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November 4, 2009

Via Electronic Filing
Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

Notice of *Ex Parte* Communication

RE: A National Broadband Plan for our Future: **GN Docket No. 09-51**

Dear Ms. Dortch:

In response to an inquiry from Arnab Das, a member of the FCC's Omnibus Broadband Initiative, Clearwire provided the attached information to Mr. Das today. The attachment is a white paper entitled "4G by the Numbers."

Pursuant to Section 1.1206(b)(2) of the Commission's Rules, notice of this *ex parte* communication is being filed electronically. If you have any questions regarding this matter, please do not hesitate to contact the undersigned at 202-351-5033.

Sincerely,

Cathy Massey

Cathleen A. Massey

cc: Arnab Das

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4G by the Numbers

R1.0, Mar 25, 2009

Systems R&D Group

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Executive Summary

This document presents the case for the need to rapidly deploy 4G technologies to alleviate capacity and latency problems for today's wireless carriers trying to cope with the ever growing demand for bandwidth as users embrace data oriented devices and applications. The take-home message is that a media-rich, mobile Internet is rapidly proving to be such a positive change to the wireless user experience that 3G networks are already experiencing significant degradation of service. A core reality that much of the industry hasn't yet realized is that the performance and scalability requirements of a mobile broadband network can only be practically met by the deployment of 4G technology. This has created a critical need to move to 4G sooner than some carriers are able to. An examination of the technological and financial barriers which 3G carriers face because of their existing infrastructure reveals that a clean slate, greenfield 4G approach delivers far superior performance at a much lower cost.

Note: A full version of this paper which provides in depth technical analysis is available at upon request.

Introduction

The inherent limitations of the traditional network technologies upon which 3G services are based have been written about within the industry for some years now. More recently, the capacity problems that have been exacerbated by increased use of iPhones and other bandwidth-hungry 3G devices are being covered by the popular press. On March 13, 2009 the New York Times, for example, published an article titled "3G Phones Exposing Networks' Last-Gen Technology"[1] which reports on the frustrations of consumers trying to pull 3G performance out of overworked networks. In addition to the challenges of providing raw capacity, wireless carriers must concern themselves with latency. Latency that would be inconsequential in a 2G world of voice, SMS, and basic data services, becomes a major usability issue if it is interfering with watching a video clip, streaming music, or using a range of other mobile broadband applications.

All of this leads to a simple fact: 4G technology is needed now. However, the build-out of 3G CDMA/WCDMA networks has been an expensive proposition, so much so that significant delays are anticipated in these companies making the next move to 4G. These delays are expected for a number of reasons, including:

- It's well understood that incumbent carriers have enormous investments in their existing 3G infrastructures, and will seek to extract maximum return on this investment before migrating them to 4G OFDMA technology.
- In many cases the spectrum which 3G carriers would hope to use for their 4G migration is limited and not yet available.
- For many of these operators, their natural technology evolution path of choice (3GPP Rel8, LTE) does not yet have mature specifications or equipment available.
- Even after the specs and equipment are ready and tested, for existing 3G operators to deploy them would require either a complete re-design of their existing networks or building out a completely new infrastructure on top of their current architecture.

There will be an inclination by some wireless carriers to try to evolve 3G systems to 4G, for a perceived CapEx savings, and to protect sunken investments. However, the reality is that the perceived CapEx "hit" of building a new, properly architected, flat IP 4G network disappears in a very short period of time. Meanwhile, the augmented 3G network is simply incapable of sustaining the services/revenues which the 4G network will continue to deliver (and even foster).

[1] Source: http://www.nytimes.com/2009/03/14/technology/14phone.html?_r=2&th&emc=th

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Aside from the core issue of 3G networks not being able to keep up with current demand, the key differentiator between 3G and 4G is the ability to cultivate continuous growth for a new Internet services based business model—which can be reliably delivered and sustained over time. Features such as "always-on" connectivity and network awareness of a user's "presence" are vital elements of the mobile broadband experience, yet they place formidable design constraints on existing 3G wireless architectures which never considered these concepts. The network capacity and performance required to usher in an entirely new paradigm of differentiated mobile applications on new generations of consumer devices anywhere, anytime will require far more than just new technology. If 3G operators wish to remain even moderately competitive in the mobile broadband space, they are facing major paradigm changes in system design methodologies, along with massive infrastructure replacement costs. Beyond this, the largest question is whether they can get access to new spectrum.

The deployment and spectrum barriers associated with a 4G migration present a monumentally complex business decision for most incumbent 3G operators. While 3G mobile operators are scrambling to figure out what this means for their business model, Clearwire's resources and 4G framework are well positioned as the lead solution.

Capacity Demands of the Mobile Internet

Capacity demand from wireless users is expected to show unrelenting growth. The mobile Internet has proven so popular that a recent study from IBM found that more than 50% of consumers would substitute their Internet usage on a PC for a mobile device. As technology provides more bandwidth, mobile users find new ways to fill the air. The enormous popularity of sites such as MySpace, YouTube, and Facebook was documented in a recent British Telecom Webcast[2], which provided an example (Figure 1) of key application/services growth over the last five years.

