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4G Wireless Air-Interface: Design Requirements & Criteria

Instructor: Terry S. Cory MSEE, EE

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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PREFACE

Much has been written about the 4G technologies and the intricacies of the architectures and functional characteristics...much, of which, involves learning many acronyms. This course does not do this. Instead, it addresses the very practical RF design of a 4G interface, distilling the requirements of the two major technologies into a common design process that will work for either.

This course will provide the attendee with guidelines, requirements, and a process for designing a 4G air interface upgrade from an existing 2G wireless network. The course will convey an understanding in broad terms of 4G attributes and possible pitfalls, considering HSPA+ and LTE technologies; but, to show that the RF design for either one converges toward a common process, enabling high-speed data broadband transfer—as opposed to separate narrow band CDMA2000 and UMTS/GSM network technologies.

The attendee will be able to enact an optimum air-interface RF design process for a 4G wireless network; and, will be able to direct and manage this process from an RF engineering viewpoint.

In many instances, cell site topologies suited to 800 MHz cellular operation were used as they were for 2G 1.9 GHz PCS operation also. In many instances, the narrowband nature of 2G masked the possible difficulties or insufficiencies of such topologies for obtaining optimum broadband performance....except in urban areas where the possibilities of interference were greater.

1.0 INTRODUCTION

Installing 4G equipment on existing 2G towers will not yield 4G performance over the 2G coverage area. If we upgraded the network with additional towers and confirmed 4G performance with field testing with no loading, it is unlikely that 4G performance could be sustained when the network is loaded with users. Also, classic drive-testing, while good for confirming mobile broadband performance outside of buildings, is insufficient for assessing fixed-located user links having elevated Customer Premises Equipment (CPE) antennas–especially under traffic loading.

To baseline an existing site topology using 4G equipment parameters and spectrum is the best starting point for a network upgrade. This is accomplished by predicting the radio wave propagation and, then, simulating performance under traffic loading for varying user environments using an RF planning software tool. Several such tools are available for sale or lease; or, services are also available from a number of sources to accomplish this baseline process.

An optimum 4G design requires a geographic distribution estimate of potential users. The efficient design approach is to target this traffic with greater cell density and/or greater data throughput potential....more channels/spectrum, more sectors, higher MCS index, spatial multiplexing, etc. Available link data rate under low traffic loading is very much dependent on the signal level; and, so is typically dependent on user range from the serving cell/sector. Neglecting interference, 16QAM modulation requires about 7.5 dB more margin over QPSK modulation to double the data rate; and 64QAM requires about 13.5 dB more margin over QPSK to triple the data rate.

LTE, rather than confining operation to one or more specific shared frequency channels of fixed width, enables scalable bandwidths to be defined, ranging from 1.25 to 20 MHz (1.25, 2.5, 5, 10, 20 MHz); and, then a raster of orthogonal (isolated) sub-bands of 15 kHZ width via Orthogonal Frequency Division Multiple Access fitted to the particular scaled band. Thus, a few high-rate close-in users can be accommodated with, say, the shared full spectrum—while at the same time as narrower band data users at greater distances are accommodated by the purposeful quasi-real time partitioning of the channel/sub-channels. And, forward link fast power control is available at the 'channel/sub-channel' level.

Shared spectrum results in interference...the nemesis of a CDMA access method, whether CDMA2000 or UMTS based. To be useful, the RF planning tool must be able to compute forward-link interference vs traffic loading at any location from all cells/sectors sharing spectrum. Rather than received signal level in dBm, the significant field performance metric is then Ec/Io...the ratio of pilot power to total interference. In the case of LTE the metric is RSRQ, similar to Ec/Io except that the reference signal is more complex and the bandwidth over an ensemble of sub-carriers is variable.

There is little difference, RF wise, between 2G CDMA2000 and WCDMA(UMTS). This is because CDMA operation operates within a restricted set of parameters. Case in poiut, CDMA2000 employs about 21 dB of processing gain while W-CDMA employs up to about 27 dB for 2G voice operation. The 6 dB difference lies in W-CDMA having to dig a little deeper to recover signals spread over a larger bandwidth. This is compensated for by a 5-dB difference in signaling rate...so that these two systems in 2G function within about a dB in Ec/Io of one another. Whether the above technologies or newer HSPA/HSPAS+ releases, the CDMA parameters are rather tightly defined. The typical power partition is:

Pilot power	17%	of total power (20 watts, 43 dBm)
Page power	6%	
Synch power	2%	
Traffic power	75%	

LTE operation will experience co-channel interference to a lesser degree than HSPA+ because less overall shared spectrum will be involved. However, as opposed to GSM where cell coverage overlap is permitted, the optimum 4G network design will have 'quilted cells' in a mosaic with minimum overlap to minimize the possibility of all interference. And the design will consider the worst case which assumes shared spectrum in all cases.

2.0 SUMMARY

To design an air interface upgrade to 4G, we need not know the details of the technologies as, except for differences in spectrum and base station (cell/sector) power level, the requirements are the same. There is a tendency to make the design problem too complicated. Much has been written in detail regarding features and network

At this time, the more viable commercial options going forward for 4G appear to be HSPA+ as a logical upgrade from WCDMA, and LTE. Over time as wireless broadband becomes more distant from a classic phone network and approaches the flexibility of a packet-switched all IP network, LTE has advantages, the most significant of which the absence of a Base Station Controller (BSC)/Radio Network Controller (RNC) that here-to-fore has provided the connection between several base stations to the switch via a vendor proprietary interface. LTE is ultimately more flexible in network configuration; and, if well managed, can provide more efficient spectrum usage because of the dynamic allocation of sub-channels. In essence, the LTE network becomes a wide-area wireless router.

