EXPLOITING MICROCELLS ON CABLE PLANT TO LEVERAGE SPECTRUM ASSETS

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Abstract

This paper will describe how cable operators can exploit their outside plant assets to host wireless microcells to do more than compensate for their smaller spectrum assets relative to mainstream cellcos who employ macrocell architectures. By means of computations and modeling, it is demonstrated that exploiting microcells can not only provide competitive parity to mainstream cellcos with more spectrum, but in fact a hybrid macrocell/microcell architecture with only 20MHz of licensed spectrum can actually enhance the ability of the wireless operator to offer leaf-frog services that incumbent cellcos will not be able to duplicate without adding more much more spectrum.

INTRODUCTION

Following the FCC's AWS auction the SpectrumCo consortium of MSOs now owns approximately 20MHz of spectrum with nearly ubiquitous national coverage. The 137 licenses acquired cover 260.5 million pops at a cost of $2.4 billion (equates to $0.46/MHz-pop).

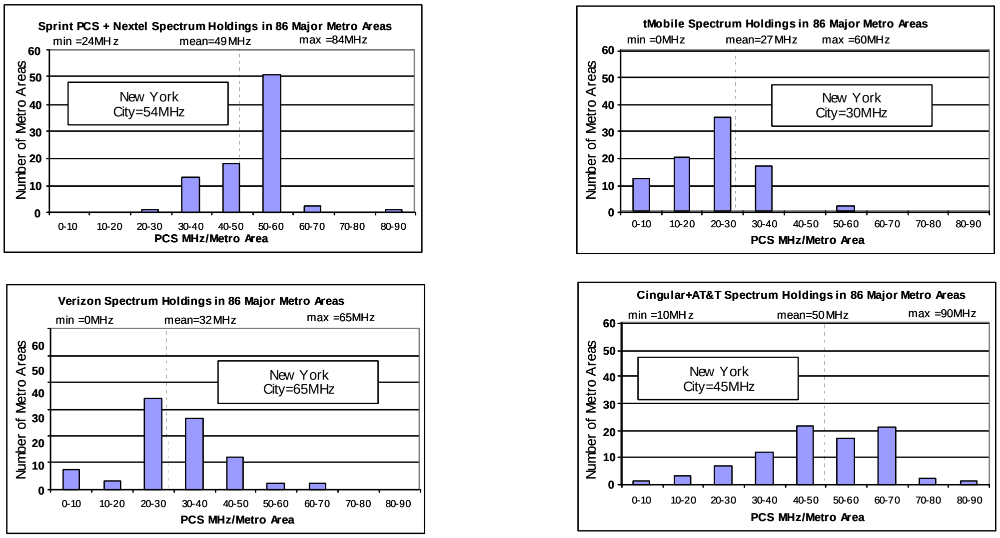
This spectrum is situated between the existing 800MHz and 2GHz incumbent cellular bands and is prime "real estate" to launch wireless services that could be employed to enable a "quad-play" service offering that would be competitive with incumbent cellular operators (cellcos).

A competitive wireless service for cable is not just an upside opportunity, it is a survival imperative as Table 1 demonstrates.

Table 1 Strategic Imperative for Cable

Issue	Implication
Verizon and AT&T already lead in wireline and wireless market share, have significant high speed internet adoption, and are moving rapidly to add IPTV to their mix	To defend against churn cable must be able to offer at least a competitive quad play bundle
The mainstream cellcos have covered their historical fixed CapEx investment in wireless plant and are largely investing success capital	For cable to build a me-too greenfields wireless network with competitive coverage and quality of service will require massive fixed capital investment with long payback periods
Wireless voice adds already exceed wireline adds and over time, significant migration from wireline to wireless can be expected	Although cable is realizing impressive growth and revenue from wireline services, unless the industry has the ability to offer wireless voice it will lose out in the future migration
Cellular is so competitive that voice margins are depressed so the mainstream carriers are attempting to develop high value added non-voice services to boast ARPU	Cable has control of, and experience in formulating, highly valued multimedia assets that could allow cable to leap-frog over simple me-too voice service offerings

Figure 1 Histograms of Spectrum Holdings of Mainstream Cellcos



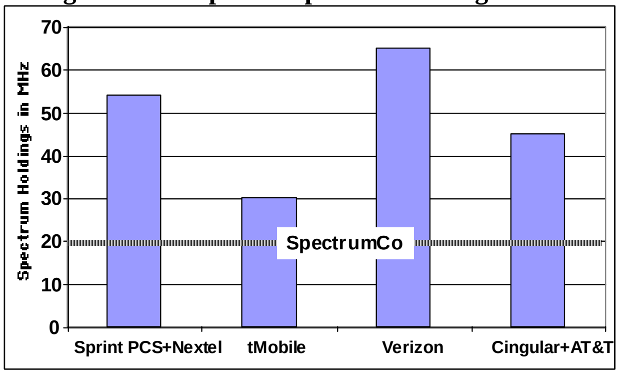
Source: computed from RCR News database prior to AWS auctions

Spectrum Required

The mainstream cellcos typically hold on the order of 40MHz of nationwide spectrum nearly twice the spectrum won by cable in the AWS auctions. As shown in Figure 1.

Furthermore, as Figure 2 shows, to support the very high population density of New York City (NYC) and their >20% share of market, Verizon is holding 65MHz of spectrum in NYC.

Figure 2 Example Competitive Holdings in NYC



In fact as Figure 3 shows, based on today's rapidly growing voice+data traffic load, more than 20MHz of spectrum is required in the top 20 USA cities (as ranked in order of highest population density).

Figure 3 Spectrum Required to Support 2006 Levels of Cellular Traffic

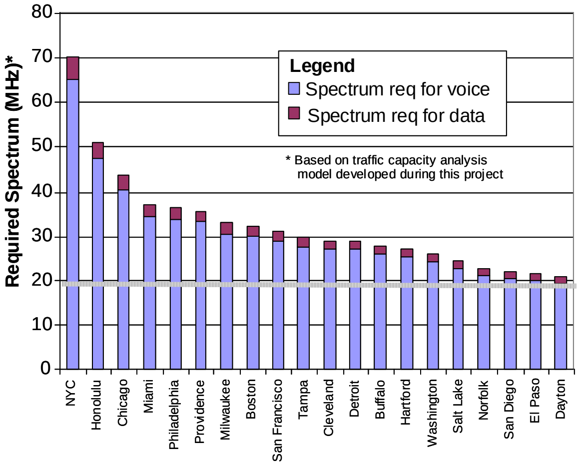


Figure 3 is based on a model to be further described in this paper under the following set of key assumptions:

- CDMA2000 all IP EVDO-Rev A air interface
- A 25% market share typical of Cingular and Verizon market share leaders

- Traffic load of
  - 142 minutes of use per month of voice traffic engineered for 2% grade of service blocking
  - Additional data traffic based on 10% adoption of data by voice subs who consume on the average of 25MBytes/month of downstream data
- Macrocell architecture with the minimum radius of macrocell of 0.5 mile

Figure 3 is actually a best case for incumbent carriers since they need to *waste* some spectrum to support legacy, less spectral efficient, air interfaces and manage dual use while they transition to new 3G and 4G technologies.

