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Comments on Citi "Wireless Supply and Demand"

1 Overview

On September 22, Citi Investment Research & Analysis released a report titled "Wireless Supply and Demand." This report calculates the capacity of wireless networks based on certain values of spectral efficiency of certain technologies. Relative to my own analysis, the spectral-efficiency values used in the Citi report are incorrect to a significant degree, and hence much of the technical analysis and related conclusions are also incorrect. In particular, the bottom line conclusion that Citi arrives at "We do not believe the US faces a spectrum shortage" is invalid because it is predicated on the incorrect analysis that 4G technologies have *six times* more capacity than they really do. This incorrect capacity analysis means Citi's estimations of the amount of spectrum needed to support deployment of 4G LTE technologies are also incorrect. Citi's analysis of spectrum demand for widespread 4G deployment would only anticipate one sixth the amount of spectrum than is actually needed for such deployment.

2 Basis of Rysavy Research Analysis

Since 2002, Rysavy Research has published twelve publically-available reports that include spectral-efficiency analysis. The most recent report, published by 4G Americas in September, 2011, is titled "Mobile Broadband Explosion – 3GPP Broadband Evolution to IMT-Advanced."[1] Spectral efficiency is covered in pages 53 through 61. The spectral efficiency values presented in this paper are the outcome of a detailed analysis done jointly and on a consensus basis by Rysavy Research working with representatives of 4G Americas board-of-governor companies[2] who are 3GPP technical experts. The representatives were from both leading wireless operators and infrastructure vendors. Due to the experience and expertise of this workgroup, the spectral-efficiency values presented are highly credible. These values are also consistent with other industry groups as detailed further below.

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[1] Available at http://www.rysavy.com/Articles/2011_09_08_Mobile_Broadband_Explosion.pdf.

[2] 4G Americas board of governor companies are listed at http://www.4gamericas.org/index.cfm?fuseaction=page&sectionid=160.

