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Straight Path Communications Inc. (STRP)

The Next Generation of Overblown Spectrum Hype

As we discussed a year ago in our original report on Globalstar, the stock market has a sad history of gullibly buying into grandiose narratives about spectrum value. In Straight Path (NYSE MKT: STRP), the latest and, in some ways, most egregious example of this phenomenon, the market has found an unlikely object for its enthusiasm: a company with only seven employees and $426,000 of annual core revenue headed by a 29-year-old whose previous job was serving as the rabbi of a 50-person synagogue in the Bronx – a far cry from telecom.

Despite these obvious red flags, Straight Path trades at an almost $600 million market cap because investors regard it as a play on "5G," the nebulous label applied to the next generation of cellular technology after 4G LTE. Though still years away from standardization, let alone commercial release, 5G might include (as just one component) the ability to use extremely high, "millimeter-wave" (mmWave) frequencies that are currently relegated to niche, non-mobile use cases as a result of their very poor propagation. Straight Path holds a large portfolio of spectrum licenses (primarily in the 39GHz band), supposedly making the company an enormous beneficiary of the move toward mmWave technology. In 2015 alone, Straight Path's stock price has appreciated 151%, with the latest move up triggered by Verizon's marketing announcement in September that it would launch 5G "field trials" next year.

But mmWave is just one small subset of 5G, and Straight Path's spectrum is just one minuscule fraction of the gargantuan amount of mmWave bandwidth likely to be available, much of it for free. For example, telecom regulators from the Americas, including the FCC, are already considering rezoning almost 34 *gigahertz* of mmWave spectrum for mobile use, and that total is likely to grow. Straight Path's 39GHz portfolio – with less than 0.7 GHz of average bandwidth nationwide – is thus a tiny fraction of the pending supply. Not only is the portfolio nothing special; it also has the distinct *dis*advantage of being fragmented and non-contiguous. Though one sell-side bull has characterized the future of Straight Path's spectrum as "[p]erhaps…no different than Manhattan real estate," a more appropriate analogue would be a few small, scattered plots of undeveloped land in the middle of the world's largest desert.

Moreover, though even widespread deployment of mmWave frequencies would still fail to generate real value for Straight Path, such deployment is unlikely to ever take place. While complex multi-antenna arrays may help to overcome weak propagation in a cost-effective way – itself an open question – mmWave transmissions still won't be able to go through walls or over hills, severely limiting their usefulness, and will require extremely dense and thus very expensive networks. There is no straight path here – just a winding, dusty road to failure.

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I. Investment Highlights

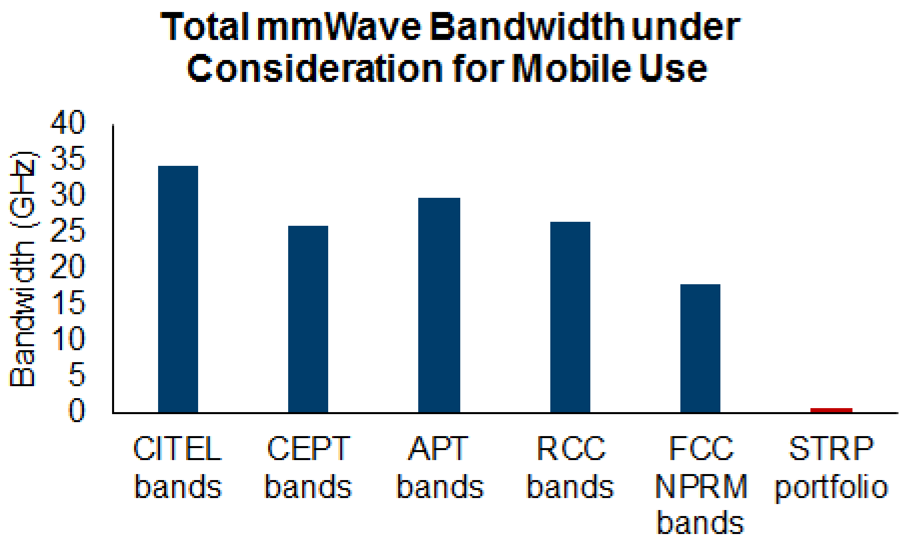
5G ≠ mmWave. Straight Path enthusiasts tend to mix up distinct concepts, speaking as if every new announcement about "5G" – like Verizon's – necessarily involves mmWave. But many key aspects of the nascent 5G vision have nothing to do with high-frequency spectrum at all. New air interfaces and massive MIMO, for instance, are technologies that can greatly enhance throughput in the bands *already* used for 3G and 4G, as well as low-frequency bands to be rolled out in the future, like the 600MHz band, which FCC Chairman Tom Wheeler described in August as "a prime candidate for deployment of a wide-area 5G coverage layer." In early October, the Chinese equipment vendor Huawei and the Japanese carrier NTT DOCOMO "announced…the world's first successful large-scale field trial of 5G new radio access technologies," including Sparse Code Multiple Access and Filtered OFDM, achieving peak downlink throughput of 3.6 gigabits per second (Gbps). *But this trial didn't use mmWave:* the press release clearly states that it used "the sub-6GHz frequency band." Indeed, the first commercial deployments of 5G – whenever they occur – are widely expected to use conventional bands, not mmWave.