Because MSOs could build a greenfields wireless network that fully exploits 3G+ air interfaces that are more spectrally efficient than legacy cellco networks, it would be possible to build out a fully competitive voice-centric cellular network with comparable voice capacity to cellcos even with one half the spectrum. However, it would be desirable to do more than construct a "me-too" wireless voice service offering. In the short term, a "me-too" service offering would make the acquisition of subscribers a slow process that is a highly undesirable position to be in as a late entry competitor in the marketplace. In the longer term, cellco competitors would be likely to use their additional spectrum to launch non-voice services that would make the spectrum starved MSO's cellular network non-competitive.

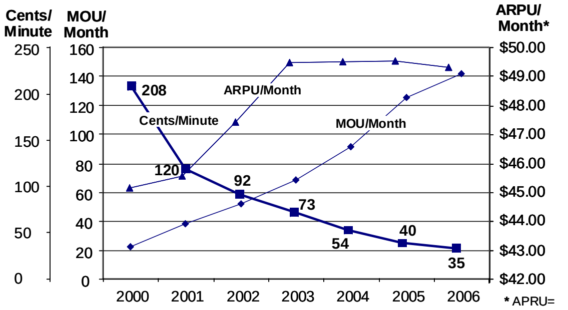
For both short and long term reasons, it would be highly desirable for the cable AWS spectrum owners to leap-frog beyond a me-too voice centric wireless offering and instead offer a multimedia rich voice+non-voice service from the start. However it would also be highly desirable to build this leap-frog network without having to engage in the expensive and uncertain process of acquiring additional spectrum much beyond the 20MHz already in hand.

Market Reality

Formulating a plan that optimizes the cable industry assets requires an understanding of the marketplace realities. In particular what must be understood are the underlying economics and the implications for the current and future traffic load.

As Figure 4 shows, the average revenue per user (ARPU) is flat to slight declining while minutes of use continue to grow as a rapid rate. Data traffic today is minimal since only it accounts for only 10% of ARPU and further because most of the data revenue is from very low bandwidth messaging services.

Figure 4 Historical Trends in Cellular Voice Traffic Load and Revenue



* APRU= 90%Voice+ 10%Data in 2006

The net result is that the ratio of revenue to traffic is rapidly declining. This trend toward a commodity status for voice demonstrates the need to find new non-voice services that will generate high margin ARPU.

Table 2 Revenue and Bandwidth of Over-the-Air Unicast Non-Voice Wireless Services

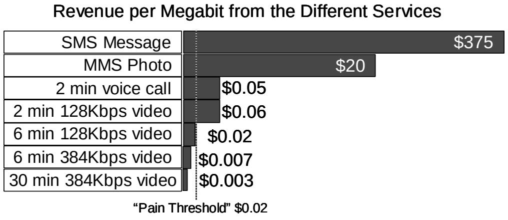
Service	Bandwidth	Average Revenue	Capacity Usage Mb/s
SMS Message		$0.07	0.0002
MMS Photo		$0.20	0.0098
2 minute voice call	12 Kbps	$0.07	1.4400
2 minute low-resolution video	128 Kbps	$0.99	15.3600
6 minute low-resolution video	128 Kbps	$0.99	46.0800
6 minute high-resolution video	384 Kbps	$0.99	138.2400
30 minute high-resolution video	384 Kbps	$1.99	691.2000

Source: "The Economics of Mobile Broadcast TV", Yoram Solomon, Mobile DTV Alliance

The challenge however is that although subscribers will pay substantial fees for highly valued multimedia services, these highly valued services (e.g. video) generate very large traffic loads. Examples of non-voice traffic are shown in Table 2.

These traffic loads are so intense that that their $/megaByte can not be economically supported on today's macrocellular 3G cellular networks at economic levels of CapEx investment in infrastructure as shown in Figure 5.

Figure 5 Revenue Per Megabit from Example Non-Voice Wireless Services



Source: "The Economics of Mobile Broadcast TV", Yoram Solomon, Mobile DTV Alliance

A NATURAL STRATEGY FOR CABLE

Assuming greenfield wireless build-out for cable, a leap-frog wireless strategy is called for given cable's late start and the need to accelerate subscriber take-up to cover the large fixed CapEx investment needed to build a network with competitive coverage. Greenfields spectrum can be built by cable using most advanced spectral efficient technology to gain on the order of a 2X capacity advantage over incumbents who carry legacy technology baggage; however, incumbents will soon catch up as they rebuild to next generation air interfaces.

Cable's natural strategy is to employ multimedia highly valued video and other entertainment assets integrated with wireline and high speed data products to create highly differentiated services and counter declining ARPU/minute trends. Although next generation air interfaces can provide some temporary capacity advantage, it will not be possible to execute a multimedia bandwidth hungry leap-frog strategy employing conventional cellular architectures without spectrum well in excess of that held by competitors. The ideal situation for cable is to execute a strategy that not only builds on content assets but also employs a non-conventional architecture that leverages the installed base of cable plant and technology.

Compared to cellcos, the cable industry has unique access to a broadband low cost wired backbone network that can be leveraged to provide economically attractive high bandwidth multimedia services. Furthermore, we will show that even with 40-60MHz of spectrum, incumbent cellcos can not economically scale their macrocellular networks to support the capacity needed to satisfy consumer's appetite for high bandwidth multimedia services. On the other hand, the cable operators can exploit their extensive HFC network to economically support a microcell underlay network* that can more than compensate for the cable operators limited 20MHz of spectrum.

Not only will we demonstrate the ability for such a microcellular based underlay network to offer a non-voice traffic capacity advantage, we will also note that a hybrid macrocellular network combined with a microcellular underlay will allow additional degrees of freedom in the overall architecture and the associated service offerings that further leverage cable industry multimedia interests and assets.