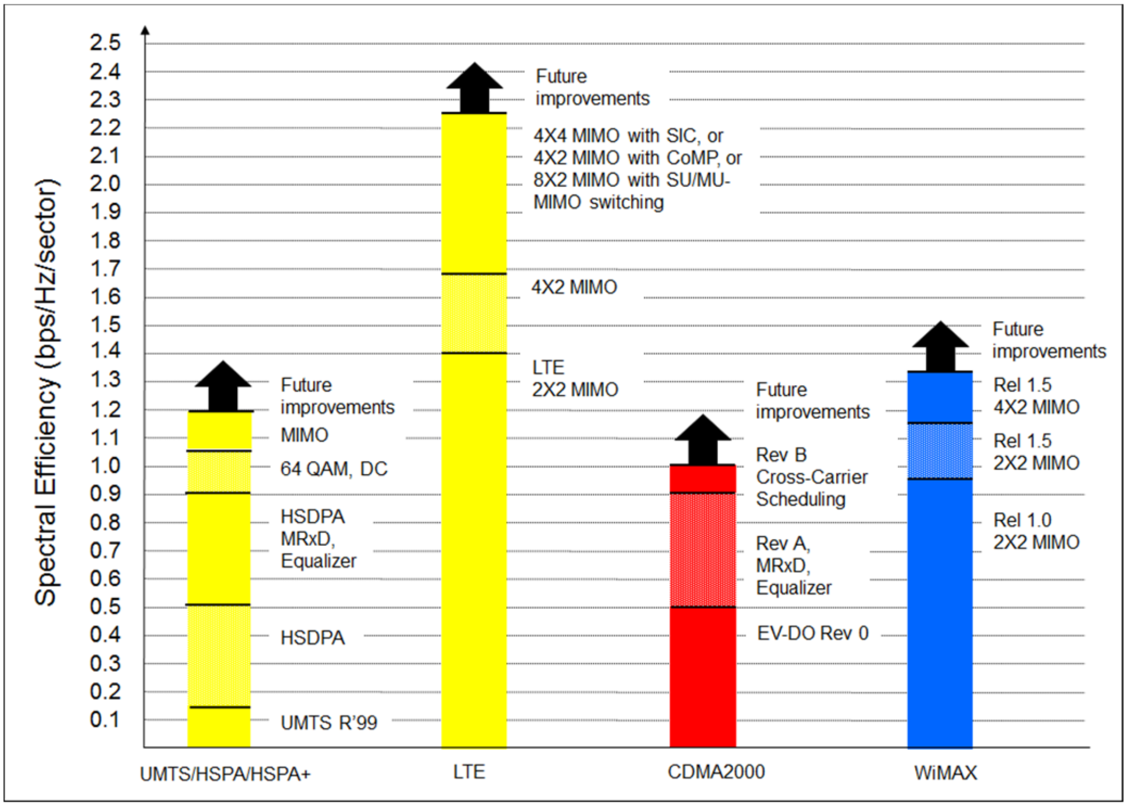
3 Analysis

Spectral efficiency is the value by which amounts of spectrum measured in Hertz (Hz) can be equated to bits per second (bps) of data throughput. Given exploding mobile-broadband data growth, understanding the real capacity of cellular networks is of huge importance. In 2010, Rysavy Research published a report on this topic titled, "Mobile Broadband Capacity Constraints and the Need for Optimization."[3] It is important to realize that there is a difference between average spectral efficiency and peak spectral efficiency. Under ideal conditions of low network loading and good signal quality, today's adaptive wireless networks can achieve extremely high throughput rates, and so the peak spectral efficiency value can be very high. For network-capacity analysis, however, one must use the average spectral efficiency value, a value that is much lower than the peak value, since this is what allows for the calculation of the aggregate capacity of a cell sector.

On page 7, the Citi report presents HSPA+ downlink spectral efficiency as 2.1 bps/Hz and LTE spectral efficiency as 8.6 bps/Hz. In contrast, my analysis, as depicted in Figure 22 of "Mobile Broadband Explosion" and shown below in Figure 1 below presents HSPA+ spectral efficiency for current deployment configurations as 1.05 bps/Hz and LTE as 1.4 bps/Hz. These are huge and dramatic differences. Relative to my analysis, the Citi report overstates HSPA+ spectral efficiency by 100% and LTE spectral efficiency by 614%. It is unusual that the Citi report does not provide any external references for its spectral-efficiency values.

[3] Available at http://www.rysavy.com/Articles/2010_02_Rysavy_Mobile_Broadband_Capacity_Constraints.pdf.

Figure 1: Rysavy Research Downlink Spectral Efficiency Comparison



Much of the Citi report depends on these values. Given these errors, much of the data and conclusions in the Citi report sections are misleading or incorrect.

Page 1: "Bottom Lines — We do not believe the US faces a spectrum shortage." This conclusion is invalid because it is predicated on the incorrect analysis that 4G technologies have six times more capacity than they really do. This incorrect capacity analysis means Citi's estimations of the amount of spectrum needed to support 4G technologies are also incorrect. Since capacity is direct proportionate to the amount of available spectrum, Citi's analysis on spectrum demand for widespread 4G deployment would only anticipate one sixth the amount of spectrum than is actually needed.

Page 1: "Full 4G Can Deliver 5Mbps — 100% conversion of 538 MHz allows carriers to offer 5Mbps with 10% simultaneous usage during peak busy-hour." This is incorrect because again it assumes 4G to have over 6 times the capacity than it really does. Assuming the Citi model is correct (which I cannot confirm based on the details provided), with 6 times less capacity, either the 5 Mbps value must be reduced by a factor of six to .83 Mbps, or 6 times the amount of spectrum is actually needed, 3.2 GHz, to meet this 5 Mbps objective.