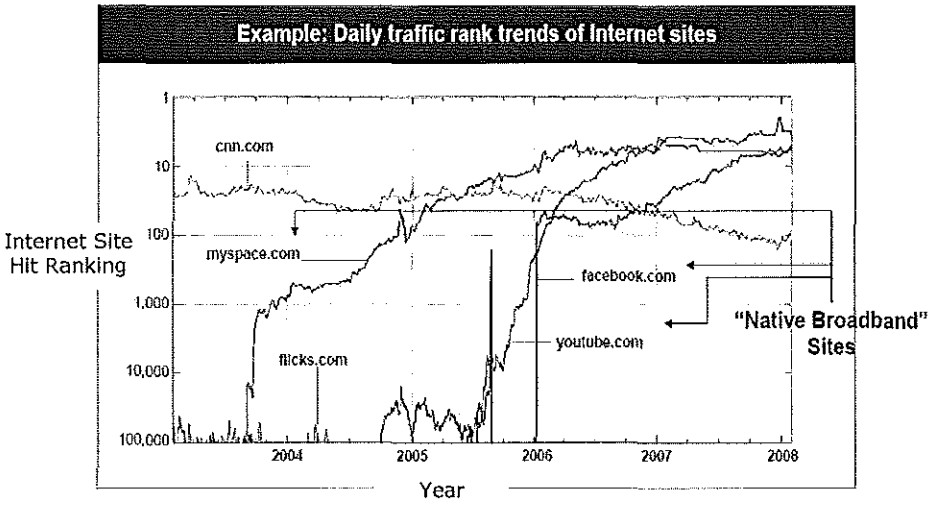

Figure 1: The growth of "Native Broadband" sites.

Note the vertical-line growth of MySpace in 2003, the near-vertical growth of YouTube in 2006, and the completely vertical growth of Facebook in 2006, all against the backdrop of the slow decline of CNN over the 5-year period. Dubbed *"Native Broadband"* sites, for the propensity of users to furnish their own content, MySpace, YouTube, and Facebook represent the leading edge of a very broadband-hungry tomorrow.

[2] Hossein Moiin, "NSN Ecosystem Build Carrier Profitability", Trends & Business Drivers, Dec, 2008. http://www.wirelessweek.com/ngnecosystem.aspx

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At the recent Mobile World Congress in Barcelona, the *Financial Times* reported[3] iPhone users shocked Google by performing 50 times more search requests than any other mobile handset. Similar growth is being seen elsewhere and there are already reports of congestion on 3G networks in the U.S., Canada, EU, and Australia, with blogs and tech forums presenting ever more talk about declining download speeds and congestion.

Technology Summary

The historical cellular rivalry between GSM and CDMA is well known. Generally, 3GPP/WCDMA is considered to be a descendent of the GSM heritage. At this point, 3GPP2's evolution path to 4G has converged with 3GPP, with a focus on OFDM based LTE. The CDMA Development Group articulated this view at a recent conference[4], and many 3GPP2 operators such as Sprint and Verizon in the USA have clearly stated public plans to alter their course towards either WiMAX or LTE as their 4G migration path.

At a very high level, the key technology differences between 3G and 4G are shown below:

	3G	4G
Bandwidth	1.25 - 5 MHz fixed	5—20+ MHz scalable
Access	CDMA	OFDMA
Duplexing mode	FDD	TDD & FDD
Antenna technology	Mostly SISO, 2x2 DL-MIMO	2x2/4x2 DL-MIMO, 1x2/2x4 UL-MIMO, Beamforming
Network	Circuit/packet	Pure IP

Table 1: 3G/4G Technology Summary

The key attributes which allow a wireless technology to meet the ITU requirements for the emerging IMT-Advanced 4G specifications are:

- OFDMA
- Wide channel bandwidths
- Higher order modulation/coding schemes
- Smart antennas
- Simplified flat IP network architectures

WiMAX R1.0 is based on these features, and was the first mobile broadband technology standardized by the ITU under IMT-2000 in 2007. Because of this, some in the wireless industry have termed WiMAX as the first 4G technology—even though the official ITU IMT-Advanced 4G requirements specifications are not yet complete. As a greenfield operator deploying a network today based on these features, using an infrastructure with a clearly defined hardware/software upgrade path to both 16m and LTE, perhaps the most technically accurate way to describe the Clearwire network would be a "4G enabled framework".

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[3] Palmer, Maija and Tayler Paul, "Google homes in on revenues from phones", Financial Times, Feb 13, 2009.

http://www.ft.com/cms/s/667f13de-da60-11dc-9bb9-0000779fd2ac,Authorised=false.html?_i_location=http%3A%2F%2Fwww.ft.com%2Fcms%2Fs%2F0%2F667f13de-da60-11dc-9bb9-0000779fd2ac.html%3Fnclick_check%3D1&_i_referer=&nclick_check=1

[4] Samra, Sam, "CDMA2000 Path to LTE", CDMA Development Group, LTE Conference Paper, January 26, 2009.

www.cdg.org/technology/3g/resource/CDMA2000%20Path%20to%20LTE_CDG_ATIS%203GPP%20Conference_26JAN2009.pdf

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HSPA vs. WiMAX Performance Analysis

Next we dig deeper into the two technologies that matter most. HSPA and WiMAX are both now deployed in the real world. With HSPA+ and WiMAX R1.5, each has a respectable next upgrade step available within the 2012 timeframe, and appear to be jostling as the lead technologies from a commercial network deployment perspective in the USA. Below we provide a practical comparative analysis, which includes average throughput calculations based on actual realistic system configurations which are actually deployed today by AT&T and Clearwire in the USA.

