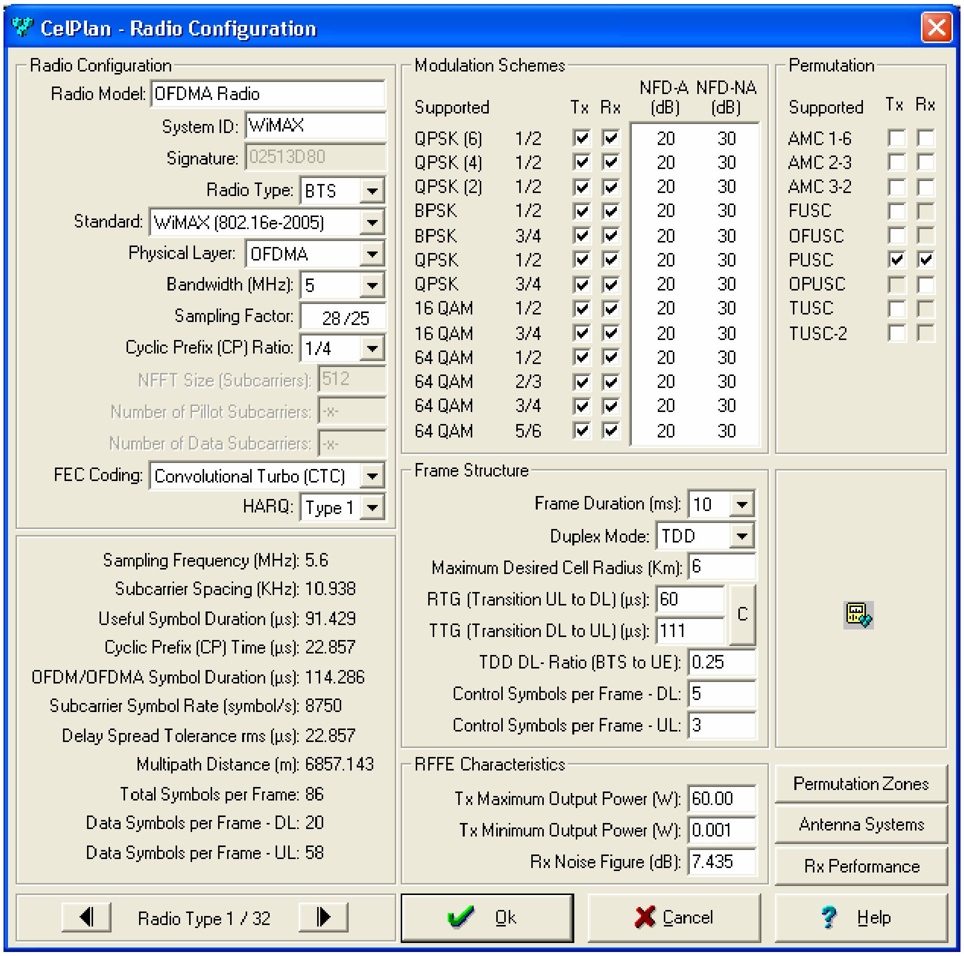

CelPlan - Radio Configuration
Radio Configuration
Radio Model: OFDMA Radio
System ID: WiFi
Signature: 025C0DFA
Radio Type: BTS
Standard: WiFi (802.11a-OFDM)
Physical Layer: OFDM
Bandwidth (MHz): 20
Sampling Factor: 8/7
Cyclic Prefix (CP) Ratio: 1/4
NFFT Size (Subcarriers): 64
Number of Pillot Subcarriers: 4
Number of Data Subcarriers: 48
FEC Coding: Convolutional Turbo (CTC)
HARQ: Type 1
Sampling Frequency (MHz): 20
Subcarrier Spacing (KHz): 312.5
Useful Symbol Duration (µs): 3.2
Cyclic Prefix (CP) Time (µs): 0.8
OFDM/OFDMA Symbol Duration (µs): 4
Subcarrier Symbol Rate (symbol/s): 250000
Delay Spread Tolerance rms (µs): 0.8
Multipath Distance (m): 240
Total Symbols per Frame: 2457
Data Symbols per Frame - DL: 613
Data Symbols per Frame - UL: 1836
Modulation Schemes
Supported Tx Rx NFD-A (dB) NFD-NA (dB)
QPSK (6) 1/2 20 30
QPSK (4) 1/2 20 30
QPSK (2) 1/2 20 30
BPSK 1/2 20 30
BPSK 3/4 20 30
QPSK 1/2 20 30
QPSK 3/4 20 30
16 QAM 1/2 20 30
16 QAM 3/4 20 30
64 QAM 1/2 20 30
64 QAM 2/3 20 30
64 QAM 3/4 20 30
64 QAM 5/6 20 30
Frame Structure
Frame Duration (ms): 10
Duplex Mode: TDD
Maximum Desired Cell Radius (Km): 6
RTG (Transition UL to DL) (µs): 60
TTG (Transition DL to UL) (µs): 111
C
TDD DL- Ratio (BTS to UE): 0.25
Control Symbols per Frame - DL: 5
Control Symbols per Frame - UL: 3
RFFE Characteristics
Tx Maximum Output Power (W): 60.00
Tx Minimum Output Power (W): 0.001
Rx Noise Figure (dB): 7.435
Permutation
Supported Tx Rx
AMC 1-6
AMC 2-3
AMC 3-2
FUSC
OFUSC
PUSC
OPUSC
TUSC
TUSC-2
Permutation Zones
Antenna Systems
Rx Performance
Radio Type 1 / 32
Ok
Cancel
Help