Multimedia Non-Voice Traffic Loads

Today's cellcos offer data plan pricing that top out at about 50MB/month, but even modest multimedia traffic in excess of webpage surfing breaks this 50MB budget and places a non-economic load on their >40MHz of macrocellular infrastructure. Some examples of multimedia traffic are shown in Table 3. Note that all the examples

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* While microcells on aerial plant are straightforward to add, in congested business districts with underground plant the costs will be higher.

beyond webpage downloads, break the 50MB/month threshold.

Table 3 Illustrative Multimedia Data Traffic Load

Media Event	MegaBytes (MB)/Event	Events/Day	20% Busy Hour kb/s	MB/Month (22 days)
6 min 384 kb/s video QVGA (320x240 pixels) at 15 f/s	17.28	1	7.68	380
MP3 Song Download	5	5	11.11	550
eMailFile Attachment Downloads	0.3	20	2.67	132
WebPage Downloads	0.05	50	1.11	55

Since building a bottom up forecast for consumer's appetite for non-voice data consumption is so dependent on forecasting the adoption of specific services, it is highly speculative to rely upon a bottom up buildup of traffic. A top down approach looking at consumer's appetite for fixed wired data consumption on high speed cablemodem or DSL residential services can be viewed as a high end upper bound for wireless data usage.

Table 4 is based upon today's average data consumption by cablemodem subscribers. It shows that the current fixed wired downstream consumption of 1,209 Mbytes/sub/month is 240 to 24 times the 5-50 Mbytes/sub/month consumed by today's wireless data subscribers. Furthermore if one considers that today's wireless data ARPU is only 10% of today voice+data ARPU, if data were adopted by a larger percentage of voice subscribers well in excess of what 10% ARPU implies; the total data traffic load on the wireless system could well grow on the order of 10 times additional.

Table 4 Average Data Consumption by Fixed Wireline Cablemodem Residential Subscribers

Average Wired BB Downstream Busy Hour Data Rate/Sub (kb/s)	25
Busy Hour Downstream Data Consumption/Sub (Mbytes)	11
Busy Hour Concentration Factor (percent of all daily usage)	20%
Monthly Downstream Data Consumption/Sub/Month (Mbytes)	1,209
Ratio of Upstream to Downstream Data Rate	20%
Monthly Upstream Data Consumption/Sub/Month (Mbytes)	242

Study Methodology

Our analysis employed the following steps:

- Employ the central business districts in New York City as a worst case USA example for spectrum needed in high population congestion limited areas.
- Compute the amount of spectrum required to serve today's traffic load for a conventional macro-cellular architecture
- Propose an alternative microcellular architectures for cable
- Re-compute the capacity provided for each microcellular alternative under consideration and compare that to
  - Today's voice+data traffic loads
  - Future possible multimedia intensive data traffic loads

MACROCELLULAR ANALYSIS

In order to have a baseline to compare with a recommended microcellular approach for cable, we begin by analyzing the capacity of a conventional macrocellular architecture in the example NYC CBD.

Manhattan Central Business Districts

The amount of spectrum required in any one market area is determined by the traffic capacity of the most density loaded cellsite in that market area. Using the NYC market area as an example, the most density loaded cellsite can be expected to be in either Lower or Midtown Manhattan areas shown in Figure 6 Lower and Midtown Manhattan Central Business Districts.

Table 5 Macro Cell Analysis Model for CDB in Manhattan

Manhattan Demographics

1	Manhattan land area (miles^2)	28.4	input
2	Nighttime population	1,487,536	input
3	Daytime Population	3,389,300	input
4	Ratio Day/Night	2.3	calc
5	Mid-town Manhattan land area (mile^2)	1.64	input
6	Lower Manhattan land area (mile^2)	1.72	input
7	Nightime PopDensity pops/mile^2	52,378	calc
8	Nightime Pops in lower Manhattan	90,090	calc
9	Nighttime Pops in midtown Manhattan	85,900	calc
10	Pop Increase btwn Night to Day	1,901,764	calc
11	Pop Increase into lower due to migration into Manhattan	973,522	calc
12	Pop Increase into midtown due to migration into Manhattan	928,242	calc
13	Pop Increase into lower due to 25% migration within Manhattan	190,369	calc
14	Pop Increase into midtown due to 25% migration within Manhattan	181,515	calc
15	Total daytime Pops in lower Manhattan	1,253,981	calc
16	Total daytime Pops in midtown Manhattan	1,195,657	calc
17	Total Daytime PopDensity in lower (mile^2)	729,059	calc
18	Total Daytime PopDensity in midtown (mile^2)	729,059	calc

CellSite Loading

19	CellRadius (miles)	0.50	input
20	CellArea (miles^2)	0.79	calc
21	Daytime Pops in lower Manhattan cellsite	572,602	calc
22	Cellular Adoption	72%	Input
23	CellSubs in lower Manhattan cellsite	412,273	calc
24	Market Share	10%	input
25	Own subs in lower Manhattan cellsite	41,227	calc

Voice Traffic Load per Subscriber

26	Voice Minutes of Use/year/Sub	1,700	input
27	Minutes of Use/work-day/Sub	6.54	calc
28	Busy hour concentration of minutes	20%	input
29	Busy Hour Minutes/Sub during work day	1.31	calc
30	Busy Hour voice traffic load/Sub (mE)	21.8	calc

Data Traffic Load per Subscriber

31	Average Wired BB Downstream Busy Hour Data Rate/Sub (kb/s)	25	input
32	Ratio of Upstream to Downstream Data Rate	20%	input
33	Throttle on Wireless Data Rate Ratio to Wired Rate	4.13%	input
34	Busy Hour Concentration Factor (percent of all daily usage)	20%	input
35	Percent of Subs who Take Data Service	10%	calc
36	Equivalent downstream megabytes/sub/month of Data Usage	50.0	calc

Data Only CellSite Capacity for CDMA2000 EVDO Rev A all IP

37	Downstream throughput for 3Sector Site (Mb/s)	2.7	input
38	Upstream throughput for 3Sector Site (Mb/s)	1.35	input
39	Downstream Capacity/sub requirement for data traffic (kb/s)	1.03	calc
40	Upstream Capacity/sub requirement for data traffic (kb/s)	0.21	calc
41	Downstream Capacity/site requirement for data traffic (Mb/s)	4	calc
42	Upstream Capacity/site requirement for data traffic (Mb/s)	1	calc
43	Number of Channels Required for Downstream	2	calc
44	Number of Channels Required for Upstream	1	calc
45	Worst Case Number of Channels Required	2	calc