Throughput Peak/Average Calculations

PHY overhead (OH) for WiMAX (for peak throughput calculation)

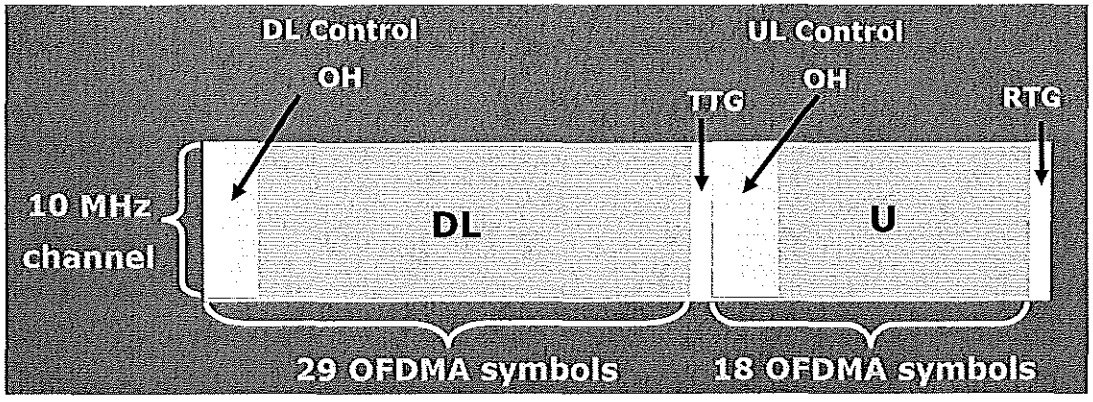

Figure 2: WiMAX PHY Diagram

Downlink:

- Control OH (Preamble, MAP): 2 OFDMA symbols
- 720/120 data/pilot subcarriers per OFDMA symbol
- Modulation and coding: Spatial multiplexing with 64QAM 5/6
- Peak throughput: 27 symbols*720 data tones*5 bits per tone* 2 MIMO order/ 5 ms = 38.9 Mbps

Uplink:

- Control OH (Ranging, BW Req, CQI, ACK/NACK): 3 OFDMA symbols
- 560/280 data/pilot subcarriers per OFDMA symbol
- Modulation and coding: Collaborative spatial multiplexing with 16QAM 3/4
- Peak throughput: 15 symbols*560 data tones*3 bits per tone* 2 MIMO order/ 5 ms Mbps = 10.1 Mbps

MAC+TCP/IP overhead

- Assumptions:
  - Transmission of 600 bytes per user (approximately 1 Mbps)
  - TCP flow with 1400-byte packet length
- MAC overhead: 6 bytes GMH, 4 bytes CRC, 2 bytes HARQ-CRC, 2 bytes fragmentation subheader, 6 bytes BW Req header
  - Total overhead: 20 bytes
- HARQ/ARQ overhead: Conservative assumption of 20%
- TCP/IP overhead: 20+20=40 bytes

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- Scanning overhead: 9% OH
- Total data: (600-20)*(1-0.2)*(1360/1400)*(1-0.09) ~= 410 bytes
- Total efficiency: 410/600 = 68.3%

WiMAX peak and average throughput in 10 MHz

- Peak throughput:
  - Peak downlink PHY throughput: 38.9 Mbps
  - Peak downlink TCP throughput: 25.5 Mbps
  - Peak uplink PHY throughput: 10.1 Mbps
  - Peak uplink TCP throughput: 7 Mbps
- Calculation of average sector throughput: Rule of thumb is 25%-30% of peak throughput (depending on number of users per sector, mobility mix, and traffic mix)
- Average sector throughput:
  - Average downlink throughput: 9-11 Mbps
  - Average uplink PHY throughput: 2.5-3 Mbps

Calculations for HSPA 5+5 MHz

- Assumptions:
  - Downlink: 14 Mbps with 16-QAM coding rate 1
  - Uplink: 5.76 Mbps with QPSK coding rate 1
  - Transmission of 600 bytes per user (approximately 1 Mbps)
  - TCP flow with 1400-byte packet length
- PHY overhead: 25% assuming coding rate 3/4
- MAC overhead: 15 bytes
- HARQ/ARQ overhead: Conservative assumption of 20%
- TCP/IP overhead: 20+20=40 bytes
- Total data: (600-15)*(1-0.2)*(1360/1400) ~= 454 bytes
- Total efficiency: 454/600 = 75%

HSPA peak and average throughput in 5+5 MHz

- Peak throughput:
  - Peak downlink PHY throughput: 10.5 Mbps
  - Peak downlink TCP throughput: 8 Mbps
  - Peak uplink PHY throughput: 4.3 Mbps
  - Peak uplink TCP throughput: 3.2 Mbps
- Calculation of average throughput: The same rule of thumb of 25%-30% of peak throughput is applied for HSPA
- Average throughput:
  - Average downlink throughput: 2.5-3.0 Mbps
  - Average uplink throughput: 1.0-1.3 Mbps

Table 2: WiMAX vs. HSPA Throughput Summary

	Downlink			Uplink		
	Peak PHY throughput (Mbps)	Peak TCP throughput (Mbps)	Average sector throughput (Mbps)	Peak PHY throughput (Mbps)	Peak TCP throughput (Mbps)	Average sector throughput (Mbps)
WiMAX	38.9	25.5	9-11	10.1	7	2.5-3
HSPA	10.5	8	2.5-3	4.3	3.2	1-1.3

Sources: WF, 3GPP/Rel6, Intel

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Table 3: Latency Estimates (Typical)