Modulation	Coding Ratio	Maximum Data Rate (Mbps)	Rayleigh K <= 1 BER					Ricean 1 < K <= 2 BER					Ricean 2 < K <= 10 BER					AWGN K > 10 BER				
			10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
QPSK (6)	1/2	0.49	4.2	9.7	17.2	24.3	30.2	1.0	4.9	10.1	14.9	19.0	-2.2	0.0	2.9	5.6	7.9	-5.4	-4.8	-4.3	-3.8	-3.3
QPSK (4)	1/2	0.736	5.9	11.5	19.0	26.1	32.0	2.7	6.6	11.8	16.7	20.8	-0.4	1.8	4.7	7.4	9.7	-3.6	-3.1	-2.5	-2.0	-1.5
QPSK (2)	1/2	1.471	8.8	14.4	22.0	29.1	35.0	5.6	9.6	14.8	19.7	23.8	2.4	4.7	7.7	10.4	12.7	-0.8	-0.1	0.5	1.0	1.5
BPSK	1/2	1.471	8.8	14.4	22.0	29.1	35.0	5.6	9.6	14.8	19.7	23.8	2.4	4.7	7.7	10.4	12.7	-0.8	-0.1	0.5	1.0	1.5
BPSK	3/4	2.207	12.3	19.0	27.9	36.3	43.4	8.9	13.7	20.0	25.9	30.8	5.5	8.4	12.1	15.4	18.3	2.1	3.1	4.2	5.0	5.7
QPSK	1/2	2.942	11.6	17.3	25.0	32.1	38.0	8.4	12.4	17.8	22.7	26.8	5.2	7.6	10.7	13.4	15.7	2.0	2.8	3.5	4.0	4.5
QPSK	3/4	4.414	14.9	21.8	30.9	39.3	46.4	11.5	16.5	23.0	28.9	33.8	8.1	11.2	15.1	18.4	21.3	4.8	5.9	7.2	8.0	8.7
16 QAM	1/2	5.885	16.6	23.2	31.0	39.0	46.0	13.6	18.5	24.1	29.8	34.8	10.7	13.8	17.3	20.7	23.7	7.8	9.1	10.5	11.5	12.5
16 QAM	3/4	8.827	20.8	28.0	36.3	44.6	51.8	17.6	22.8	28.8	34.6	39.7	14.4	17.7	21.3	24.6	27.5	11.2	12.5	13.8	14.6	15.4
64 QAM	1/2	8.827	20.0	25.5	32.6	39.7	46.6	17.2	21.3	26.4	31.5	36.4	14.4	17.0	20.2	23.3	26.3	11.6	12.8	14.0	15.2	16.1
64 QAM	2/3	11.77	23.6	29.7	37.5	45.2	53.0	20.6	25.1	30.6	36.2	41.8	17.6	20.4	23.8	27.2	30.5	14.6	15.8	17.0	18.1	19.3
64 QAM	3/4	13.241	24.0	30.5	38.5	46.5	54.6	21.0	25.7	31.5	37.3	43.1	18.0	21.0	24.5	28.0	31.6	14.9	16.2	17.5	18.8	20.1
64 QAM	5/6	14.712	24.5	31.2	39.5	47.8	56.2	21.4	26.3	32.4	38.4	44.4	18.3	21.5	25.2	28.9	32.7	15.2	16.6	18.0	19.5	20.9