5G is also about far more than just higher throughput for smartphones. Key players see it primarily as a platform for communicating with large numbers of distributed sensors (the "Internet of Things") and other machines, like driverless cars, that may require extremely low latencies and high reliability but not necessarily large quantities of data. (Driverless cars, for instance, are not going to be watching lots of ultra-high-resolution video.) For these crucial and novel use cases at the heart of 5G planning, mmWave is irrelevant. Indeed, Verizon's own promotional video about its 5G efforts emphasizes the Internet of Things and features the company's vice president of network planning stating (at 0:54) that "people have enough throughput for the kinds of services they're performing today on the mobile network" – hardly an indication that enormous amounts of mmWave bandwidth will come in handy any time soon.

Straight Path's spectrum is just one tiny drop in the mmWave bucket. Straight Path likes to point out (see slide 6) that it holds "96% of active 39GHz FCC licenses"; credulous listeners interpret this as a monopoly on "5G spectrum." Yet the company's 828 39GHz licenses comprise just 34% of the total 2,450 licenses that were up for bid at the FCC's 2000 auction. The explanation is that so many of the companies that attempted to use the 39GHz band gave up, went out of business entirely, or ran into trouble with the FCC that large numbers of licenses across the country were voluntarily canceled or forcibly terminated. (Indeed, Straight Path itself, in its previous identity as IDT Spectrum, canceled 298 of its 39GHz licenses in 2010 – almost a third of the portfolio it had acquired out of the Winstar bankruptcy.) Based on the FCC's recently released Notice of Proposed Rulemaking (NPRM), these unused licensed will ultimately be re-auctioned to the public, thereby completely circumventing Straight Path.

But the future sale of a large amount of 39GHz spectrum not held by Straight Path is just a small part of a very large problem: *the only reason to use mmWave bands at all is because* *there is so much spectrum available there.* Without this vast supply, research into mmWave mobile broadband might be an interesting academic problem but would be an obvious commercial non-starter given all the immense and as yet unsolved technical difficulties. The only practical reason to bother is the prospect of accessing huge blocks of spectrum, which regulators around the world are beginning the process of freeing up. From a technological perspective, there is nothing special about Straight Path's 39GHz band as opposed to the many other mmWave bands, including several that either are or are likely to become unlicensed and thus free to use.