	HSPA (typical) 3GPP Rel 6 (2008)	HSPA+ (target) 3GPP Rel 8 (2010)	WiMAX R1.0 (typical) 2008
Network Round-Trip-Time	70 ms	25 ms	25 ms
Idle to active	460 ms	<100 ms	85 ms
Sleep to active	250 ms	<50 ms	35 ms
Call set-up time from idle	820 ms	300 ms	285 ms
Call set-up time from sleep	610 ms	250 ms	235 ms

Sources: WF, 3GPP/Rel6, Intel

Real-World Testing

Clearwire conducted real-world tests that demonstrated the constraints of existing 3G infrastructure and the power of WiMAX 4G technology. Testing compared WiMAX throughput and latency performance compared to three other carriers—two using Evolution-Data Optimized (EVDO) Rev-A technology, and the third using high-speed packet access (HSPA). All following tests were done with commonly available FTP clients, Web-based speed test tools and ICMP pings running on typical consumer laptops using commercial mobile products acquired from retail offices of their respective operators. To control for the fact that the 3G networks were mature and had more subscribers than the newly deployed WiMAX network, testing was conducted during the middle of the night to minimize any impact of load to the 3G networks. As shown in Figure 3, the Clearwire Mobile WiMAX network dwarfs the 3G field, delivering nearly 6 times the downlink data rate of the three 3G carriers. The same tests found WiMAX out-performing the 3G carriers in reducing latency by 200%to 300%.

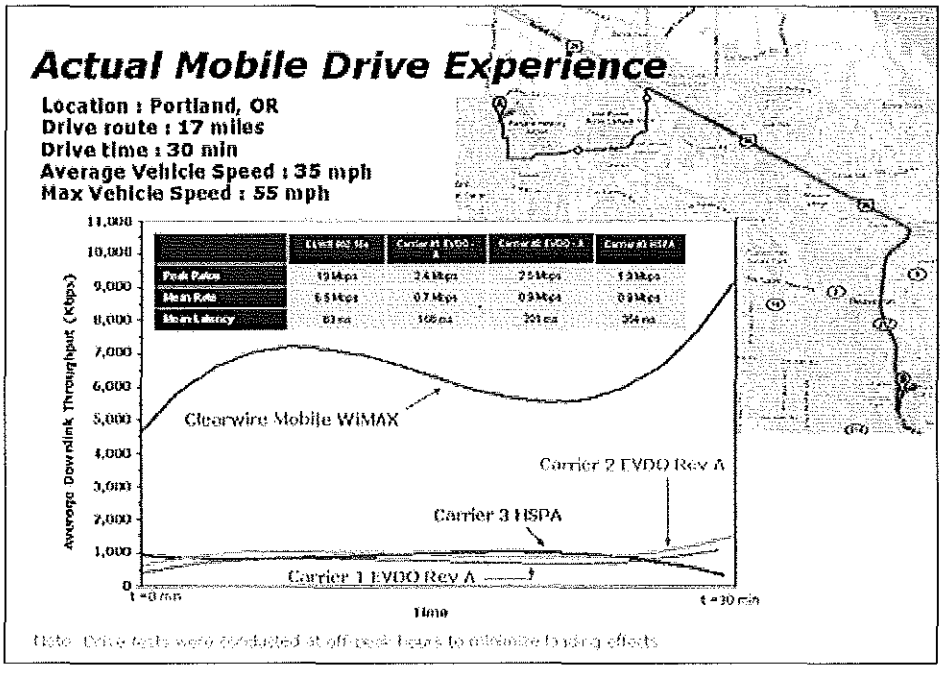

Figure 3: WiMAX outperforms EVDO Rev-A and HSPA carriers.

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Additional testing compared downlink throughput from within 14 indoor locations including downtown office spaces and several hotels. The measurements were performed deep in lobbies and restaurants located inside hotels—meant to be representative of hotspot locations where "road warriors" are likely to heavily use their mobile broadband product at fixed locations. As shown in Figure 4, downlink throughput was many times faster with WiMAX technology than either EVDO Rev-A or HSPA carriers.

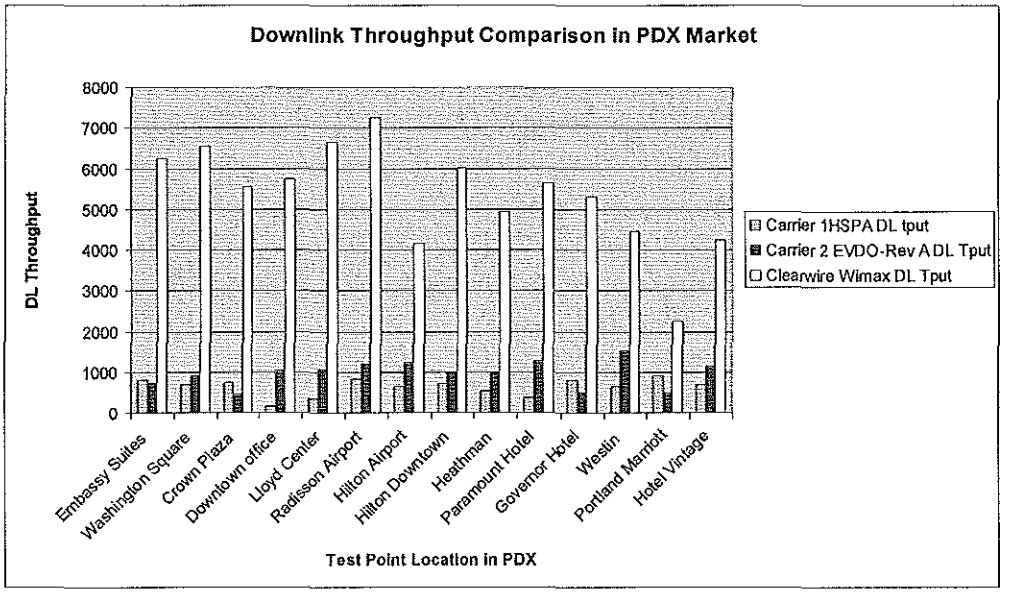

Figure 4: WiMAX delivers several times faster downlink throughput.