Voice Only CellSite Capacity for CDMA2000 EVDO Rev A all IP

46	Downstream throughput for 3Sector Site (Mb/s)	2.7	input
47	Upstream throughput for 3Sector Site (Mb/s)	1.35	input
48	Capacity requirement for voice traffic (kb/s)	10	input
49	Voice Circuits Available (upstream limited)	135	calc
50	Traffic Capacity/3Sector Site in Erlangs @2% Blocking	87.97	calc
51	Number of Voice Subs Supported/Site/Channel	4,036	calc

Computation of Spectrum Required

52	Number of 1.25MHz channel pairs required for Voice	10	calc
53	Required Spectrum for Voice (MHz)	25	calc
54	Number of 1.25MHz channel pairs required for Data	2	calc
55	Required Spectrum for Data (MHz)	5	calc
56	Total Spectrum Required for Both Data+Voice (MHz)	30	calc
57	Ratio of Data Channels/Total Channels	17%	calc

Figure 6 Lower and Midtown Manhattan Central Business Districts

Lines 1 through 18 of the Table 5 model shows the process of arriving at a population density of 729,059 pops/mi^2 which is the same in both Lower and Midtown districts.

The approach presented in the table for estimating the worst case NYC population density in the central business districts (CBD)is based upon:

- The base population in the CBD is the nighttime population (lines 7&8)

- One component of increase above the nighttime base population is migration into Manhattan from elsewhere. The computations in the table assume this migration is divided between lower and midtown based on their respective land areas (lines 11&12)

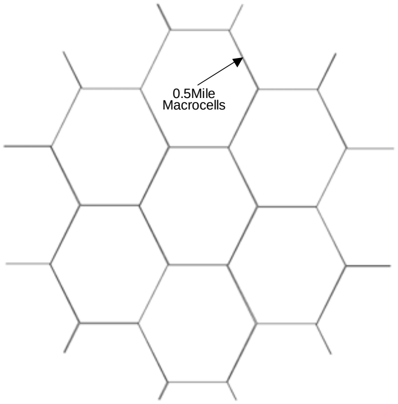
- A second component of increase in the CBD is based upon an estimated 25% migration from other parts of Manhattan into the CBD (lines 13&14)

- The resulting work week daytime population density in the CBD is computed and is the same for both lower and midtown districts (lines 17&18)

CellSite Loading

Although the standards for modern 3G air interfaces support smaller cell sizes, we assume for this analysis the smallest economic macrocellular architecture is built using 0.5 mile radius 3 sector macrocells as shown in Figure 7.

Figure 7 Conventional Macrocellular Architecture



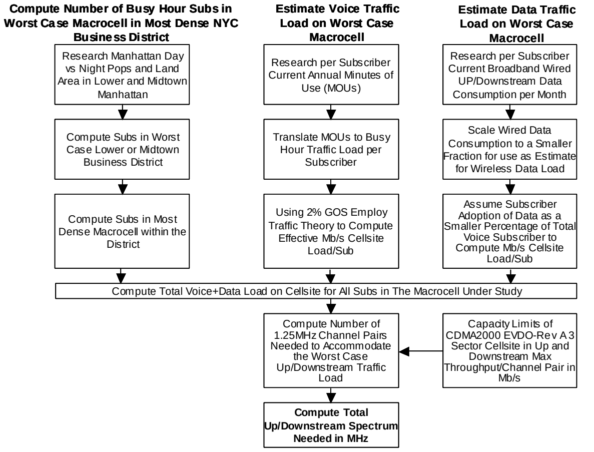
Employing the CDB population density computed above, the number of subscribers in the worst case 0.5 mile cellsite is computed in lines 19 through 25 of the Table 5 model.

The cellsite area in line 20 is multiplied by the CBD population density to arrive at line 21 pops in the macrocell. Using the CTIA 72% figure for cellular adoption results in the cellular subscribers in the macrocell in line 23. On line 24 the market share for the cable company is assumed to be 10% comparable to that enjoyed by t-Mobile but much less than the 25% market share enjoyed by Verizon and AT&T/Cingular. This results in a line 25 estimate of 41,227 of your own subscribers generating traffic in your worst case macrocell.

Model Flow Chart

The total spectrum required to support today's voice+modest data load is computed to be 30MHz in line 56 of the Table 5 model for a 10% market share carrier but would need to be on the order of 75MHz for the mature carriers who enjoy 25% market share. The process for computing the required spectrum is shown in the Figure 8 flow chart.

Figure 8 Flow Chart for Macrocellular Analysis



The analysis assumes the following key inputs to the model:

- Each macrocell employs CDMA2000 EVDO-Rev A all IP technology
- The traffic load is typical of today's cellular system averages of
  - Voice traffic of 142 MOUs/month
  - Data traffic based on 10% fraction of voice subscribers who consume 50 megabytes/month of downstream data
- The market share of the carrier under study is 10%

Voice Traffic Load

Lines 26 through 30 of the Table 5 model compute the voice traffic load. Starting with the CTIA reported average 1,700 minutes of use per year per subscriber (MOUs) of voice traffic, the number of MOUs per work day is computed on line 27 and based upon an assumption of 20% of all daily minutes being used in the busy hour, the busy hour MOUs is computed on line 29 and shown in mili-Erlangs per subscriber during the busy hour of 21.8 mE on line 30.

Data Traffic Load

Lines 31 through 36 of the Table 5 model are employed to compute the busy hour non-voice data traffic load. Line 31 represents today's average daily downstream consumption of today's wired cable modem service as reported by a cable operator. Since modern air interfaces generally support higher downstream (i.e. base to mobile) throughput then upstream (i.e. mobile to base), the upstream subscriber data consumption is computed based on a ratio of upstream to downstream of 20%.

Line 33 of the model represents a factor to scale the wireless rate to a 4.13% fraction of the wired rate. The 4.13% number was computed in order to generate a typical data consumption of 50 megabytes per data subscriber per month (MB/mo) as shown on line 36. Further more, line 34 estimates the busy hour usage by assuming that 20% of all daily usage occurs during the busy hour. Finally line 35 assumes that data subscribers represent only 10% of total voice subscribers (i.e. data consumption averaged across all voice subscribers is 5 MB/mo).