One might say that HSPA+ (10 MHz with dual-carrier) and HPSA+ Advanced (to 40 MHz) in Release 11 from the 3GPartnershipProject (3GPP) is more bearer service and device oriented, providing functional capability and compatibility to meet the current market as it advances; whereas, LTE is advancing toward provision of an 'everywhere available' IP pipe. The success of one over the other may well be determined in the handset marketplace. Right now, there are few phones equipped for VOIP and for the latest 4G advances. But down the road, the ability to directly connect picocells/femtocells tethering a variety of devices directly to the network via an IP interface at home will likely make LTE the surviving technology.

Both HSPA+ and LTE are in a logical progression of Releases from the 3GPP with HSPA+ defined in Releases 7 & 8. LTE is defined in Releases 9, 10 and beyond...as is HSPA+ Advanced in Release 11. Rather than a smooth evolution, Release 9 represents a fork in the road.

All 4G networks achieve advertised peak data rates only when a sector user consumes the entire spectrum. From an air-interface RF perspective, the practical transport rates on most user links to/from the base station are comparable. A CDMA-based Radio Transport Technology (RTT) uses code division for multiple access of narrow channels, with the spectrum of each user consuming the entire bandwidth as broadband noise. Each channel is protected from the others by virtue of the processing gain. For higher data rates, the number of simultaneous users diminishes as the processing gain goes away. According to 3GPP notation, The maximum number of HS-DSCH codes is 15. LTE implementation requires frequency planning; and, soft frequency reuse is a possibility, using the near/far capability of LTE. This leads to the following RF advantage/disadvantage of these two RTT's.

2.1 4G RTT ATTRIBUTES & NEGATIVES

For LTE:

1. The use of 15 kHz sub-channels obviates the effects of multipath so that no diversity antennas are required; this is particularly important for mobile broadband operation in urban environments
2. Power control at the sub-channel level offers a 'near-far' option for frequency reuse; that is, close-in high-rate users may use the entire bandwidth at low power with far-out users at less than full bandwidth may be served with higher power. A small amount of dedicated spectrum near the cell edges may reduce interference between cells in these regions (a soft frequency reuse concept)
3. Dynamic operation balancing spectrum usage of the bandwidth increases the peak-to-average power ratio in the forward link(downlink) amplifier, which will reduce the available capacity of the network
4. For low to moderate traffic loading, the interference is expected to be significantly less than with HSPA+; however, at high traffic loading the interference levels of the two RTT's relative to signal are expected to be comparable...unless conventional 7-cell frequency reuse is implemented.
5. Practical frequency reuse in order to maintain high-speed (large bandwidth) include soft reuse as in the 'near-far' description above, and hard reuse with a cell cluster size of 3 in which the bandwidth is partitioned into 3 parts. The author believes a cell cluster size/reuse factor of 7 diminishes the available data rate too severely. Thus, co-channel interference is inherent in high-speed wireless networks.
6. The flexibility of LTE offers high capacity if the planning is used correctly to target traffic...both the planning and management processes may be more difficult than with HSPA+
7. LTE requires a 'ground-up' build; whereas, HSPA+ involves a equipment/system upgrade only.

For HSPA+:

1. The spread spectrum nature of CDMA tends to distribute capacity across the network in a relative traffic-balanced manner if there are sufficient cells/sectors to target the user traffic geographically and according to data rate demand
2. The design metric for coverage—and available data rate—is Ec/Io, rather than received power
3. Interference is spread uniformly across the entire bandwidth, which may result in lower C/I levels than for LTE
4. The capacity of HSPA+ is forward-link (downlink) limited...by virtue of the peak power limitations of the sector amplifier.
5. Because of the 'noise-equivalent interference,' of CDMA, the traffic loading may be characterized as a percent...50% loading corresponds to a 3 dB noise rise, 75% loading corresponds to a 6 dB noise rise, with soft blocking beginning at about 67% loading.

2.2 4G PARAMETERS AND CHARACTERISTICS

Assuming shared spectrum, the following are approximate threshold metrics for data performance for an HSPA+ network used as an example in this course.

Ec/Io (dB) Downlink
HSPA+ 21.1 mb/s 4G Max Rate 5 MHz Bandwidth

	Modulation	Initiate	Nominal	Drop	Speed
4G	64QAM	-2	-(3-4)	-5.5	15-20 mb/s typ
3G	16 QAM	-5	-(6-8)	-11.5	4-6 mb/s typ
2G	QPSK	-9	-(10-12)	-18	0.3-0.5 mb/s typ

Correspondingly, for signal sensitivity limits of noise and/or interference:

Downlink Receive Sensitivities in 10 MHz Bandwidth (5 dB Noise Figure Rx)

	Modulation	Code Rate	Threshold	C/No
4G	64QAM	5/6	-76 dBm	98 dB
		3/4	-77	97
		2/3	-78	96
		1/2	-80	94
3G	16QAM	3/4	-83	91
		1/2	-86	88
2G	QPSK	3/4	-90	84
		1/2	-95	79

The sensitivities will increase (become less negative) with interference. Note that these sensitivity thresholds are not the receiver sensitivity. They are this sensitivity plus the Eb/No margin required by the modulation.

For a network upgrade from 2G to 4G, the probability is high that more cells/sectors will be needed for coverage and to target the anticipated community of users with an expected grade of service These 'fill in' and/or 'expanded region' cells. require isolation from any existing sites being modified as do these existing cells/sectors from each other.

As both the 4G technologies are defined in sequential 3GPP releases, progressing in increments (categories) of increased capability, the list of these follows. Maximum data rates and coding rates are given.