Why Spectrum Depth is Critical to 4G

Shannon's Theorem[5] has not changed—capacity is directly related to channel bandwidth. Due to lack of spectrum depth and technology limitations, 3G operators have hit he wall when it comes to scalability. For wireless carriers to actually deliver hundreds of megabits per second of capacity per base station, significant spectrum depth is essential.

Current 3G wireless carriers have reached a point of diminishing returns with their circuit-switched architectures in terms of performance and scalability—and will not be able to sustain the exponential growth and demand that the current mobile Internet paradigm is rapidly producing. Even as 3G operators take steps to upgrade their radio access networks (RAN) via HSPA, HSPA+, and potentially Long Term Evolution (LTE)—their backhaul transport and core networks are entirely architected around legacy circuit-switched designs, which create large throughput/latency choke points.

For carriers seeking to enhance scalability, there are three key mechanisms whereby peak bandwidth can be fundamentally increased in the 3G vs. 4G space:

1) Improved modulation schemes, i.e. moving from Quaternary Phase Shift Keying (QPSK) to 16QAM, to 64QAM (each step basically doubling peak throughput) for very high signal-to-noise ratio (SNR) users.

2) Multiple-input and multiple-output (MIMO) spatial multiplexing, doubling peak throughput for medium high SNR users with de-correlated channels across multiple antennas.

[5] Shannon's Theorem is a tenet of information theory, established in 1948 - that defines an upper bound to the capacity of a link, in bits per second (bps), as a function of the available bandwidth and the signal-to-noise ratio of the link.

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3) Improving channel bandwidth—i.e. moving from 5 MHz to 10 MHz channels.

The reality is that 3rd Generation Partnership Project 2 (3GPP2)/EVDO systems have no evolution path to any of these 3 options. 3GPP can achieve #1 and #2 with HSPA+ (Release 8) of 3GPP specs, but both of these options only improve total sector capacity by incremental steps, at great cost/complexity to implementation for an existing carrier (requires new devices, antennas, etc). A move to LTE actually provides very little incremental feature/capacity benefits over HSPA+.

Beyond these aspects, even for carriers who can deploy features #1 and #2—while these provide nice benefits for high SNR users with good quality radio links to a base station—these 2 features are not generally available to all subscribers in a cell. In contrast, a cell site which provides more bandwidth via wider channels provides tremendous improvements for every user in the system. Moving from 5 MHz to 10 MHz channels will literally double the total available bandwidth for all users in a cell.

A hard truth is that the overwhelming bulk of the capacity improvements provided by 4G systems—whether WiMAX or LTE—come from the fact that both of these routes provide much wider channel bandwidths than 3G systems. However, this key jump in bandwidth is obviously only available to carriers who have enough spectrum to take advantage of it.

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Beyond Coverage: The Need for Capacity

From time to time, industry pundits have raised questions about the perceived coverage challenges of the 2.5 GHz spectrum compared to coverage provided by 700 MHz. The argument goes that due to the better propagation characteristics of 700 MHz compared to 2.5 GHz, many more sites will be required to cover a market area, and thus 4G-based networks utilizing the 2.5 GHz spectrum will be more expensive to deploy than 700 MHz-based 4G networks.

This argument is fatally flawed—on a number of aspects. The truth is that Clearwire's 2.5 GHz and 3.5 GHz holdings in the U.S. and EU pose massive advantages for 4G deployments; this aspect of the company has been vastly misunderstood and undervalued.

To be sure, 700 MHz has propagation benefits. A single base station using this frequency can cover a large area. For systems that provide very narrow bandwidth services, or which only cover very low-density population areas (low capacity requirements per cell site), such as rural towns—the 700 MHz coverage benefit would be seen. However, 4G broadband systems are by definition providing high-bandwidth coverage, in which *capacity* is the overriding determining criteria for designing the network, not *coverage*. In this paradigm, the single 700 MHz base station which provides coverage to a large geographic area—by virtue of the very fact that it does cover so much area—will also cover many high-bandwidth users, and will rapidly become overloaded. This means that 700 MHz networks will require more sites to support the increased capacity of broadband services.