Page 3: "First, US carriers have licensed roughly 538 MHz of spectrum today. And, according to the FCC National Broadband Plan, up to 300MHz of additional spectrum may become available over time. As

such, there is lots of spectrum." 538 MHz may "sound" like a lot of spectrum, but whether this amount of spectrum is sufficient can only be assessed by modeling demand and calculating the amount of spectrum needed to satisfy that demand using available technologies. The Rysavy Research demand model predicts, consistent with FCC projections, that at least 500 MHz of additional spectrum will be required over the next decade. The Citi conclusion of the industry currently having "lots of spectrum" is not credible because again it assumes the industry can extract far more capacity than it really can from current allocations using available technologies. The limits of available spectrum and the consequences of insufficient spectrum are detailed in my March 2011 Rysavy Research report, The Spectrum Imperative: Mobile Broadband Spectrum and its Impacts for U.S. Consumers and the Economy – An Engineering Analysis."[4]

Page 4: "The real impediment today is that incumbent wireless networks have not converted enough of their current spectrum to 4G services and do not have enough excess spectrum within their pipeline to accelerate the 4G conversion." This is an incorrect conclusion because it is based on the assumption that 4G technologies at 8.6 bps/Hz are four time more efficient than enhanced 3G technologies at 2.1 bps/Hz. Referring to Figure 1 above (which is consistent with other industry values), 4G technologies such as LTE in the configurations being deployed[5] are at most only 50% more efficient than enhanced 3G technologies, not 400% more efficient. There are many reasons that operators are deploying LTE, including higher peak speeds, lower network costs, lower latency, quality-of-service control, but huge capacity gains is not one of the immediate reasons.

Page 7, Figure 6: "Three Wireless Technology Standards." This is where Citi states that HSPA+ has 2.1 bps/Hz/sector and 8.6 bps/Hz/sector, values that are completely inconsistent with commonly used industry values, as discussed above. Based on these erroneous spectral-efficiency values, Citi calculates that with 10 MHz for the downlink, a three-sector LTE cell would have an aggregate capacity of 258 Mbps[6]. In the real world, however, it would have a dramatically lower capacity of 42 Mbps.[7] For HSPA+, Citi calculates aggregate capacity of 63 Mbps[8], but in the real world HSPA+ would only have capacity of 31.5 Mbps.[9]

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[4] Available at http://www.rysavy.com/Articles/2011_03_Spectrum_Effects.pdf.

[5] For example, LTE is being deployed today in a 2X2 Multiple Input Multiple Output (MIMO) configuration.

[6] Calculated at 3 sectors X 10 MHz X 8.6 bps/Hz.

[7] Calculated at 3 sectors X 10 MHz X 1.4 bps/Hz.

[8] Calculated at 3 sectors X 10 MHz X 2.1 bps/Hz.

[9] Calculated at 3 sectors X 10 MHz X 1.05 bps/Hz.

Page 13 to page 14, Figures 13 to 17. Carrier Level and Target Speed Scenarios. Citi does not disclose the methodology of their models in these figures, but given that the figures assume erroneous capacity values for 3G and 4G technologies as discussed above, none of the quantitative results are valid.

Page 16: "Question #6: What Can Dish Offer with Its Spectrum. We've used our wireless model to assess what sort of speeds Dish Network might offer consumers if it builds a 4G network using 47 MHz of spectrum. The data suggests Dish could offer 10% of the population 5Mbps service." This conclusion, assuming Citi's model is correct (which I cannot confirm based on the details provided) except for spectral-efficiency values, overstates the capacity of what Dish could offer by a factor of six. Thus Dish could only offer 5 Mbps to one sixth of 10% (1.7%) of the population or one sixth of 5 Mbps (.83 Mbps) to 10% of the population.

4 Other Sources of Spectral Efficiency Information

Without doing an exhaustive listing of other sources of spectral-efficiency information, this section lists several instances that confirm the spectral-efficiency values used in my analysis above are consistent with common industry values. It is important to note that spectral-efficiency values depend on a considerable number of assumptions about network configuration, device configuration, as well as the mobility of users. Hence, it is not unusual for values between different sources to vary somewhat. Such variability, however, is in tens of percent at most, never in the hundreds of percent as suggested by the Citi report.

3GPP "Technical Report 25.912 V10.0.0 (2011-03), Feasibility study for evolved Universal Terrestrial Radio Access (UTRA and Universal Terrestrial Radio Access Network (UTRAN), available at http://www.3gpp.org/ftp/Specs/archive/25_series/25.912/25912-a00.zip, page 5, Table 13.4j, Case 3, E-UTRA (LTE) 2X2 MIMO, **1.56 bps/Hz**. 3GPP is the organization that developed the LTE specification and so should know something about the capabilities of the technology. This table presents the 3GPP assessment of LTE performance. The value is slightly higher than the 1.4 bps/Hz in my 4G Americas paper due to differences in underlying assumptions. The 4G Americas values are meant to be more representative of real-world conditions and realistically-available devices.[10] Adjusted for assumptions, the 4G Americas values are consistent with 3GPP values. As for 4X2 and 4X4 MIMO configurations, these may eventually be deployed but represent significant added expense in subscriber units, the infrastructure, or both, and at this time all deployments are 2X2 MIMO.