3GPP Release #	Cat	#of codes HS-DSCH	Modulation Type	MIMO/ Multi-cell	Code Rate	Data Rate Mbits/s
Release 5	1	5	16-QAM		.76	1.2
Release 5	2	5	16-QAM		.76	1.2
Release 5	3	5	16-QAM		.76	1.8
Release 5	4	5	16-QAM		.76	1.8
Release 5	5	5	16-QAM		.76	3.6
Release 5	6	5	16-QAM		.76	3.6
Release 5	7	10	16-QAM		.75	7.2
Release 5	8	10	16-QAM		.76	7.2
Release 5	9	15	16-QAM		.70	10.1
Release 5	10	15	16-QAM		.97	14.0
Release 5	11	5	QPSK		.76	0.9
Release 5	12	5	QPSK		.76	1.8
Release 7	13	15	64-QAM		.82	17.6
Release 7	14	15	64-QAM		.98	21.1
Release 7	15	15	16-QAM MIMO		.81	23.4
Release 7	16	15	16-QAM MIMO		.97	28.0
Release 7	19	15	64-QAM MIMO		.82	35.3
Release 7	20	15	64-QAM MIMO		.98	42.2
Release 8	21	15	16-QAM Dual-Cell		.81	23.4
Release 8	22	15	16-QAM Dual-Cell		.97	28.0
Release 8	23	15	64-QAM Dual-Cell		.82	35.3
Release 8	24	15	64-QAM Dual-Cell		.98	42.2
Release 9	25	15	16-QAM Dual-Cell + MIMO		.81	46.7
Release 9	26	15	16-QAM Dual-Cell + MIMO		.97	55.9
Release 9	27	15	64-QAM Dual-Cell + MIMO		.82	70.6
Release 9	28	15	64-QAM Dual-Cell + MIMO		.98	84.4
Release 10	29	15	64-QAM Triple-Cell		.98	63.3
Release 10	30	15	64-QAM Triple-Cell + MIMO		.98	126.6
Release 10	31	15	64-QAM Quad-Cell		.98	84.4
Release 10	32	15	64-QAM Quad-Cell + MIMO		.98	168.8
Release 11	33	15	64-QAM Hexa-Cell		.98	126.6
Release 11	34	15	64-QAM Hexa-Cell + MIMO		.98	253.2
Release 11	35	15	64-QAM Octa-Cell		.98	168.8
Release 11	36	15	64-QAM Octa-Cell + MIMO .		98	337.5

3.0 4G NETWORK PERSPECTIVE

The following is a monolog contained in a reporting e-mail to a customer explaining an analysis using an RF planning tool. The MCS index refers to modulation and coding levels for Wifi 802.11n that are similar to the 3GPP release categories.

"I used 3 sectors 65-degree panel antennas at 40, 140, 270 degrees @ 190 feet. The transmit power level was taken to be 28 dBm (-2 dBw). Two CPE configuration were used, mobile at ground level and fixed at 15 feet. The levels were set at -91.5 dBm for QPSK modulation, -87.5 dBm for 16QAM and -80 dBm for 64QAM. The QPSK was an average of values expected for MCS1 and MCS2....somewhere between the 1/2 and 3/4 coding. Similarly for 16QAM, an average between MCS3 and MCS4 1/2 and 3/5 coding values. The 64QAM was essentially an average of MCS 5,6,&7 values...about 3/4 coding. As you can see from the map, the main coverage area is about 1.5 to 2 mi[les from the tower for mobile (or ground-level fixed) broadband."

"I tried raising the CPE antenna separately (without adding antenna gain) and, surprisingly, it made very little difference in the coverage (going from 5 feet up to 15 feet). Then, I added 8 dB of gain and the difference was great as you can see...the 64QAM range now extends out to about 2 miles."

"The practical difference in data capacity per sector is that QPSK delivers a total rate equal to the bandwidth, 16QAM delivers a capacity of twice the bandwidth, and 64QAM delivers a capacity equal to 3 times the bandwidth. So, anyway, the link gain is very important. This means keeping CPE losses to a minimum and using as much link gain as possible. A CPE antenna gain of 12 dBi would be better than 8 dBi..and, the panel antenna gain of 18 dBi I used is much better than, say, 13 dBi for the integrated CPE antennas."

This analysis was for the downlink without spatial multiplexing (MIMO). The speed increase over the bandwidth in MHz 1:1 in mbits/sec can be up to a theoretical factor of 6 by changing the modulation type and the coding rate options for each type.

Another e-mail monolog discussed testing using the author's smart phone.

"I've been correlating available PCS mobile broadband data speed vs Ec/Io as measured on my Galaxy S phone...AT&T HSPA service using WCDMA. An Ec/Io of at least -4 dB is required for 4-G speeds. My tests show downlink speeds at this value to be about 2.6 megabits/sec down. At an Ec/Io of -7 dB, my speed tests show about 1.2 megabits/sec down. And, with an Ec/Io of -10 dB the speed is reduced to about 0.5 megabits/sec down. My 3G data plan topped out at about 2.6 megabits; but, the lower speeds vs Ec/Io should be typical. I downloaded and installed the speedtest.net Android app; and, to access the support/test mode on your phone enter *#0011#. The higher speeds enabling 4G 64QAM modulation require an Ec/Io of at least -2."

"To further frame this for you, the basic RF bandwidth for WCDMA is 5 MHz; where the 'pipe' is theoretically capable of handling speeds of up to 14.4 mb/s down with 16QAM , 21 mb/s with 64QAM and 42 mb/s with dual-cell (10 MHz) HSPA+ or with 2x2 MIMO. Considering the AT&T network as being capable of a 42 mb/s 'pipe,' and with a service factor of 16 (users), 42/16 is about 2.6 mb/s that I attribute to the bottom end 4G performance...which just happens to be the speed limit of my data plan. 2.6 mb/s is sufficient to support full streaming video without buffering."