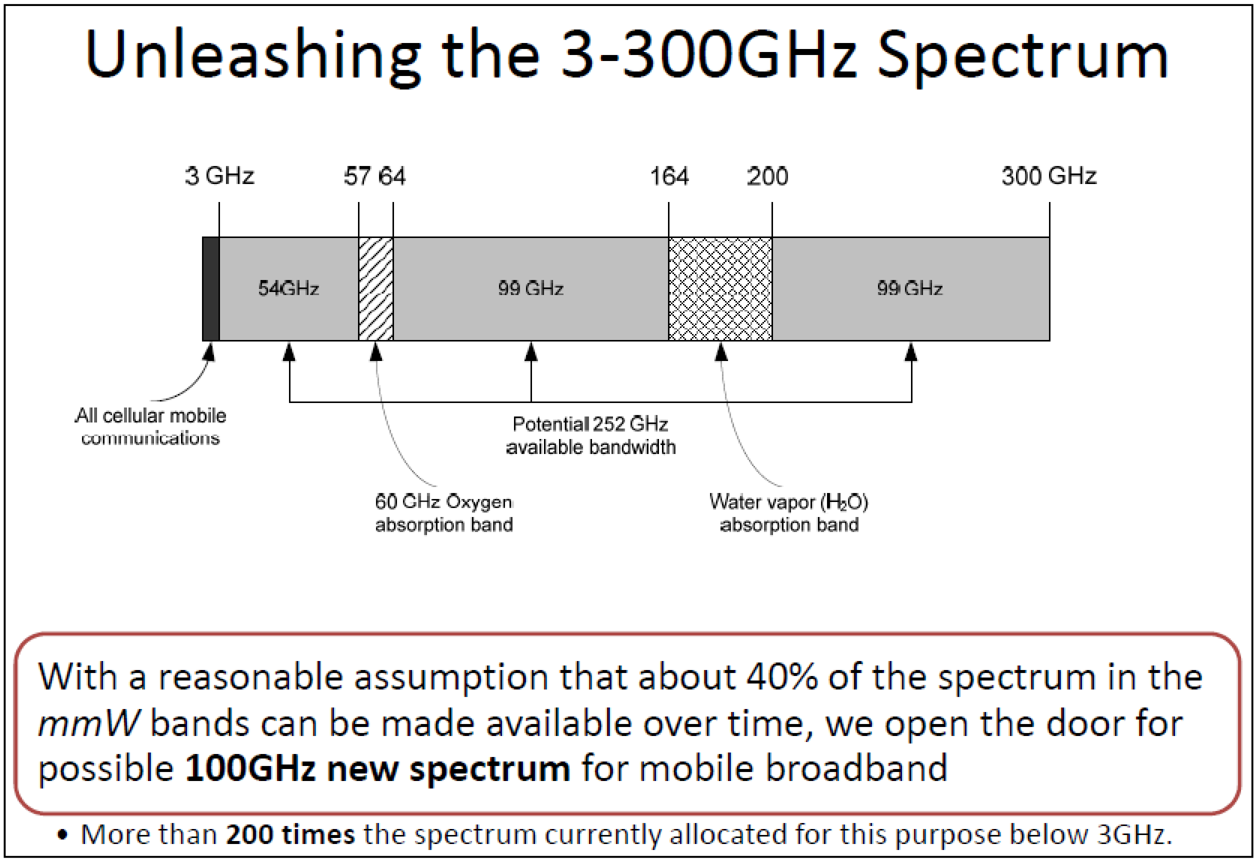
The chart below illustrates the size (in gigahertz of bandwidth) of the mmWave bands most likely to be repurposed for mobile use in the medium term, putting Straight Path's holdings in perspective:



CITEL/CEPT/APT/RCC are regional regulatory bodies for the Americas/Europe/Asia/Eurasia, respectively.
Note: "FCC NPRM bands" includes the 60GHz band (57-64 GHz) already available for unlicensed use.
Source: DIGITALEUROPE summary of regional proposals, mmWave NPRM, Kerrisdale analysis

Above, on the left, we show the aggregate amount of high-frequency bandwidth proposed for consideration as future homes for mobile broadband by various regional regulatory bodies, including CITEL, the Inter-American Telecommunication Commission, of which the FCC is a member. These proposals will be further discussed at the upcoming World Radiocommunication Conference (WRC) in November and finalized in 2019. We also show the total size of the bands in the FCC's recent NPRM, including the existing 60GHz band, already available for unlicensed use, including mobile. But these bands are only the first step – FCC Chairman Tom Wheeler has already publicly pledged to consider others in the near future. With 20 to 30 GHz in sight, Straight Path's nationwide average of 817 *MHz,* including 691 MHz in the 39GHz band and 126 MHz in the LMDS band, looks trivially small. (Even that total is overstated since much of the LMDS band is excluded from both the NPRM and the international proposals.) Far from a mmWave monopoly, Straight Path's holdings amount to a drop in the bucket. Anyone interested in using mmWave spectrum will have an embarrassment of riches.

Moreover, the supply is likely to grow further, from tens to *hundreds* of gigahertz, a point ably made in 2011 by two of the mmWave researchers then at Samsung, one of whom went on to become Straight Path's chief technology officer. They argued that there was 252 GHz of readily usable bandwidth between 3 and 300 GHz, and that even if only 40% could be unlocked for mobile networks, it would amount to "more than **200 times** the spectrum currently allocated for this purpose below 3GHz."



Source: "Millimeter-wave Mobile Broadband: Unleashing 3-300GHz Spectrum"

Indeed, one of the benefits of mmWave technology that the Samsung mmWave group has often pointed out is that there's so much spectrum for the taking that even exclusive access will be incredibly cheap – potentially good news for carriers and consumers but not spectrum owners like Straight Path.