Once it's understood that the value of 4G broadband deployments is based upon the need to enhance *capacity*, not *coverage*, the perceived benefits of 700 MHz vanish. If 700 MHz operators are wishing to provide true mobile broadband services, they won't get away with deploying fewer sites. In fact, when looking at technical aspects of advanced MIMO technologies and micro/pico cell strategies which are rapidly emerging for 4G, the RF characteristics of the 700 MHz band actually become a liability—particularly in dense urban areas. In the arena of 4G mobile broadband, the systems must provide high SNR coverage and are focused on delivering capacity—meaning that high-density cellular designs are needed from day one. High-density cellular systems are by definition highly interference limited. In the paradigm of dense urban, interference-limited systems, the characteristics of the higher frequencies such as 2.5 and 3.5 GHz are far superior. Figure 6 illustrates the true situation with respect to 4G capacity:

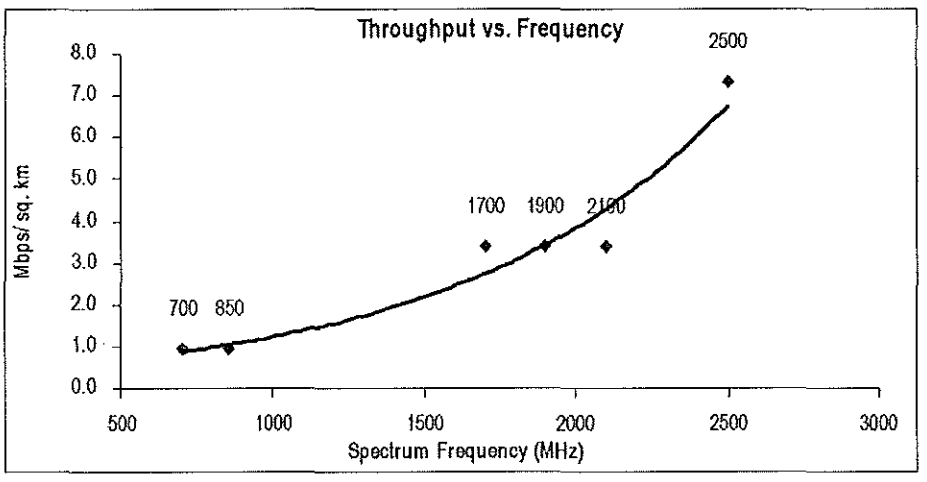

Figure 6: Capacity vs. Frequency based on Mbps per sq km shows true advantage of 2.5 GHz[6]

[6] North America Equity Research, "2.5 GHz Spectrum Appears Misunderstood and Significantly Undervalued", JP Morgan Investment Advisory Report, Feb 26, 2008.

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Base stations using MIMO antenna systems which rely on spatial diversity typically require antenna separations of at least 4 wavelengths. This means 700 MHz MIMO antenna systems will have to space their elements 3.6 times further apart than 2.5 GHz based MMO systems. Due to the relatively short wavelengths of 2.5 GHz (and even more so at 3.5 GHz) it's possible to co-locate separate antenna elements into a single physical antenna radome while still achieving the required physical separation required by MIMO/Beamforming transceiver applications. Since this spacing increases almost 4 times for 700 MHz, such designs would not be practical in this band.

In an era where tower site space is at a premium and site lease fees are negotiated based on size and number of physical antennas and related hardware (brackets, cables, etc), these issues related to wavelength are not trivial. It will be far more difficult and costly for operators deploying HSPA+ or LTE in 700 MHz to enjoy the radio performance and spectral efficiency advantages of multi-antenna technologies such as MIMO, compared to operators deploying 4G in 2.5 or 3.5 GHz MHz. These base station antenna form-factor issues get exacerbated even further in dense urban deployments which increasingly use micro/pico cell sites located on smaller structures—in these situations, size, spacing and numbers of antennas are a huge consideration.

The World is Flat

4G mobile networks have introduced the concept of a flat IP architecture. This refers to the fact that base stations in a radio network provide an IP interface directly to the core network, thus many of the hierarchical circuit-switching network control elements present in 2G/3G architectures can be removed from the network. Simply stated, this simplified architecture has a streamlining effect that improves performance while reducing CapEx and OpEx.

3G services are being provided on existing mobile network architectures which were fundamentally designed in a hierarchal fashion to manage circuit-switched voice calls. The base stations were connected to Radio Network Controllers (RNC) with circuit switched services through T1/E1 trunks. An RNC aggregates calls from multiple base stations, allocates radio channels, enables handoffs between base stations and passes the calls on to even more centralized Mobile Switching Centers (MSC). As packet data networks emerged, packet functions (such as GPRS) new Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) network elements were added to manage and route data sessions and provide the IP interfaces to the core IP network. As all networks are rapidly transitioning into an IP data centric paradigm, these voice centric networks are having difficulty scaling.

Each box in a network has multiple physical interfaces, hardware/software processing layers, and protocol stacks through which packets flow. Each of these adds a delay/jitter component to end2end performance. From a user perspective, by reducing the number of nodes which data flows through, latency between end points is greatly reduced, offering much better support for real-time applications such as voice over IP (VoIP), gaming and videoconferencing. From an operator perspective, each network box has its own lifecycle of hardware/software maintenance, which is obviously desirable to minimize.

The new 4G architectures removes all of the circuit switching hierarchy and protocol conversions from the legacy network, and replaces them with a simpler model which collapses radio mobility management functions into the BS, allowing it to relay traffic directly to network nodes directly over flat IP networks. Even if 3G networks eventually replace all their network nodes to enable IP-based infrastructure, they will still face the issue that their architecture is interconnected using legacy circuit-switched backhaul transport networks, which is where much of their capacity/latency performance disadvantages stem from. The true benefits of a collapsed 4G flat IP architecture model only comes with the opportunity to start from scratch, with no legacy baggage.