Data Only Cellsite Capacity

Lines 37 though 45 of Table 5 compute the number of channels and spectrum required to support the upstream and downstream data only traffic loads on the CBD cellsite during the busy hour. Line 37 represents the downstream throughput per site for a three sector EVDO-Rev A macrocell while line 38 represents the upstream throughput limit for the site. These throughputs are based on a private communications to me of the results of a simulation conducted by Nortel of various 3G and 4G air interfaces under mobility conditions.

The total traffic load per subscriber is computed by using lines 31 through 36 of the model as input to compute line 39 and line 40 of the model. By using the number of data subscribers the total down and upstream load on the site is computed on lines 41 and 42. Dividing line 31 by line 37 for downstream and line 42 by line 38 for upstream yields the number of 1.25MHz channel pairs needed to support the non-voice data traffic load on lines 43 and 44 and the worst case of down and upstream resulting need for channel pairs is shown on line 45.

Voice Only Cellsite Capacity

Lines 46 through line 51 of the Table 5 model compute the maximum number of voice subscribers that a cellsite can support in order to maintain a 2% grade of service blocking factor. The throughput on line 47 and the assumption that a header suppressed VoIP channel will require 10 kilobits per second on the channel computes to a line 49 result of 135 voice circuits supported on the site. The Erlang B model is employed to compute the maximum traffic capacity of the site in Erlangs and by dividing the voice load in mE per subscriber from line 30, the line 51 result of a maximum load of 4,036 voice subscribers per site is computed.

Computation of Spectrum Required

The data only capacity from line 45 and the subscriber voice limit from line 51 is employed in lines 52 to 57 of the Table 5 model to compute the line 56 result of 30MHz of total spectrum required.

On line 52 the number of channel pairs for voice is computed by simple division of line 25 voice subs in the site by the capacity per channel on line 51.

On line 54 the number of channel pairs for data is repeated from line 45. By multiplication of the channel pairs needed on line 53 for voice and line 54 for data by 2.5MHz of spectrum per channel pair the line 53 resulting spectrum need is computed for voice and the line 55 corresponding spectrum need for data is computed. Line 53 and line 54 are added together to result in the need for 30MHz of spectrum shown on line 56 of the Table 5 model.

As a perspective on the relative drivers of bandwidth, the ratio between data and total channels is computed as 17% on line 57.

MICOCELLULAR ANALYSIS WITH LICENSED SPECTRUM

Unlike competitive carriers, cable operators have extensive HFC plant throughout their franchise area that can be used to provide economic backbone interconnection between microcells with coverage range much less than 0.5 mile radius. For the microcell case, it is assumed that the macrocell network continues to exist to support high mobility applications as well as allow for less than 100% coverage by a microcell network that underlies the macrocells. Two microcell underlay options were considered in this study: 1) Borrowing licensed spectrum from the macrocell pool of spectrum to use in microcells and 2) Using unlicensed WiFi spectrum for the microcells. In this section we analyze the licensed spectrum case.

Examination of the technical specification for CDMA2000 handsets reveals that compliant devices have the ability to backoff their transmitter power to support operation cell sizes much smaller than the 0.5 mile macrocells assumed in the previous analysis. In Table 6 we compute the range to be limited to about 350 feet under the case of maximum power backoff. Allowing for some overlap at the edges, this supports microcell sizes as small as a 300 feet coverage radius.

Table 6 Coverage Range Computation of CDMA2000 Compliant Cellular Handsets

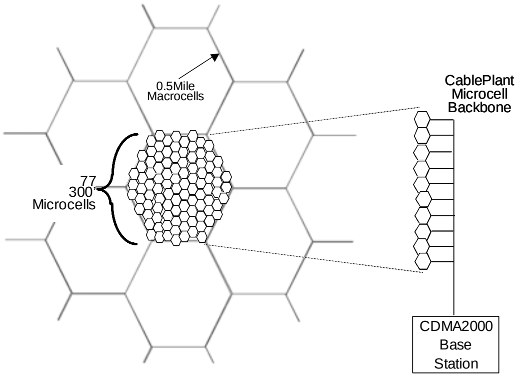
Receiver Sensitivity (dBmW)	-104
Transmitter Minimum Backoff Power (dBmW)	-25
Link Budget (dB)	79
Free Space Propagation Range @ 2000MHz (feet)	350

Free Space LinkBudget(dB)=36.56+20Log$_{10}$(Frequency in MHz)+20Log$_{10}$(Distance in Miles)

Source: “Recommended Minimum Performance Standards for CDMA2000 Spread Spectrum Mobile Stations”, Release B, Version 1, 3GPP2C.S0011-B, December 13, 2002

With reference to Figure 9, it can be seen that a 0.5mile macrocell can be filled with 77 microcells of 300 foot microcells and using the ability of CDMA2000 to allow 1:1 frequency reuse, the same spectrum can be used in each cellsite. Assuming the limited space to mount microcells and the need to keep the cost low, it is assumed that an omnidirectional antenna is used (i.e. single sector) and that a maximum of one channel pair per microcell is supported. The figure also shows the application of cable plant as a backbone for connection of the cells. A variety of backbone technologies are possible including DOCSIS to stand alone microcellular base stations as well as radio over fiber to connect a single base station to remote antenna drivers within each microcell.

Figure 9 Microcell Architecture

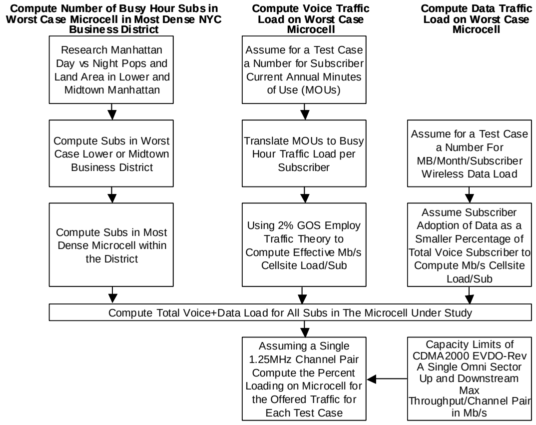


Model Flow Chart

Unlike the approach employed for computing the spectrum required per macrocell based on traffic, in this licensed microcellular option under study it is assumed there is only one channel pair allocated to each microcell. The analysis approach focus is upon understanding the capacity of such an architecture under several traffic load cases and then to compare the traffic capacity of this microcellular+macrocellular hybrid to the previous macrocellular only case.

The process for computing the capacity of the microcellular architecture is shown in the Figure 10 flow chart.