In keeping with the absence of any compelling reason to prefer Straight Path's spectrum to other similar bands, recent 5G demos have focused elsewhere. For example, back in July 2014, Ericsson, in collaboration with NTT DOCOMO and SK Telecom, demonstrated 5Gbps speeds using the 15GHz band. In March, NTT DOCOMO and Nokia achieved a speed of 4.5 Gbps using the 70GHz band. In April, at the Brooklyn 5G Summit, Nokia demonstrated "a 10 Gbps peak rate system over the air at 73 GHz." Consumer products using the large, unlicensed 60GHz band via the WiGig protocol already exist. In short, mmWave spectrum will be a commodity in vast supply, and Straight Path has nothing special to offer. In fact, because Straight Path's 39GHz holdings consist of scattered 50MHz units, not the very wide contiguous channels sought after by industry participants, it's difficult to see how, without significant favors granted by the FCC, it will ever be practical to use its spectrum for 5G.

mmWave spectrum has fundamental limitations that, even if technology improves, will sharply restrict its usefulness. To be sure, major companies have developed prototypes and simulations showing that sophisticated antenna arrays using very wide bandwidths can overcome some of the propagation problems of the mmWave bands. But it's a long way from large, clunky prototypes to real-world networks and user devices. In particular, even if signals can reliably achieve targeted ranges on the order of hundreds of meters, they will still suffer from enormous losses when going from outside to indoors – orders of magnitude worse than conventional cellular frequencies, many of which already struggle with in-building penetration. Since approximately 80% of cellular usage is indoors (almost always using signals transmitted from outside), the practical applications of mmWave technology will be few and far between. mmWave handsets also face severe challenges since the user's head and fingers can easily block the narrow beams used by mmWave signals, potentially requiring multiple duplicate antenna arrays on different sides of the handset. High power consumption is also a problem. Perhaps most dauntingly, mmWave networks will require extremely high base-station densities, thousands of times higher than existing networks, implying enormously costly and time-consuming buildouts for no clear economic benefit. It's no wonder that the CEO of one Hong Kong-based carrier dismissed 5G as the creation of "equipment vendors…asking us to plow more money in there for a purpose that is not yet entirely clear….You don't need that much bandwidth."

Valuation precedents and benchmarks imply that Straight Path's spectrum is worth >90% less than its current market cap. Even if we ignore the shortcomings of Straight Path's spectrum, the likelihood that mmWave networks will simply never be deployed on a large scale, and the vast supply of highly similar competing spectrum, Straight Path is still worth very little. For example, based on the price at which Level 3, a large, savvy telecom firm, was willing to sell 39GHz and LMDS licenses in 2012 – just $203,000 for more than 46 billion MHz-pops – Straight Path's entire portfolio is worth just $1 million. Attempting to extrapolate from dollar-per-MHz-pop levels paid for conventional cellular spectrum *but adjusting for the vastly higher cost of deploying the extremely dense network that mmWave would require* generates an estimated value of approximately $40mm – more than 90% below the current market cap. Simply put, Straight Path is a bubble, driven by hype, misconceptions, and wishful thinking.

II. Company Overview

Straight Path: Capitalization and Financial Results

Capitalization		
Share price	$	47.58
Fully diluted shares (mm):		
Shares O/S		12.1
Unvested restricted shares		0.4
Dilutive effect of options		0.0
Total		12.5
Market cap ($mm)	$	594

Financial results ($mm)	FY ended 7/31		
	2013	2014	2015
Spectrum segment:			
Revenue	$ 0.5	$ 0.4	$ 0.4
Expenses	1.4	0.9	2.1
Op. income	$ (0.9)	$ (0.5)	$ (1.6)
IP seg. op. income	$ (1.7)	$ (0.2)	$ 1.9

Source: company filings, Capital IQ, Kerrisdale analysis

Straight Path's origins date back to the FCC's auctions in 1998-2000 of large blocks of spectrum in what are now known as the LMDS (Local Multipoint Distribution Service) and 39GHz bands. The FCC viewed this high-frequency spectrum as a platform "to create robust competition to the local telephone companies" by allowing new players to transmit voice calls and data wirelessly (via line-of-sight links between fixed antennas) rather than using local phone lines. Winstar Communications, founded in 1990, was one of those players, a "Wall Street darling" that spent billions of dollars affixing microwave dishes to office buildings in order to make use of the high-frequency spectrum it had purchased. But, despite Winstar's claims that its so-called "Wireless Fiber" was superior to actual optical fiber – claims Straight Path has repeated – very few paying customers were convinced, and Winstar filed for bankruptcy protection in 2001.