4.0 TRAFFIC CONSIDERATIONS

Wireless broadband data usage has been increasing so rapidly, its 'moving baseline' makes an estimate of future usage difficult. This is particularly true with the evolution and proliferation of devices. The limiting situation will likely be full streaming video employing smart phones and tablets. Cisco estimates of data usage to be about 15 GB/month by 2016; which, at 8 bits/Byte amounts to 120 gbits that, at a presumed high-definition stream rate of 2 mb/s rate would amount to 60,000 seconds or 1000 minutes per month for peak users. This is perhaps reasonable, considering that phone usage—which is typically 1500 minutes per month anyway.

A more realistic current 4G situation for streaming would find about 3 GB/month, or 24 gbits/month at a 2 mb/sec rate would be about 200 minutes per month. Actual current composite usage (circa 2012) per user is about 2-3 gbits/month representing short message service texting along with dilute internet searching..

The impact of more streaming video of longer duration (than short clips, short messages, or VOIP) is that fewer simultaneous users can be accommodated; each, of which consumes the full available bandwidth or a short sub-multiple thereof...like 40 MHz is 2 x 20 MHz or 4 x 80 MHz, etc. The result will be to plan now for higher capacity even though full implementation may be in the future. That means anticipating at least a 200+ MHz pipe as an aggregation of three 80 MHz sectors per cell site that will support at least 1000 mb/s over gigabit ethernet in the future..

Most all authors skirt around the number of simultaneous (active) users that can be accommodated with 4G. We need a number to deal with so that we can match capacity to demographics. We will use a number of 200 users/cell (66 users/sector) for future planning purposes in a 10 MHz downlink bandwidth...for either HSPA+ or LTE...and 60 users per cell (20 users/sector) for current implementation. This is for an assumed 2 mb/s streaming video on average when near fully loaded. Of course for downloads and operation of web-based programs much higher data rates will be available that are near the tested speed of the network.

Now consider the offered traffic load per user, again stating the Cisco future example in the first paragraph of this section using an estimate of monthly usage. Consider the fore-mentioned estimate of 15 GB/month by 2016 as an example. This is 15*8 = 120 gbits/month, or 4000 Mbits/day. Using the metric where the busy hour usage is 25% of the daily usage, the busy hour estimate is 1000 Mbits over 60 minutes; or, 33 minutes. The result is the same as using a stream rate of 2Mbits/second. 33 minutes of utilization over 60 minutes amounts to 0.55 erlangs per user.

For the current estimate of 3GB/month per user, projected the utilization is a factor of 5 less, or 0.11 erlangs/user.

The offered traffic load begins with an assumed penetration rate of the total population ('pops'). Currently, the penetration rate of all devices exceeds 100% (# of devices/total population). However, during the busy hour we will assume a penetration of 30% to represent a percentage of users using video capture devices during the busy hour; and, of these, 30% using streaming video.

For an urban morphology having a population density of 3000 users/km^2, the offered busy hour streaming video load would be 3000*0.3*0.3 = 270 simultaneous users/km^2. The offered streaming video traffic would be 270*0.55 = 148.5 erlangs/km^2

For suburban business, the market density is a third of urban, or 1000 users/km^2. For this case, the offered load would be 90 users/km^2, and the offered streaming traffic would be 49.5 erlangs/km^2.

These estimates are for the future; say, circa 2016. Looking at the current estimate of 200 minutes/month...a factor of 5 less than the future estimate...the urban and suburban offered load estimates would be about 30 erlangs/km^2 and 10 erlangs/km^2.
respectively

With 60 simultaneous users accommodated per cell/sector, the return capacity available is then 60 erlangs, and similarly for 20 users/20 erlangs. The traffic load, capacity, and maximum cell size are shown in the following table.

Future & Current traffic load And Cell Size
Based on Streaming Video Service

		Video Load (erlangs/km2)	Return Capacity/ Sector(erlangs)	Cell Radius(km)
2016				
	Urban	148.5	60	0.65
	Suburban Business	49.5	60	1.12
2012				
	Urban	30.0	20	0.80
	Suburban Business	10.0	20	1.38

These exemplify 4G operation with a 10 MHz downlink and 2x2 MIMO. Expanding the bandwidth to 40 MHz will double the cell radius for the same offered traffic load. Reducing the market density by a factor of 4 will also double the cell radius.

A complete list of morphology vs market densities typifying wireless telecommunications is as follows, with cell radii included:

Morphology	Market Density (users/km2)	Future 10 MHz	Current 10 MHz
Dense Urban Peak	10,000	0.25	0.31
Dense Urban	5,000	0.50	0.44
Urban	3,000	0.65	0.80
Light Urban	1,500	0.92	1.12
Suburban Business	1,000	1.12	1.38
Inner City Residential	650	1.40	1.71
Suburban Residential	400	1.78	2.18
Upscale City Residential	250	2.26	2.76
Outer City Residential	150	2.91	3.57
City Highway	100	3.57	4.37
Rural Highway	10		

The above examples assume three sectors, deploying the standard type configuration(s) used with cellular/PCS cells. More sectors than three may be used, having more directional (narrower in azimuth) radiation patterns, to increase the return capacity...these in addition to adding spatial multiplexing and more bandwidth.

Current 4G usage, however, uses only a little streaming video—so the offered load is much less and the maximum radius of the smallest cell is much greater. To service streaming video in the future, at a minimum microcells (having diameters of about 2 km) will be needed. Such cells located at/in homes and businesses with a direct IP connection via LTE will be needed in dense environments.

4.1 TARGETING THE TRAFFIC

At the onset of an upgrade, two items are needed. The first is a map of population density for the coverage area—which can be matched to the morphology information given here. The second is a prediction of coverage using existing tower locations; but, with antennas and power levels matching the spectrum and the particular RTT to be used. The prediction will show quickly how well the coverage matches the market.