Qualcomm, "LTE Release 8 and Beyond,"
available at http://www.qualcomm.com/common/documents/articles/LTE_Benefits_090409.pdf, page

[10] Note that my 4G Americas paper in 2010 used a value for LTE of 1.5 bps/Hz but I decreased it to 1.4 bps/Hz in 2011. My explanation in this year's report was, "LTE spectral-efficiency values are slightly lower than last year's version of this paper, because of more refined assumptions that better match realistic available devices."

25, 15.1 Mbps in 10 MHz or **1.51 bps/Hz** for the downlink. HSPA+ is listed as 12.5 Mbps in 10 MHz or **1.25 bps/Hz**.

Federal Communications Commission, "Mobile Broadband: The Benefits of Additional Spectrum," available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2010/db1021/DOC-302324A1.pdf, page 14, HSPA+ **1.08 to 1.29 bps/Hz**, and **LTE 1.36 to 1.5 bps/Hz**.

WiMAX Forum, Comparing Mobile WiMAX with HSPA+, LTE, and Meeting the Goals of IMT-Advanced, available at http://www.wimaxforum.org/files/wimax_lte/wimax_and_lte_feb2009.pdf, page 13, LTE downlink spectral efficiency of **1.5 bps/Hz**.

International Telecommunications Union, "REPORT ITU-R M.2134 Requirements related to technical performance for IMT-Advanced radio", available at http://www.itu.int/pub/R-REP-M.2134-2008/en, page 4, refer to base coverage urban downlink, **2.2 bps/Hz**. These are the requirements that *future* technologies such as LTE-Advanced must meet. This requirement is consistent with the upper portion of the LTE bar in Figure 1 above which shows LTE achieving **2.25 bps/Hz** for the downlink using future enhancements such as 4X4 MIMO with Successive Interference Cancellation (SIC), or 4X2 MIMO with Coordinated Multipoint Transmission (CoMP), or 8X2 MIMO with Single-User/Multi-User (SU/MU) MIMO switching.[11] In other words, even with every currently-planned improvement applied to LTE, spectral efficiency only reaches 2.25 bps/Hz.

5 About Rysavy Research

Rysavy Research LLC is a consulting firm that has specialized in wireless technology since 1993. Projects have included reports on the evolution of wireless technology, test reports, spectrum analysis for broadband services, evaluation of wireless-technology capabilities, strategic consultations, system design, articles, courses and webcasts, and network-performance measurement.

Peter Rysavy, president of Rysavy Research, specializes in the capabilities and evolution of wireless technology. He has written more than a hundred and twenty articles, reports and white papers, and has taught forty public wireless courses and webcasts. He has also performed technical evaluations of many wireless technologies including municipal/mesh Wi-Fi networks, Wi-Fi hotspot networks, mobile browser technologies, cellular-data networks, and wireless e-mail systems.

From 1988 to 1993, Peter Rysavy was vice-president of engineering and technology at LapLink where projects included LapLink, LapLink Wireless, and connectivity solutions for a wide variety of mobile platforms. Prior to that, he spent seven years at Fluke Corporation where he worked on touch screen and data acquisition products.

[11] Refer to "Mobile Broadband Explosion," at http://www.rysavy.com/Articles/2011_09_08_Mobile_Broadband_Explosion.pdf for an explanation of these different LTE configurations.

Peter Rysavy is also the executive director of the Portable Computer and Communications Association (PCCA, http://www.pcca.org), a group that evaluates wireless technologies, investigates mobile communications architectures and promotes wireless-data interoperability. Peter Rysavy graduated with BSEE and MSEE degrees from Stanford University in 1979. More information is available at http://www.rysavy.com.

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