However, IDT, a New Jersey-based telecom company founded by Howard Jonas, bought Winstar's operating assets – including its 39GHz and LMDS spectrum – for $42.5 million in a transaction that Jonas described in the official press release like so:

> This is an incredible deal. It might not top the Dutch settlers buying the Island of Manhattan for twenty four dollars, but it comes pretty close.

But IDT had no more luck than Winstar at making money from mmWave, and by 2004 it had largely discontinued its efforts. (It even unsuccessfully sued Blackstone and other advisors involved in the Wintrust bankruptcy for, according to Law360, "costing IDT more than $300 million" by misrepresenting Winstar's financial condition.) Nonetheless, after forming a new entity, IDT Spectrum, to own the Winstar licenses, IDT attempted to take it public, filing an S-1 in 2005. The S-1 spoke of how "the continuing deployment of 3G services [would]…cause the demand for bandwidth by mobile wireless customers to increase steadily" and described IDT Spectrum as "well positioned to provide a single source of fixed wireless spectrum solutions across a variety of geographic areas and bandwidth requirements." By the end of the year, however, IDT "postponed" the Spectrum IPO, citing "market conditions" and the availability of alternative funding sources but reiterating that the company was still "developing a fixed wireless network platform that will integrate its wireless spectrum with its operational management capabilities."

But that didn't come to pass. By late 2006, IDT had closed its Spectrum operations; its CEO at the time, James Courter, noted that "it became clear that the United States is moving a little bit more slowly towards second and third and even fourth generation cellular devices. And therefore those carriers such as…Sprint and others, T-Mobile, that would use this spectrum, don't really need it at the present time" [1] – presaging likely future disappointment about 5G. Still, the company held out hope that demand might materialize beyond the following 18 months.

That didn't happen either. In late 2007, a questioner on an earnings call asked Jonas, in his role as chairman, why he no longer highlighted IDT's spectrum holdings (emphasis added):

> <Q - Clayton Moran>: Okay. One more question. You mentioned a bunch of assets in your prepared remarks; you didn't mention anything about the spectrum, you are not optimistic there anymore? Can you give us your thoughts?
>
> <A - Howard Jonas>: Yeah. Well, we have two big piles of spectrum. One is the 39-gigahertz that we have all across the country, and the other one is the 28-gigahertz that we have in the major cities. We are seeing activity in the 28-gigahertz band because there is a lot of equipment that's made for that band and so forth. So, I believe we have entered into a contract with NextLink to do some leasing, and I believe we've entered into something with Hughes in a joint venture. We are not having the same success in the 39-gigahertz field, because there's not like the equipment out there to really use to do it. We are working with universities, we are looking at new applications, I mean some of them seem nuts, like you can irradiate bugs from airplanes that are attacking plants – I don't think that's going to be where we wind up going. But, I would say, I am not **– don't think that that's one of the great hidden values of the company**. But that's what I am saying today, I mean we are working on developing it.[2]

Within six years, IDT's spectrum had gone from a bargain on par with the 17th-century "purchase" of Manhattan to a multi-hundred-million-dollar embarrassment, the best use of which might be irradiating bugs from airplanes. In 2009 a press release announced, "IDT Spectrum Puts FCC License Holdings Up for Sale":

> ID Spectrum…said today that it is accepting offers for its portfolio of 38 GHz[3] and 28-31 GHz spectrum licenses. … "Networks nationwide are straining to accommodate new bandwidth intensive applications. Our licenses enable scalable and cost effective wireless backhaul and last mile solutions," said Michael Rapaport, President of IDT Spectrum. The deadline for offers to be submitted is Thursday, November 12, 2009.

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[1] Source: Bloomberg transcript of IDT's FY2006 Q4 earnings call.
[2] Source: Bloomberg transcript of IDT's 10/29/2007 business-update call.
[3] The 39GHz band, which goes from 38.6 to 40.0 GHz, is sometimes referred to as the 38GHz band.