Census data is available from www2.census.gov/maps in Census Blocks, Census Block Groups, and Census Tracts from smaller to larger. The block level areas range in size from about a quarter mile to just over a mile, dimension wise. Population density may be mapped directly; or, the actual user penetration...which then would be your market share...(assumed to be 0.3) times population ('pops') can be mapped. The maps should be geocoded by available cell sites/towers. If your market differs significantly and in proportion from the morphology table in the previous section, a new table should be prepared that is unique to your network situation.

The coverage data should be mapped in terms of Ec/Io...to also represent RSRQ for LTE to first order. Radio signal propagation predictions are required; and, then interference should be calculated, resulting in a map of Ec/Io. The value of -4 dB should be used as the threshold for 4G performance in either case.

Coverage must be considered separately for mobile broadband and for fixed-located users because of the difference in downlink elevation of the CPE antennas. When considering fixed-located coverage, the characteristics of the CPE antennas will be important. High CPE antenna gain is to be encouraged.

An objective is to design the upgrade (both existing and new cells) so that there is minimal overlap in coverage between cells/sectors. And the task at hand is to roughly position new cells to target the geographic market area. The topology may well be time-phased to reflect growth in market/market share. Overall, the return capacity of the network should be sufficient to handle the traffic load.

5.0 RF DESIGN

5.1 OVERVIEW TIPS

There are several aspects–hopefully becoming intuitive–of air interface design to keep in mind. Whereas the 2G design process was two-dimensional, the 4G design is three-dimensional in that user CPE for fixed operation may be at different heights above ground. Thus mobile broadband at an assumed fixed height of five feet and fixed-located operation at varying heights (15-25 feet, typical) must be considered both separately and together. In n 4G network, no cell can be designed separate from contiguous cells and no cell can be designed separate from CPE configuration options. Once accomplished, the network topology of cells may be described as 'quilted;' that is, cells defining a pattern without coverage overlap.

With LTE, the coverage reality of a sector involves distributing a variety of bearer services over the sector dynamically and without (or with minimal) restriction...just like an IP pipe that is transparent to user services and devices, generally. The use of fast and dynamically allocated power control serves to implement a frequency reuse factor of '1' meaning that the same spectrum is used in all sectors of all cells...unless, the designer elects to use a reuse factor of three in a 3-cell cluster, thus dividing the spectrum available per sector by three also. We will assume the soft frequency reuse method of factor '1.' So, in this instance, HSPA+ and LTE will share a common design process as far as interference is concerned. Our expectation for LTE is that this represents the worst case for interference to be seen at high traffic loading levels.

With respect to wireless systems generally, cell boundaries reflect tower position/placement relative to terrain curvature and foreground clutter, tower height, and spatial filtering of the antenna elevation plane(vertical) radiation pattern. For broadband networks–or, CDMA RTT's of any kind–no cell should be on a hilltop any more as typified cellular AMPS/DAMPS and GSM networks. Terrain and clutter remain the primary design constituents for placing a cell boundary where it is needed. The ideal broadband network would have terrain with periodic 'dimples' or valleys...like the dimples on a golf ball; and, cells would be located at the bottom of these depressions. The boundaries would occur with drop in received signal strength as the angle of the incident radiation from the tower relative to the ground(tangential) approaches zero. This is where the direct radio wave and it's ground reflection cancel. Clutter–or terrain hills– generally present obstacles to radio waves in which the wave's strength is reduced either by diffraction (wave bending) or by absorption. With these thoughts, sites should be placed and computer-evaluated...this may involve several iterations per site.

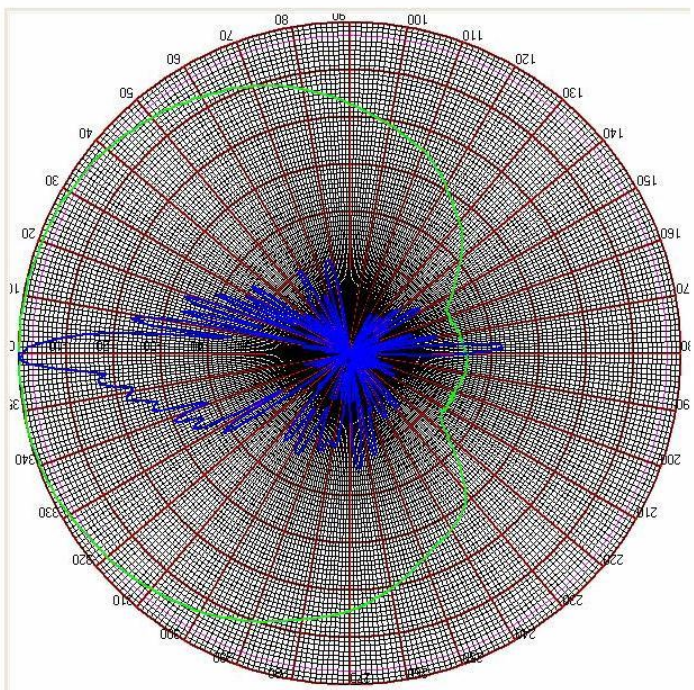
Diversity reception may be omitted in decisively rural HSPA+ or in all LTE deployments as minimal time delay dispersion is expected in these environments. In urban environments, space diversity is the best means because reflections from buildings are predominantly vertical; therefore, are not random. Thus, dual-linear polarizations will be correlated substantially at times...often at times where diversity reception is most needed. For frequencies in the 2 GHz range, the spacing should be at least twelve feet; although, six feet are often used.