Figure 10 Flow Chart for Microcellular Analysis



The analysis considers several cases in which the inputs to the model are varied:

- Each microcell employs CDMA2000 EVDO-Rev A all IP technology with single channel pair and an omni-sector antenna
- The market share of the carrier under study is 10%
- The traffic loads studied consist of two cases
- Today's voice with multimedia data traffic max'ed out to use full capacity of the microcell
  - Voice of 142 MOUs
  - Each data sub consumes 653MB/month downstream traffic
  - Data subs are 10% of voice subs
- No voice traffic with data capacity max'ed out
  - All voice traffic on the macrocell and none on the microcells

- Each data sub consumes 816MB/month downstream traffic
- Data subs are 10% of voice subs

Table 7 Licensed Spectrum Micro Cell Analysis Model for CDB in Manhattan

Manhattan Demographics

1	Manhattan land area (miles^2)	28.4	input
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4	Ratio Day/Night	2.3	calc
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17	Total Daytime PopDensity in lower (mile^2)	729,059	calc
18	Total Daytime PopDensity in midtown (mile^2)	729,059	calc

CellSite Loading

19	CellRadius (miles)	0.06	input
20	CellArea (miles^2)	0.01	calc
21	Daytime Pops in lower Manhattan cellsite	7,394	calc
22	Cellular Adoption	72%	Input
23	CellSubs in lower Manhattan cellsite	5,324	calc
24	Market Share	10%	input
25	Own subs in lower Manhattan cellsite	532	calc
26	Voice Minutes of Use/year/Sub	1,700	input
27	Minutes of Use/work-day/Sub	6.54	calc
28	Busy hour concentration of minutes	20%	input
29	Busy Hour Minutes/Sub during work day	1.31	calc
30	Busy Hour voice traffic load/Sub (mE)	21.8	calc
31	Voice Load on Site from own subs (Erlangs)	11.6	calc
32	Number of Voice Ckts to be Reserved for 2% QoS Blocking	18	calc
33	Capacity requirement for voice traffic (kb/s)	10	input
34	Upstream & Downstream load on Site from Voice Ckts in Mb/s	0.180	calc

Data Traffic Load per Subscriber

35	Average Wired BB Downstream Busy Hour Data Rate/Sub (kb/s)	25	input
36	Ratio of Upstream to Downstream Data Rate	20%	input
37	Throttle on Wireless Data Rate Ratio to Wired Rate	54.00%	input
38	Busy Hour Concentration Factor (percent of all daily usage)	20%	input
39	Percent of Subs who Take Data Service	10%	input
40	Equivalent downstream megabytes/sub/month of Data Usage	653.1	calc

MicroCellSite Capacity for Single Channel CDMA2000 EVDO Rev A all IP

41	Downstream throughput for Omni Single Sector Site (Mb/s)	0.9	input
42	Upstream throughput for Omni Single Sector Site (Mb/s)	0.45	input
43	Downstream Site throughput left after voice reserve (Mb/s)	0.720	calc
44	Upstream Site throughput left after voice reserve (Mb/s)	0.270	calc
45	Downstream Capacity/sub requirement for data traffic (kb/s)	13.50	calc
46	Upstream Capacity/sub requirement for data traffic (kb/s)	2.70	calc
47	Total Downstream data traffic Load/Site (Mb/s)	0.719	calc
48	Total Upstream data traffic Load/Site (Mb/s)	0.144	calc
49	Total Downstream Data+Voice Traffic Load on Site (Mb/s)	0.899	calc
50	Total Upstream Data+Voice Traffic Load on Site (Mb/s)	0.324	calc

Ratio Analysis

51	Ratio of DS Voice Load/Site to Total Single Channel Site Capacity	20%	calc
52	Ratio of DS Data Load/Channel to Total Single Channel Site Capacity	80%	calc
53	Ratio of DS Data Load/Channel to Max Possible Data Load	100%	calc
54	Ratio of US Voice Load/Site to Total Single Channel Site Capacity	40%	calc
55	Ratio of US Data Load/Channel to Total Single Channel Site Capacity	32%	calc
56	Ratio of US Data Load/Channel to Max Possible Data Load	53%	calc

Licensed Microcellular Capacity Computation

In a matter parallel to the macrocellular analysis model, the model of Table 7 was created to compute the capacity of the licensed microcellular alternative based upon a single CDMA2000 channel pair in a 300 foot omni-sector microcell using an EVDO-Rev A air interface.

The Table 7 model tracks the Table 5 macrocell model from lines 1 through line 30. The analysis departs from the macrocell case beyond line 30, because even this single channel pair microcell has more than enough capacity to handle today's voice plus non-voice data load. So the analysis objective in this case is not to compute how much spectrum is needed, but instead to compute how much more than today's traffic can the microcell support.

Starting at line 31 in the Table 7 model the Erlang voice load on the microcell is computed and using Erlang theory the number of voice circuits that must be reserved to support a 2% grade of service blocking is computed on line 32. Using the voice data rate on line 33, the load on the microcell in Mb/s needed to support today's voice traffic is computed on line 34.

Lines 35 through 40 in the Table 7 model directly parallel the computation in macrocell model. The input parameters for the data consumption are adjusted upward so that the capacity of the microcell is max'ed out. Line 37 of the model is set so that line 52 of the model just reaches 80% of site capacity which when added to the 20% needed for voice results in 100% of the site capacity consumed by the offered traffic.

The finding from this analysis is shown on line 40 of the Table 7 model indicating that a licensed microcellular network can support all of today's voice traffic as well as allowing non-voice data usage to grow from the 50MB/month/data-sub to 653MB/month/data-sub. What is more remarkable is that unlike the macrocellular case which required 30MHz of spectrum to support the much smaller non-voice data load, with the microcellular architecture only a single channel pair of 2.5MHz (i.e. 2 x 1.25MHz) is needed.

The licensed microcell model of Table 7 was also run with the voice traffic set to zero such as would be the case if all voice traffic was supported on the macrocell overlay and the microcellular network employed only for data. Under these conditions, the model computes a non-voice data only capacity that supports each data sub consuming 816MB/month of downstream non-voice data traffic.

MICOCELLULAR ANALYSIS WITH UNLICENSED SPECTRUM

This alternative differs from the just licensed microcell analysis, just above, in that unlicensed WiFi spectrum is employed in the microcells in an architecture similar to today's muni-WiFi systems. As with the previous licensed microcell analysis, the macrocell network continues to overlay the unlicensed microcells to support high mobility and fill any microcell coverage gaps.