But there were no buyers. IDT's CFO put a positive spin on it: "Although the auction generated no bids, we continue in discussions with interested parties."[4]

What happened next became the subject of litigation between IDT and Michael Rapaport, the former head of IDT Spectrum. In Rapaport's version of events, IDT had given up, "written down the value of these licenses to zero on its balance sheet and expressed no interest in renewing the licenses, which were set to expire in October 2010."[5] But Rapaport insisted that the licenses "could be worth millions of dollars." Though, according to Rapaport, "[t]he Jonases [Howard and his son Shmuel, IDT's chief operating officer] were initially skeptical about the future value of Spectrum's licenses," they agreed to attempt to renew some of the licenses, splitting the regulatory costs with Rapaport personally in exchange for ceding to Rapaport a percentage of any future "proceeds generated by sales or leases of such licenses"[6] – ranging from 12.5% for "Schedule A" licenses (one in each market) to 49% for "Schedule B" licenses (additional spectrum in higher-end markets). As to the remaining "Schedule C" licenses – some 298 in total – IDT allowed them to lapse.

Rapaport, who claimed he was "the only IDT employee spending any significant amount of time working on the Spectrum portfolio,"[7] began generating small amounts of revenue from spectrum leases and collecting his share of the proceeds via an entity he named Spectrum Holdings Technologies, LLC. In late 2011, he hit it big, convincing the carrier MetroPCS (since acquired by T-Mobile) to buy hundreds of megahertz in New York, Las Vegas, San Francisco, and Orlando for $6.8 million. According to Rapaport, once IDT realized that it would now be on the hook for a million-dollar payout under the terms of its deal with him, IDT reneged and cut him loose. By mid-2012, Davidi Jonas – Howard Jonas's son and Shmuel Jonas's brother – took over as head of IDT Spectrum.

Before that, however, in early 2012, Rapaport negotiated the purchase of additional 39GHz and LMDS licenses from LICT Corporation and Level 3 Communications. Although these licenses were on the verge of expiration, Rapaport – and presumably the sellers – knew that it might be possible to meet the relevant build-out requirements quickly and at relatively low cost and thus secure renewal. Still, the sellers placed little value on the spectrum: LICT sold its licenses for no money upfront but a share of any future proceeds, while Level 3 sold its licenses – amounting to 46 billion MHz-pops – for just $203,000, a price of approximately $0.000004 per MHz-pop.

But the legal buyer in these purchases was Spectrum Holdings, not IDT. As Rapaport's dispute with his ex-employer intensified – Rapaport alleged that Davidi Jonas was "dispatched…to loiter an entire day outside of [Rapaport's] house with no purpose other than to intimidate [him]" and

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[4] Source: Bloomberg transcript of IDT's FY2010 Q1 earnings call.
[5] Source: *IDT Corporation et al.* v. *Rapaport et al.,* Case 2:13-cv-00634, Document 15-7 (Rapaport declaration) p. 2.
[6] Source: *IDT Corporation et al.* v. *Rapaport et al.,* Case 2:13-cv-00634, Document 1 (IDT complaint), p. 17.
[7] Source: Rapaport declaration, p. 4.

"told [him] that IDT would 'fight dirty'"[8] – he refused to hand over the licenses that IDT claimed were rightfully the company's, not his. Under a June 2013 settlement, IDT gave Rapaport $1.5 million plus 50% of the proceeds from certain licenses up to a cap of $3.25 million; in exchange, Rapaport's Spectrum Holdings assigned to IDT the disputed licenses from LICT and Level 3. (In its financial statements, Straight Path values these licenses – 33% of its total license count – at $350,000.)

In May 2013, IDT filed to spin off its high-frequency spectrum holdings into a new company, Straight Path Communications, led by Davidi Jonas. Straight Path also included a wholly unrelated asset: a portfolio of soon-to-expire patents that the company claimed a host of deep-pocketed technology firms were infringing upon. But after recovering $18 million in gross settlement receipts, Straight Path suffered a major legal setback in late 2014 when the Patent and Trademark Office's Trial and Appeal Board invalidated many parts of a key patent; additional patents are also being challenged. Thus Straight Path's patent-troll strategy – the company's only source of positive cash flow historically – has ground to a halt, although accrual accounting has spread the recognition of its past victories across multiple quarters. While Straight Path does lease some of its spectrum to a small handful of customers for backhaul and fixed wireless connectivity, that operation generates only a few hundred thousand dollars of annual revenue; its expenses are 5x higher. But the market no longer cares about Straight Path's IP or its actual spectrum-lease business; the story it has bought into is all about 5G, which is therefore our focus in what follows.

III. 5G Is Not Near and Does Not Require mmWave

Our answer to the 5G question is, "Hell, we just rolled out LTE in the last 36 months!" For God's sake, let us sweat that for a while and utilize that!