Akin to diversity is the proposition of using dual-polarized (linear, ± 45 degrees) for Multiple In Multiple Out (MIMO) operation. This operation essentially spatially multiplexes two streams when properly implemented with corresponding dual polarization at both the cell tower and user (CPE antennas). and with 4G it doubles the available transmission rate.

Higher CPE antennas, while extending coverage range, may increase the level of interference. Narrower beam(higher gain) CPE antennas will discriminate against interference to some degree. For 4G, the CPE antenna gain should be at least 12 dBi; and, the ideal gain would be about 18 dBi. Lower gain CPE antennas will encourage interference; except, perhaps, in rural areas. But, 18 dBi would significantly increase the 4G coverage range from the base station.

5.2 ANTENNA SELECTION

Antennas are the key components of a wireless network, as the provide selectivity in power gain, off-angle(boresight) interference rejection; and, most noteworthy, spatial filtering in elevation angle. The desired characteristics are illustrated in the figure of the shaped-beam antenna below:



The majority of base station antennas are linearly polarized. Circular polarization, if available, is preferred for several reasons.

Digital phase-coherent transmission and detection are degraded by slow fading of the signal envelope from multipath reflections of this same signal; and also by reduced signal margin due to other interfering signals. The fading is results from the phase-coherence of such interference. The most ideal spatial multiplexing employs dual orthogonal circular (right- and left-hand) polarizations. Circular polarization provides inherent protection from degradation that is not available with linear polarization. While circular polarization may not be feasible in many mobile applications, it's used in fixed-located customer premises applications will give a significant performance improvement.

Using circular polarization, multipath reflection will occur in the opposite polarization sense, thus reducing multipath for a given multiplexed right- or left-hand circular link. Even with quasi-linear polarized reflections, the cross-interference between simultaneous operating polarizations will likely be random. The conditions for any coherent interference are much more stringent than with linear polarization with the protection mechanism being analogous to the classic 'FM capture' effect.

In absence of 'slow' fading, the phase detection FM 'capture'analogy is that the FM station is either 'totally there' and noise/error-free; or, is not there at all in an interfering signal environment. Now, consider further the operation of the signal 'phasor' near this capture threshold and throw polarization into the mix. Interfering coherence requires both time phase and polarization spatial phase to line up...not just time phase.

Most potential interference will occur due to depolarization of circular into elliptical or quasi-linear due to reflections from building surfaces. Such a linear polarized component is expected to be predominantly vertical because the reflecting surfaces are themselves vertical in extent. It is a virtual statistical certainty that a linearly polarized signal will be coincident both in polarization and strength with interferors at one or more time intervals...so that both 'slow' envelope fading and 'fast' modulation of the envelope by a presumably random phasor will occur. Conversely, in the presence of this linearly polarized interference environment, coincidence of desired and interfering signals of characteristically circular polarization will virtually never occur...the interfering signal would have to embody a pair of linear components in both time and space quadrature as well of near-equal amplitude. And even in the absolute worst case, an interfering linear could cause a maximum 3 dB envelope variation and a maximum 30-degree phase error.

The conclusion so far is that the RTT wireless signals should be circularly polarized. There is one company known to the author producing such antennas. That is Swedcom model SACP 2x5516. Most panel antennas available today are linearly polarized and with dual polarizations of ± 45 degrees.

Three-sector cell geometry should employ panel antennas having either 65- or 90-degree wide azimuth patterns. The author had found more success using the 65-degree antennas. The cell/sector antennas should be sufficiently long vertically that they can deliver at least 18 dBi gain(18 dB greater than if the power was radiated equally in all directions–termed an 'isotropic' radiator). If uniform area coverage is not needed, where the users are predominantly fixed-located with CPE, the conventional three-sector model may be replaced with even more directional antennas more akin to point-to-point links served with dish antennas.

5.3 DESIGN PROCESS

As mentioned before, the design process–assuming an upgrade–begins with baselining the existing sites equipped for 4G. Then, placing baseline coverage over a demographic map of population density, and then targeting the traffic thereby placing new cells. The designer should examine the area near 'targeted' cell locations before choosing any one particular candidate location(perhaps from a site acquisition list derived from a search ring).

Generally speaking, a site should be located in a terrain depression; but, not necessarily at the bottom–unless a microcell; or, that the coverage area terrain and desired cover area are circularly symmetric . Terrain sloping away 'uphill' will cut off coverage quicker; terrain sloping downhill will enhance coverage range

If available, antennas should be chosen that have shaped-beam elevation plane patterns; and, the total downtilt (beam peak, electrical + mechanical) should be positioned about 2-deg below the projection to the cell edge. The beams in azimuth should be positioned to the centers of targeted areas.

Tower heights greater than about 100 feet in cities, and greater than 200 feet in rural areas should be avoided.

A given cell/sector candidate must be evaluated in concert with all other cells within a reasonable range...never just alone. This includes the other new cells being added. The performance should be evaluated using the RF planning tool over a range of offered traffic from zero/low to 50% loading, to about 70% loading. The evaluation matrix should also be parametric in CPE height (typ. 15-25 feet) and in CPE antenna gain (typ. 8-18 dBi,..start with 12 dBi).

The downlink transmit power per cell/sector will be dynamically allocated; but, with LTE only having fast power control. The question is...what should be used as the design basis. The downlink capacity will be limited by the amplifier power; and, with LTE, by the peak-to-average power ratio as well.

For HSPA+ the amplifier power is about 43 dBm (20 watts) and the pilot strength is about 33 dBm, so 33 dBm will be used as the transmit power basis under the assumption of code-division access/isolation.