Examples of the configuration screens for WiMAX are shown on the next pages.



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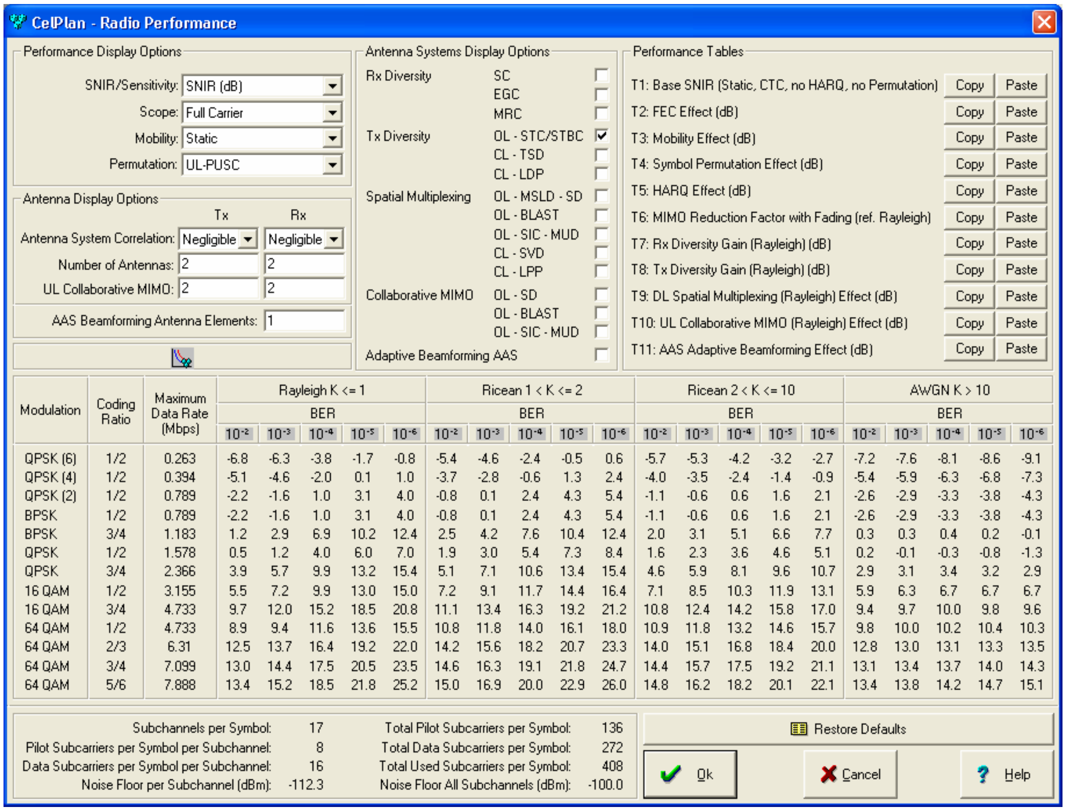