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A recent article in *Telephony Magazine*, The Flat World Theory[7] captures many of these concepts very well:

The CapEx savings and the operational efficiencies of such a simplified architecture can be dramatic, said Maniam Palanivelu, senior manager of LTE marketing for Nortel Networks. "You have fewer hops and fewer nodes on the network," Palanivelu said. "Overall the fewer nodes you have, the less infrastructure you have to deploy, the fewer elements you have to connect. That's substantial capital and operational savings."

The same article contrasted the ease with which new subscribers can be added to an IP-based network compared to the costs of upgrading traditional 3G network infrastructure:

"It's a painful, stair-stepped growing method," said Bryan Boudreaux, head of global LTE solutions for NSN. "Adding a single RNC can add another $700,000 to cost of your network." Imagine an operator having to add 100 new HSPA carriers to support increased data demands. Depending on the load of the current RNCs and where the new base stations are clustered, multiple new RNCs might be needed, multiplying the investment required in the network, Boudreaux said. "We're getting so much data traffic we needed to find a way to deal with it in a completely different manner," he said.

Breaking the Backhaul Bottleneck – the Clearwire World is Even Flatter

Increasingly, the community is becoming more aware that the true challenge of mobile broadband is backhaul. The fundamental challenge is how Gigabits of packet data from thousands of cell sites can be efficiently moved to the core network—cost effectively. Existing 3G network architectures simply cannot do this. If a service provider continues to augment capacity at their cell sites using their currently deployed TDM-based architectures, the recurring cost for a market can easily reach the tens of millions with only a marginal increase in bandwidth to each site.

In contrast, the Clearwire implementation of a flat IP architecture leverages an extremely flat Layer 2 Ethernet based wireless backhaul transport layer which provides an OpEx cost structure that literally changes the game. Traditionally, Layer 2 networks were assumed to not scale beyond the LAN environment. However, the simplicity and cost advantages of L2 networking have led to significant evolutions in L2 as a viable Metropolitan Area Network (MAN) or Wide Area Network (WAN) technology. With a focus on L2/Ethernet-based wireless transport years before the buzzword of "Flat IP Architecture" came into the 4G cellular vernacular, Clearwire has pushed the concept one layer flatter than many of its current proponents envision.

In 2004, Clearwire began early operations with an eye on optimizing wireless backhaul transport and small-form-factor base stations as key ingredients for successful broadband wireless. Attention was focused on the development of scalable Ethernet centric transport technologies with infrastructure partners. At that time, large scale L2/Ethernet-based radio transport networks were only an emerging concept on the horizon.

Now, in 2009, all Clearwire commercial markets are deployed with 90% of macro cell sites using Layer2 Metro Ethernet based microwave radios which can deliver up to 1.6Gbps throughput and sub millisecond latency per hop. Running advanced Provider Backbone Bridge Traffic Engineering (PBB-TE) layer 2 switching fabric technologies across microwave P2P backhaul—achieves significant capacity, performance and OpEx advantages. The paradigm shift in cost allows the company to design fully redundant, auto healing, nested ring topologies with deterministic Quality of Service (QoS) that achieve 99.99% link availability and scalable, fast restoration times. The performance of these transport networks rivals SDH/SONET in traditional telecom cores—for a fraction of the cost. Compare this to the model of outdated T1/TDM based backhaul connections typical of 3G, which only offer a fraction of the capacity at an order of magnitude higher recurring fees.

The Ethernet based architecture which Clearwire has been deploying commercially for 5 years has been standardized by the MetroEthernet Forum (MEF) and is receiving much attention from

[7] Fichard, Kevin, "The Flat World Theory", Telephony Online, Jan 26, 2009. http://telephonyonline.com/wireless/news/core_networks_090201/index1.html

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industry analysts. An independent financial analysis conducted by Infonetics Research[8], is shown in Figure 7 below.

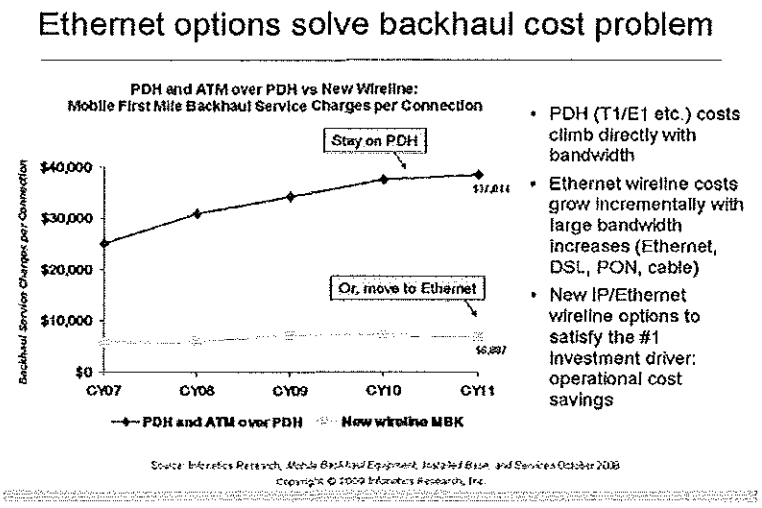

Figure 7: Independent Backhaul Financial Analysis

Superior Economics – The Fusion of Spectrum, Technology, and an Efficient Approach

The many system level progresses in RF technologies of recent years offer significant advantages to an operator deploying 4G base stations today. A 3G base station is typified by a large cabinet at the base of a tower with many 1.5″ diameter RF cables going up the tower to multiple antennas per sector, separated by 10 feet (3m). The AC/DC, climate control, and battery backup systems for a 3G macro BS typically require an entire shelter facility.