—Dave Mayo, T-Mobile SVP of technology, September 2015[9]

5G is not all about bands above 6 GHz; bands below 6 GHz are just as, if not more, important.

—Ofcom (UK telecom regulator), April 2015

Anyone that claims today to know the details surrounding 5G is either a clairvoyant, a liar, or a little bit of both. The truth is that while there are a number of generally accepted principles regarding the requirements of 5G, no one knows for certain when those requirements will be implemented (Phase 1 or Phase 2), or the detailed technical specifications regarding how they will be implemented.

—Signals Research Group, September 2015

By 2020 the global investment in LTE will amount to something like $1 trillion, with physical infrastructure, spectrum licenses, software and service. LTE will have had many significant

[8] Rapaport declaration, p. 16.

[9] Source: Tower and Small Cell Summit 2015 at ~25:55.

updates, and be on Release 16. Why would the CFO of an MNO [mobile network operator] *want to obsolete that? What is the financial case for an upgrade? Why can't we sweat that asset, rather than scrapping it? I fear we are in danger of creating a very expensive white elephant: a compromise that does not actually deliver any compelling advantages or business case.*

—Rupert Baines, technology strategy and marketing consultant at Real Wireless, April 2015

While 5G is often discussed in the context of the higher frequencies, existing "traditional" mobile frequencies may also be candidates for employing a next generation of technology. Moreover, the term "5G" sometimes appears to be used to describe an evolution from the existing technology (4G) to a more advanced version – but in reality the technologies for above-24 GHz spectrum may involve radical departures from existing ones.

While it is important to explore the potential for use of the above-24 GHz bands, the Commission and industry will need to overcome substantial hurdles before the spectrum can potentially be used for mobile commercial use. Technological breakthroughs and major investments will be necessary before these frequencies are commercially viable. By contrast, the know-how to deploy mobile operations using more traditional mobile frequencies already exists…

—Verizon, January 2015

Rather than focusing principally on the mmW bands above 30 GHz, the Commission would be better served by a focus on bands below 6 GHz and subsequently 10-30 GHz, with bands above 30 GHz being phased in over time…Systems will need to be engineered for the mass market, and the state of the art is yet to make significant headway beyond laboratory prototypes…It is premature to address what licensing and regulatory mechanisms are most appropriate for 5G systems, especially mmW spectrum, given the substantial technical development that needs to be done.

—Ericsson, January 2015

I would say, people are expecting that the U.S. is going to be populated with 5G cell sites by 2020, whatever they're having I would like to have some of it, but I don't think that's a realistic expectation.

—Davidi Jonas, Straight Path CEO, June 2015[10]

Before we discuss the technological and economic problems facing Straight Path's spectrum, it's important to distinguish between 5G marketing and lobbying, on the one hand, and reality, on the other. The telecom industry has a long history of forecasting imminent triumphs and disasters, only to experience far less dramatic outcomes. One study outlined the story of 3G:

[10] Source: Bloomberg transcript of Straight Path FY2015 Q3 earnings call.

> In the late 1990s and early 2000s, many hailed the then upcoming allocations of 3G spectrum as a revolutionizing step in telecommunications. Fueled by the success of the Internet, 3G promised to take "mobile telephony beyond just voice … giving people a whole range of new exciting services down to their mobile phone" … The anticipated significance of 3G initially led to exuberantly high spectrum valuations. …
>
> With 3G reaching mass markets, analysts quickly began speculating [about]…when 3G would become the dominant technology. … Recent data on 3G penetration rates demonstrate that these and many other statements and forecasts were far too optimistic as actual 3G penetration rates fell significantly short from most of these claims. … The December 2009 US 3G penetration rate was 26.1 percent, which is less than one third of the number forecasted for the US by various analysts for 2010.

Eventually, the popularity of smartphones led to more widespread usage of 3G and now 4G, but, relative to the early optimism about deployments, these technologies arrived more than a decade late. When industry players now talk about 5G timelines, it's important to parse their language carefully: "beyond 2020" may sound soon, but the interval between completed technical standards and real-life commercial build-outs has typically been many, many years. LTE Advanced, for instance, dates back to at least 2009, but capacity-enhancing features like carrier aggregation have barely begun to be used.