Modulation	Coding Ratio	Maximum Data Rate (Mbps)	Rayleigh K <= 1 BER					Ricean 1 < K <= 2 BER					Ricean 2 < K <= 10 BER					AWGN K > 10 BER				
			10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
QPSK (6)	1/2	0.263	-6.8	-6.3	-3.8	-1.7	-0.8	-5.4	-4.6	-2.4	-0.5	0.6	-5.7	-5.3	-4.2	-3.2	-2.7	-7.2	-7.6	-8.1	-8.6	-9.1
QPSK (4)	1/2	0.394	-5.1	-4.6	-2.0	0.1	1.0	-3.7	-2.8	-0.6	1.3	2.4	-4.0	-3.5	-2.4	-1.4	-0.9	-5.4	-5.9	-6.3	-6.8	-7.3
QPSK (2)	1/2	0.789	-2.2	-1.6	1.0	3.1	4.0	-0.8	0.1	2.4	4.3	5.4	-1.1	-0.6	0.6	1.6	2.1	-2.6	-2.9	-3.3	-3.8	-4.3
BPSK	1/2	0.789	-2.2	-1.6	1.0	3.1	4.0	-0.8	0.1	2.4	4.3	5.4	-1.1	-0.6	0.6	1.6	2.1	-2.6	-2.9	-3.3	-3.8	-4.3
BPSK	3/4	1.183	1.2	2.9	6.9	10.2	12.4	2.5	4.2	7.6	10.4	12.4	2.0	3.1	5.1	6.6	7.7	0.3	0.3	0.4	0.2	-0.1
QPSK	1/2	1.578	0.5	1.2	4.0	6.0	7.0	1.9	3.0	5.4	7.3	8.4	1.6	2.3	3.6	4.6	5.1	0.2	-0.1	-0.3	-0.8	-1.3
QPSK	3/4	2.366	3.9	5.7	9.9	13.2	15.4	5.1	7.1	10.6	13.4	15.4	4.6	5.9	8.1	9.6	10.7	2.9	3.1	3.4	3.2	2.9
16 QAM	1/2	3.155	5.5	7.2	9.9	13.0	15.0	7.2	9.1	11.7	14.4	16.4	7.1	8.5	10.3	11.9	13.1	5.9	6.3	6.7	6.7	6.7
16 QAM	3/4	4.733	9.7	12.0	15.2	18.5	20.8	11.1	13.4	16.3	19.2	21.2	10.8	12.4	14.2	15.8	17.0	9.4	9.7	10.0	9.8	9.6
64 QAM	1/2	4.733	8.9	9.4	11.6	13.6	15.5	10.8	11.8	14.0	16.1	18.0	10.9	11.8	13.2	14.6	15.7	9.8	10.0	10.2	10.4	10.3
64 QAM	2/3	6.31	12.5	13.7	16.4	19.2	22.0	14.2	15.6	18.2	20.7	23.3	14.0	15.1	16.8	18.4	20.0	12.8	13.0	13.1	13.3	13.5
64 QAM	3/4	7.099	13.0	14.4	17.5	20.5	23.5	14.6	16.3	19.1	21.8	24.7	14.4	15.7	17.5	19.2	21.1	13.1	13.4	13.7	14.0	14.3
64 QAM	5/6	7.888	13.4	15.2	18.5	21.8	25.2	15.0	16.9	20.0	22.9	26.0	14.8	16.2	18.2	20.1	22.1	13.4	13.8	14.2	14.7	15.1

Conclusion

Care should be taken by a network designer when considering technology throughput claims. A wrong assumption will lead to a bad design which may even work initially, while the network is lightly loaded, but will create huge problems at expansions.

A designer must also be responsible to save spectrum, a limited resource for other deployments, mainly in Public Safety, where the same band is shared by many agencies.

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