For LTE, the average strength of the reference signal will be the practical peak power minus the peak-to-average power ratio of an assumed ensemble of equal strength subchannels...this ratio is about a constant 8 dB for many subchannels. If we start with a 40-watt peak amplifier (46 dBm),and further assume a near-far power allocation split of 50%, having an approximate 2 dB further impact on the peak-to-average ratio, the reference signal power would become 46 dBm - 3 dB - 8 dB - 2 dB again equaling 33 dBm. So, we will assume 33 dBm as the transmit power for LTE assessment as well.

Considering the Ec/Io and RSRQ metrics governing availability of 4G service, the specific power level used in computation is not key as long as the received signal level is suitably greater than the sensitivity threshold of the receiver. In this regard, a performance calculation with '0' traffic loading may be useful.

Of course, the actual downlink traffic power allocated for a given user will vary over the power control range, using as little power as is necessary to establish and sustain the particular grade of serve. But, the viability of a user link requires only the Ec/Io or RSRQ metric; that is, the strength of the reference signal.

Our objective is now to compute the network performance for an assumed level of data traffic loading. Parameters for computing include traffic loading (say, 50%) distributed equally across all cells/sectors, for both mobile broadband (0 dBi gain antenna at 5 feet elevation), and for fixed-located broadband (start with 12 dBi at 15-feet elevation). The radio propagation of the pilot/reference signal is first computed; then, from this, the interference from all cells/sectors at all user locations (everywhere) is computed. The results of the desired signal and the interference are ratioed to give the metric. We will prepare a composite area plot of Ec/Io or RSRQ over the network–or, significant portion thereof–and will look in the vicinity of the cell boundaries. The metric range nominal thresholds will be equal to or greater than -4 dB for 4G (drop at -5.5 dB), -7 dB for 3G (drop at -11.5 dB), -11 dB for 2G (drop at -18 dB).

At an ideal two-sector boundary, the metric will degrade by 3 dB; or, if the traffic loading increases from 50% (3 dB noise rise) to 75% (6 dB noise rise) using the uniform loading/noise-equivalent interference model, the metric will degrade by 3 dB. Considering an unloaded self-interference Ec/Io value of about -1.7 dB, these conditions are borderline for sustaining 4G performance. In a three-sector boundary region, the metric will degrade by 4.7 dB. In this latter region, it is doubtful that 4G service is even possible. So, in the best of circumstances, these boundaries should be located where there will be the least impact on the market–geographically. If the metric degrades substantially over an area across a cell boundary, or if the expected degradation covers too large an area, there is likely excess overlap.

The variables for 'tweeked' minor adjustments include"

1. The antenna mounting height
2. The antenna orientation
3. The antenna azimuth beamwidth
4. The antenna downtilt
5. The antenna polarization

In the standard three-sector configuration, the author has found 65-degree antennas to be helpful in minimizing cell overlap in CDMA systems. For 4G, dual slant-linear polarization at ± 45-degree could well be used on the base station (NodeB) for MIMO. If it becomes difficult to provide 4G in cell/sector boundary regions, it may be more prudent to use orthogonal polarizations in adjacent troublesome sectors.

5.2.1 RF PLANNING TOOL(S)

The RF planning tool used must have 1-arc-second (30-meter) resolution; 3-arc-second (100-meter) resolution will not suffice

The RF planning tool must include an interference engine that can accommodate variable traffic loading on a per-site basis. The author does not warrant the capability of any particular RF planning tool...with the exception of Athena

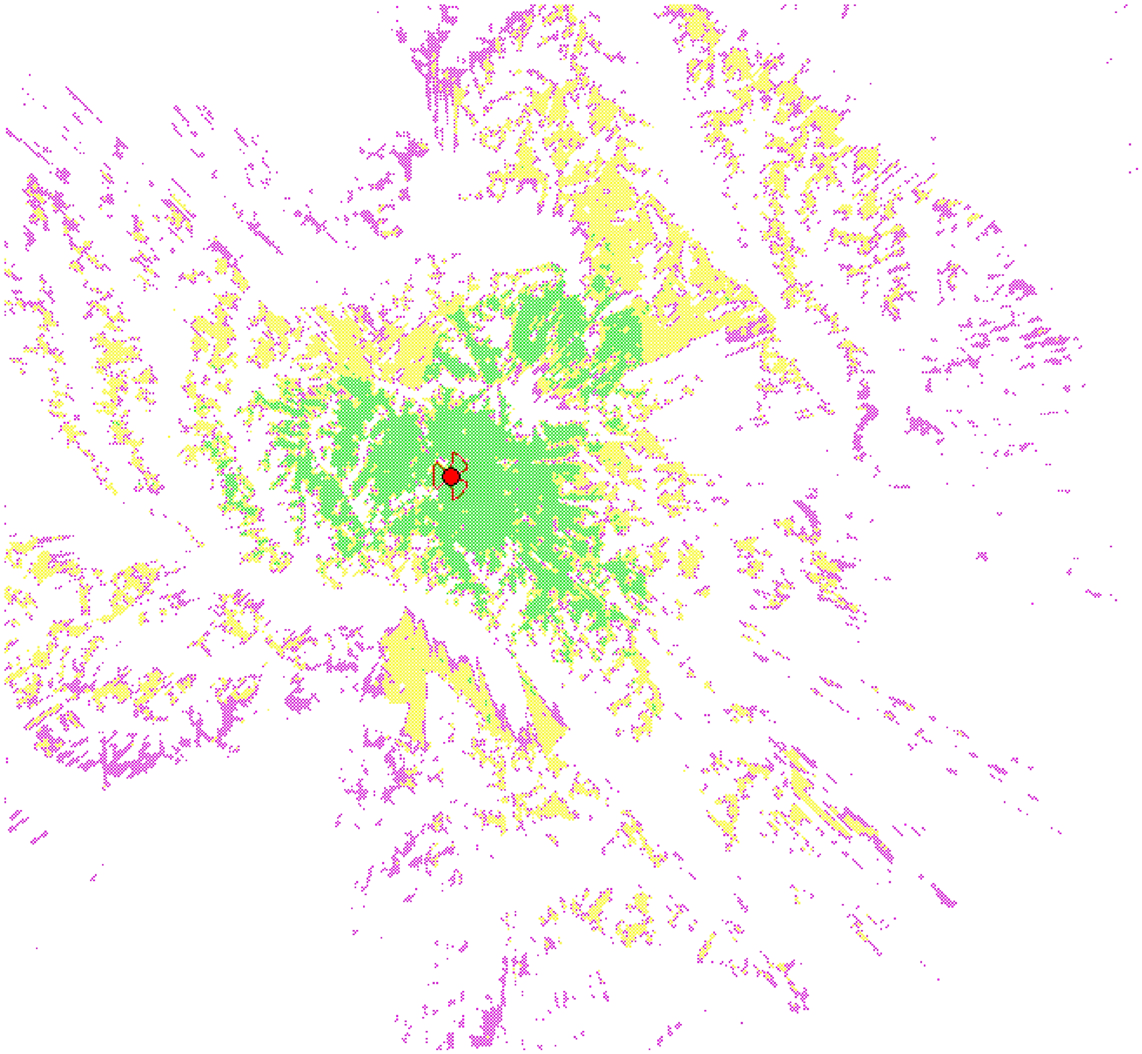
A partial list of RF planning tools includes:

1.	Wave Concepts Intl	Athena
2.	Berkeley Varionics Systems	DB Planner
3.	Mentum	Planet 5
4.	EDX	Signal Pro
5.	Optimi	x-Wizard
6.	Salient 3 Comm/SAFCO	Wizard

Other tools are readily identifiable via an internet search. Each purveyor can supply a reference for services using a given tool, if the attendee wishes.

Specifically, the empirical modeling employing the Cost 231 Hata model is now passe...having sufficient accuracy for cellular AMPS only at lower VHF frequencies. The Longley-Rice [ESSA Tech Rpt. ERL 79 ITS-67] and the U.S. Government ECAC TIREM models, suited to 3-arc-second resolution, have insufficient resolution to compute Ec/Io and RSRQ performance metrics. Rather, a physical optics model such as the Canadian CRC-Predict Fresnel-Kirchoff method that solves a two-dimensional boundary value problem point-by-point is needed. Essentially, such a method obtains the spatial impulse response of the terrain/clutter. This particular model is well known to the author ...others may now exist.

An example of a 4G WiMAX plot to an assumed fixed-located elevated CPE is illustrated below, the area shown fitting within a 26-mile square. Green is 4G, yellow is 3G, and magenta is 2G as far as speed is concerned.



NETWORK

2G networks were simple in that each had only to be self-consistent in mobility management, for example. As the wireless networks have progressed, the requirements for compatibility with legacy versions of each network have grown; and their scope has expanded to embrace a variety of handsets. The direction is apparent...toward an IP pipe that is transparent to devices in the same manner as ethernet connection to the internet. Additionally, the evolved technologies have moved from mobile-only toward more localized mobile/portable

This evolution path has resulted in more complex and sophisticated control and management signaling, measurement/test conditions, dynamic power control and user resource allocation. The details of all this are unknowable except to the astute technical professionals working with the technologies. The network RF issues involved remain classic and are more akin to the laws of physics.

Network RF issues include:

1. Pilot (reference signal) pollution...occurring when there is not a dominent server available to the user, often when/with too-few cells. For mobile users, the experience will be dropped calls due to target failures;
2. Handoff/handover...soft or hard, hard only with LTE. This is more difficult conceptually using data (including VOIP voice) than with 2G and adjusting hysteresis properly may be very frustrating
3. Cell Shrinking...occurring with increasing traffic load; and, therefore, more interference and lower Ec/Io or RSRQ. The loading used in the design process to establish boundaries should be high–like 70%.
4. Capacity...video streaming will impose long 'call' times so that the number of simultaneous users and the number of subscribed users will approach each other. Right now, no one needs more than about 10 mbits/s per user single video device
5. Last-mile, pico/femto-cells, device tethered operation.

If you watch the receive signal (RSCP) and the Ec/Io or RSRQ at the same time on an Android service mode display, several observations can be made.

For a 10 MHz bandwidth and a 5 dB handset noise figure: if RSCP is in the -70's (-80 or better) then 64QAM modulation is possible, raising the available speed(data rate) on a given link by a factor of 1.5. In a 5 MHz bandwidth and a 2 dB noise figure the RSCP can be 5 dB lower for these same conditions. But, 64QAM modulation will not happen unless the nominal Ec/Io is also between about -2 dB and -5.5 dB. This is broadly the author's definition of 4G, RF wise.

1. If the RSCP is high(typ > -85 dBm) and constant but the RSRQ is low (say, -8 to -10 dB) and varying, the link is interference-limited and the cell is 'breathing' with varying traffic
2. If the RSCP is low(typ < -90 dBm) but the RSRQ is high(say, -4 dB), the link is signal limited and does not support the maximum speed
3. If the RSCP is high and the RSRQ is also high, the link will support the maximum speed.
4. If the RSCP is low and the RSRQ is also low, the coverage is not adequate and only low rates–2G at best–will be supported.

cell shrinking...decide mobile BB vs fixed to pick design traffic load
pilot pollution...what happens when the network is too dilute and there is no dominant server
handoff hard (LTE) mobility management becomes more complex in integrating frequency bands and technology interoperability; soft handoff capacity limits
function....geared toward localized or fixed vs on-the road mobile operation
handling...VOIP, device evolution
when a network is new and unloaded, signal prop governs (RX sig), when loaded, interference governs

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LINKS

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