In contrast, the Clearwire approach builds a 4G macro cell site with a single RF module the size of a briefcase that weighs 36 pounds and a single 3-foot tall antenna radome per sector—connected to a baseband shelf the size of a pizza box at the bottom of the tower. This small, highly efficient system will offer best-in-class WiMAX macro cell coverage today utilizing 4-transceiver based advanced MIMO/antenna technologies. With advanced power amplifier design, it can support up to six 10-MHz channels, offering ~240 Mbps peak throughput per sector—allowing Clearwire to progressively leverage its spectrum advantage via a one-time hardware package per site. A macro BS with such a diminutive physical footprint significantly reduces cell site both CapEx and OpEx compared to conventional 3G models, while also moving cell sites towards a safer, greener operating environment. This same base station, via software and simple baseband module changes (no change to tower RF/antenna hardware) can migrate forward to 16m/LTE and 20 MHz channels at which point the maximum throughputs are planned to roughly triple.

The benefits of an efficiency-centric approach increase with Clearwire's strategy for backhauling these base stations to the core network. Clearwire's simplified 4G network architectures which use flat L2 transport networks between base stations to a regional data center which collapses multiple access service networks (ASNs) and the core IP networking infrastructure into a single ASN which terminates into a regional data center. The base stations that used to belong to multiple ASNs in

[8] Buckley, Sean, "MEF sets foundation for Ethernet-based backhaul", Telecom Magazine, Feb, 2009.

http://telecommagazine.com/search/article.asp?HH_ID=AR_4856&SearchWord=

classic reference architecture diagrams are actually now part of a large, regionally switched L2 transport domains. In this architecture a single ASN gateway router can serve as the primary router to the Internet. Additionally, partner provided core POPs can be optimally leveraged for cost-effective access to the Internet, while reducing the points in the network where partitioning of multiple MVNO traffic needs to occur. This provides the optimal path to the Internet for all retail and wholesale subscriber traffic.

A side-by-side comparison, as shown in Figure 8, of the recurring backhaul transport costs associated with deploying a 3G vs. 4G network shows that the Ethernet backhaul of a 4G system has low recurring cost and high bandwidth per site—with the 4G recurring cost going mostly to support the 10% of sites that do not have microwave for backhaul. In contrast, the TDM backhaul has soaring recurring cost, which is massively disproportional to the slight increase in site bandwidth.

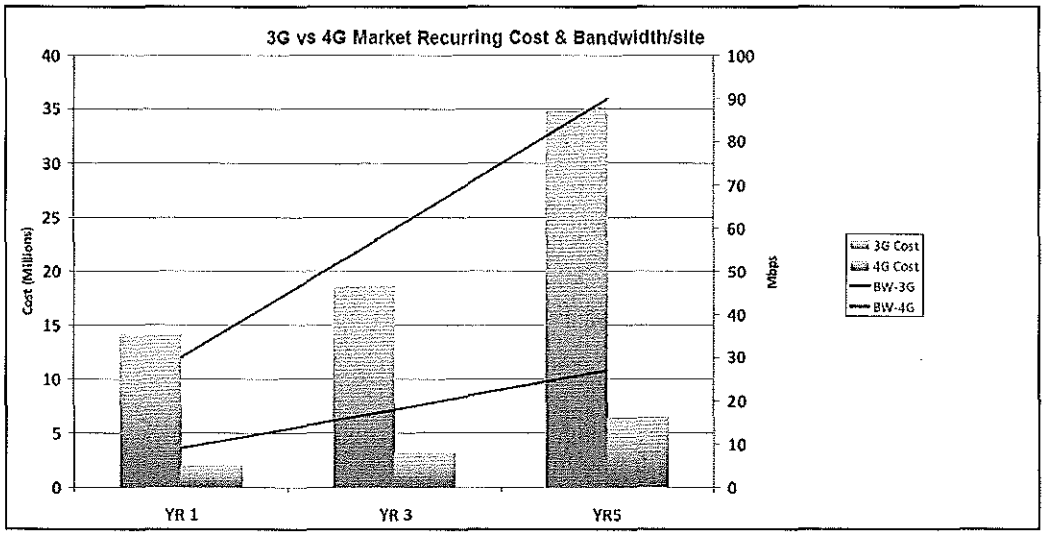

Figure 8: BW soars while recurring costs remain low with Clearwire's approach to 4G backhaul

Summary

The current generation of mobile Internet devices and applications are still in their relative infancy, yet their popularity with consumers has already placed formidable performance and capacity constraints on existing 3G networks. Real world network tests show that user throughputs and latencies of WiMAX systems are in a completely different paradigm than current 3G systems. EVDO is widely recognized to be reaching the end of its lifecycle. Independent field comparison studies of HSPA show that with only mild loading, HSPA sectors experience very severe degradations in user performance. All indications confirm that 3G networks are in trouble and even with major upgrades will have serious scaling difficulties.

Delivering the promise of open broadband wireless networks at an attractive cost point is a function of combining spectrum and standards based technology with entirely new deployment approaches to the radio access, transport and core networks. Clearwire has a combination of enormous spectrum depth, 5 years head-start of successful commercial OFDM-based wireless broadband deployment experience, and advanced RF and core IP networking technologies that are available today, yet flexible to seamlessly migrate to either 16m or LTE. Clearwire is uniquely positioned to deliver a high performance, scalable pure IP 4G framework today at a far superior cost structure than 3G and quite possibly other approaches to 4G.

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