Examination of the performance of WiFi network access points in Table 8 shows that such outdoor unlicensed microcells have 300 foot radius of coverage comparable to the same coverage radius assumed for the licensed microcellular option considered above.

Table 8 Typical Performance of WiFi Network Access Points

Protocol	Release Date	Operating Frequency	Data Rate (Typ)	Data Rate (Max)	Range (Indoor)	Range (Outdoor)
802.11a	1999	5.15-5.35 / 5.47-5.725 / 5.725-5.875 GHz	25 Mbit/s	54 Mbit/s	~25 meters	~75 meters
802.11b	1999	2.4-2.5 GHz	6.5 Mbit/s	11 Mbit/s	~35 meters	~100 meters
802.11g	2003	2.4-2.5 GHz	25 Mbit/s	54 Mbit/s	~25 meters	~75 meters
802.11n	2007 draft	2.4 GHz or 5 GHz bands	200 Mbit/s	540 Mbit/s	~50 meters	~125 meters

Source: Wikipedia entry for 802.11

Unlike the approach employed for computing the spectrum required per macrocell based on traffic, in this unlicensed microcellular option under study it is assumed there are a fixed number of four WiFi channels allocated to each microcell. As with the licensed microcellular option, this analysis approach focus is upon understanding the capacity of such an architecture under several traffic load cases and then to compare the traffic capacity of this microcellular+macrocellular hybrid to the previous macrocellular only case.

Model Flow Chart

The process for computing the capacity of the unlicensed microcellular architecture is shown in the Figure 11 flow chart.

Figure 11 Flow Chart for Unlicensed Microcellular Analysis

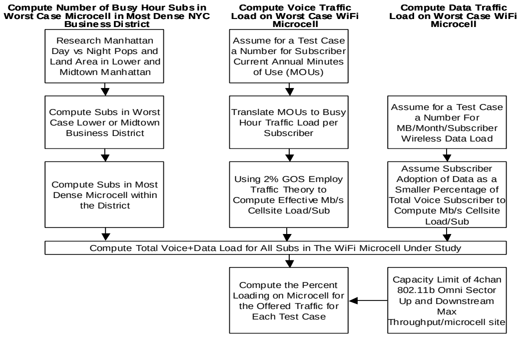

Table 9 Unlicensed Spectrum Micro Cell Analysis Model for CDB in Manhattan

Manhattan Demographics

1	Manhattan land area (miles^2)	28.4	input
2	Nighttime population	1,487,536	input
3	Daytime Population	3,389,300	input
4	Ratio Day/Night	2.3	calc
5	Mid-town Manhattan land area (mile^2)	1.64	input
6	Lower Manhattan land area (mile^2)	1.72	input
7	Nightime PopDensity pops/mile^2	52,378	calc
8	Nightime Pops in lower Manhattan	90,090	calc
9	Nighttime Pops in midtown Manhattan	85,900	calc
10	Pop Increase btwn Night to Day	1,901,764	calc
11	Pop Increase into lower due to migration into Manhattan	973,522	calc
12	Pop Increase into midtown due to migration into Manhattan	928,242	calc
13	Pop Increase into lower due to 25% migration within Manhattan	190,369	calc
14	Pop Increase into midtown due to 25% migration within Manhattan	181,515	calc
15	Total daytime Pops in lower Manhattan	1,253,981	calc
16	Total daytime Pops in midtown Manhattan	1,195,657	calc
17	Total Daytime PopDensity in lower (mile^2)	729,059	calc
18	Total Daytime PopDensity in midtown (mile^2)	729,059	calc

CellSite Loading

19	CellRadius (miles)	0.06	input
20	CellArea (miles^2)	0.01	calc
21	Daytime Pops in lower Manhattan cellsite	7,394	calc
22	Cellular Adoption	72%	Input
23	CellSubs in lower Manhattan cellsite	5,324	calc
24	Market Share	10%	input
25	Own subs in lower Manhattan cellsite	532	calc
26	Voice Minutes of Use/year/Sub	1,700	input
27	Minutes of Use/work-day/Sub	6.54	calc
28	Busy hour concentration of minutes	20%	input
29	Busy Hour Minutes/Sub during workday	1.31	calc
30	Busy Hour voice traffic load/Sub (mE)	21.8	calc
31	Voice Load on Site from own subs (Erlangs)	11.6	calc
32	Number of Voice Ckts to be Reserved for 2% QoS Blocking	18	calc
33	Capacity requirement for voice traffic (kb/s)	10	input
34	Upstream & Downstream load on Site from Voice Ckts in Mb/s	0.180	calc

Data Traffic Load per Subscriber

35	Average Wired BB Downstream Busy Hour Data Rate/Sub (kb/s)	25	input
36	Ratio of Upstream to Downstream Data Rate	20%	input
37	Throttle on Wireless Data Rate Ratio to Wired Rate	112.00%	input
38	Busy Hour Concentration Factor (percent of all daily usage)	20%	input
39	Percent of Subs who Take Data Service	100%	input
40	Equivalent downstream megabytes/sub/month of Data Usage	1355	calc

MicroCellSite Capacity for Single Channel CDMA2000 EVDO Rev A all IP

41	Typical Down+Upstream throughput per 802.11b channel (Mb/s)	6.5	input
42	Number of active 802.11b channels/access point	4	input
43	Derating percentage based on contention	70%	input
44	Down+Upstream throughput for Omni Single Sector Site (Mb/s)	18.2	calc
45	Down+Upstream Site throughput left after voice reserve (Mb/s)	17.84	calc
46	Downstream Capacity/sub requirement for data traffic (kb/s)	28.00	calc
47	Upstream Capacity/sub requirement for data traffic (kb/s)	5.60	calc
48	Total Down+Upstream data traffic Load/Site (Mb/s)	17.888	calc
49	Total Downstream Data+Voice Traffic Load on Site (Mb/s)	18.068	calc

Ratio Analysis

50	Ratio of Voice Load/Site to Total WiFi Site Capacity	1%	calc
51	Ratio of Data Load/Channel to Total WiFi Site Capacity	98%	calc
52	Ratio of DataLoad Max Possible Data Load	100%	calc

The analysis considers several cases in which the inputs to the model are varied:

- Each microcell employs 4 channels (1, 4, 8,11) of 2400MHz 802.11b WiFi network access points.
- The market share of the carrier under study is 10%
- The traffic loads studied consist of two cases however the capacity of the system is now so great, we assume the limit case in which non-voice data adoption grows from the 10% assumption employed in the licensed cases to approach 100% adoption of non-voice data services by basic voice subscribers.
  - — Today's voice with multimedia data traffic max'ed out to use full capacity of the microcell
    - – Voice of 142 MOUs
    - – Each data sub consumes 1,355MB/month downstream traffic
    - – Data subs are 100% of voice subs
  - — No voice traffic with data capacity max'ed out
    - – All voice traffic on the macrocell and none on the microcells
    - – Each data sub consumes 1,379MB/month downstream traffic
    - – Data subs are 100% of voice subs

Unlicensed Microcellular Capacity Computation

In a matter parallel to the licensed microcellular analysis model, the model of Table 9 was created to compute the capacity of the unlicensed microcellular alternative based on a muni-WiFi type of architecture employing 802.11b technology.

The Table 9 model is the same as the licensed microcellular model from line 1 through line 40 with the exception that the line 37 data load is set to max out the cellsite capacity as shown in line 52. Lines 41 through line 43 have been added to unlicensed model to compute the cellsite (i.e. 4 channel WiFi access point) capacity on line 44. Otherwise this model is the same as that used for the licensed microcellular case.

Line 41 of the Table 9 model shows an assumption for a typical data throughput of 6.5Mb/s per WiFi 802.11b channel which is multiplied by 4 channels on line 42 and further by a 70% derating factor on line 43 to result in the throughput of 18.2Mb/s on line 44. The 70% factor is meant to represent overhead associated with the WiFi contention protocol. Employing more recent 802.11X technology could increase the throughput.

Because the voice load on the site is so small in comparison to the non-voice data load, there is virtually no difference in the maximum non-voice capacity of site with or without voice traffic. The model computes a maximum capacity of 1,355MB/month/sub with voice traffic on the microcell and 1,379MB/month/sub with voice traffic moved to the macrocellular overlay network.

Since today's cable modem subscriber consumes 1,209MB/month/subscriber of datastream high speed internet services, this unlicensed microcellular network has a capacity that exceeds today's wired cablemodem data consumption.

ALTERNATIVE ARCHITECTURES

One concern that might be raised with regard to implementation of a microcellular network is the difficulty of obtaining reliable 100% area coverage with such small 300 foot radius cells. However, this concern is mitigated when you consider that the underlay need not have 100% coverage of the macrocell in order to support high quality multimedia services because the wide area microcell is always available for fallback when microcell coverage may be lacking or marginal.

Also of interest is designing non-voice applications which take advantage of the increasingly low cost but very capable storage and intelligence in today's cellphones to implement applications in which low latency low bandwidth user interface traffic is delivered over the wide area macrocell and high latency tolerant block file transfers are conducted using the microcells. Such an approach in which the wide area network is employed for user interface and control and the very wide bandwidth delay insensitive traffic can be delivered over the microcellular data network without any noticeable impairments notice by user for many applications of interest, e.g:

- Synchronizing mp3 music files stored locally in the phone with an online server
- Enhancing *Cache and Carry* of video by supporting intervals of a few minutes between reloading the cache
- Automatically delaying large email file uploads or downloads until within range of a microcell

SUMMARY AND CONCLUSIONS

Although cable operators may currently own 20MHz of spectrum versus competitors holding 2-3 times more, cable can more than compensate by exploiting unique backbone cableplant assets that would be non-economic for competitors to match. Stealing one 1.25MHz channel pair from the macrocell inventory to implement a single channel pair microcell underlay would support today’s voice traffic load as well as allowing data subscribers to scale from today’s 10%

adoption to 100% adoption at the same 50MB/month/sub rate of consumption. Using four unlicensed 802.11b channels in the microcell in a MuniWiFi like architecture would allow cable to offer competitive wide area voice services as well as support 100% adoption by subs who consume data at rates even greater than today's wired cablemodem subscribers.

A summary of the modeling results in Table 10 demonstrates the significant increase of a microcellular network versus conventional macrocellular plant.

an unimpaired level of user satisfaction resulting in significant CapEx cost savings for the microcell underlay.

By intelligent design of the services offered, the coverage quality of the microcell underlay need not be made equal to the macrocell overlay network in order to provide

Table 10 Summary of Systems Capacity Modeling Results

Case Under Study	Architecture	Per Subscriber Traffic Load		Total Licensed Spectrum Employed (MHz)	Portion of Licensed Spectrum Needed		Total UnLicensed Spectrum Employed (MHz)	Portion of UnLicensed Spectrum Needed	
		Voice Traffic Load (Minutes of Use Per Month)	Downstream Data Consumption (MegaBytes per Month)		For Voice Traffic (%)	For Data Traffic (%)		For Voice Traffic (%)	For Data Traffic (%)
Macrocells with Unlimited Licensed Spectrum	0.5Mile radius 3-sector EVDO-Rev A all IP CDMA2000	142	5 DataSubs=10% Each Sub 50MB	30=1.25X2X12	83%	17%	None	0%	0%
Underlay of Microcells Employing a Single Channel Pair Mixed Voice+Data	300' radius single channel omni sector EVDO-RevA all IP CDMA2000	142	5 DataSubs=10% Each Sub 50MB	2.5=1.25X2X1	40%	2%	None	0%	0%
Underlay of Microcells Employing a Single Channel Pair Voice+Maxed Out Data	300' radius single channel omni sector EVDO-RevA all IP CDMA2000	142	65 DataSubs=10% Each Sub=653MB	2.5=1.25X2X1	40%	60%	None	0%	0%
Underlay of Microcells Employing a Single Channel Pair Voice+Maxed Out Data	300' radius single channel omni sector EVDO-RevA all IP CDMA2000	142	65 DataSubs=100% Each Sub=65MB	2.5=1.25X2X1	40%	60%	None	0%	0%
Underlay of Microcells Employing a Single Channel Pair Maxed Out for Data Only	300' radius single channel omni sector EVDO-RevA all IP CDMA2000	0	82 DataSubs=10% Each Sub=816MB	2.5=1.25X2X1	0%	100%	None	0%	0%
Underlay of WiFi Microcells Today's Wired Data Consumption	300' radius four channel omni sector 802.11b WiFi	0	1209 DataSubs=100% Each Sub=1209MB	None	0%	0%	74MHz 4 Chans 1, 4, 8, 11	0%	88%
Underlay of WiFi Microcells Maxed Out for Data Only	300' radius four channel omni sector 802.11b WiFi	0	1379 DataSubs=100% Each Sub=1379MB	None	0%	0%	74MHz 4 Chans 1, 4, 8, 11	0%	100%