The same disconnect between rhetoric and reality characterizes discourse about the so-called spectrum crunch. In 2010, an FCC technical paper suggested that mobile data usage was growing so rapidly that "an additional 275 MHz of spectrum will be needed…in 2014," beyond the 547 MHz estimated to be already available in 2009. These projections assumed steady network densification, with cell sites reaching almost 345,000 by 2014, but concluded that infrastructure alone wouldn't be enough. In reality, data from the wireless industry group CTIA show that the number of cell sites in 2014 fell short of these projections by 14%, and large amounts of the 547 MHz of spectrum allocated in 2009 have only just started to be deployed or are still unused today, in particular the large 2.5GHz band largely controlled by Sprint. Nonetheless, even with fewer cell sites and much less spectrum in use than expected, the spectrum "deficit" never materialized. A combination of Wi-Fi usage, better spectral efficiency, consumer price elasticity, and faulty projection methodologies, among other factors, have belied the doomsaying.

Even today, with smartphones nearly universal, CTIA figures indicate that growth in cellular data usage has *decelerated* sharply, from 120% in 2013 to just 26% in 2014. Moreover, with large stores of available spectrum still unused, including DISH's ~75 MHz, the carriers' recently acquired AWS-3 licenses, the virgin 100MHz in the 3.5GHz small-cell band, the 600MHz band scheduled for auction next year, the unlicensed 5GHz band expected to be used by the controversial LTE-U and LAA technologies, and Sprint's still largely fallow 2.5GHz holdings, there are hundreds of untouched megahertz available. In the words of two telecom analysts, "Spectrum exhaust is simply not on the horizon." Both 4G LTE technology itself and the existing wireless spectrum inventory will work perfectly well for many years to come – perhaps indefinitely.

If that's the case, then why is the industry talking about 5G and mmWave at all? One reason is intra-sector self-interest: equipment vendors, especially newer entrants, would always like carriers to buy more sophisticated, more expensive next-generation infrastructure and thus must pitch the next big thing. Another reason is politics: *ceteris paribus,* the mobile industry would always prefer the option of more spectrum and therefore constantly competes with other groups, like the satellite industry, to convince regulators that its spectrum needs are more pressing than theirs. Indeed, the timing of the recent wave of 5G demonstrations is likely linked to the upcoming global regulatory conference WRC-15, which will help to define the agenda for the next major conference, WRC-19, where the FCC and its international peers will begin to reallocate high-frequency spectrum. The more enticing the 5G vision, the more likely regulators will be to favor mobile interests over satellite interests; the more dire the forecasts of spectrum scarcity, the more generous the allocations. This political process does not tend to foster even-handed analysis. "We probably have enough spectrum already, but we wouldn't mind some more!" makes for an underwhelming rallying cry.

Indeed, novel spectrum is just one part – arguably a small one – of the industry's early plans for 5G. As wireless service revenues have, in the aggregate, stopped growing, and ARPUs have declined, a compelling financial rationale for deploying a costly new network just to provide an enhanced version of the now familiar consumer mobile-broadband experience is difficult to imagine. Instead, operators hope to broaden their addressable market by serving connected machines – for example, remote-controlled industrial equipment or autonomous vehicles. Such use cases have little in common with looking at Instagram on an iPhone. The challenge is less a lack of bandwidth than high latencies, inadequate reliability, an uncertain business model, and other orthogonal issues. Connecting with far-flung sensors and devices won't require gigabits per second of throughput but likely will require good, cost-effective signal propagation; mmWave is pointless on the first count and worthless on the second. Even for conventional mobile broadband – looking at Instagram on an iPhone – improvements like massive MIMO (using large numbers of coordinated antenna elements to simultaneously transmit signals) can improve throughput using existing spectrum, as well as greenfields like the 3.5GHz band.

In response to the FCC's Notice of Inquiry regarding mmWave spectrum, commenter after commenter pointed out that 5G, when it comes, will come to low-band spectrum first. AT&T, for instance, spoke of the "ample lead time for 5G deployment" and said, diplomatically, "As the earliest form of 5G will occur in frequency bands below 6 GHz, the near-term spectrum need for 5G is not only the spectrum above 24 GHz, but also the spectrum located below 6 GHz." T-Mobile noted that "LTE is still in the early stages of its lifecycle, which for cellular technologies has historically been approximately 20 years from launch to peak penetration" and urged the FCC to focus on freeing up more sub-1GHz spectrum. Verizon was similarly tepid – albeit politely so – about any near-term application for mmWave spectrum in a world where LTE and conventional bands still have a long way to go. Indeed, by far the most enthusiastic supporters of mmWave 5G are incumbent license-holders like Straight Path, who hope to profit from it, and academic and industry researchers, who view it as an interesting technical problem but are removed from direct market pressures. More practical-minded operators have barely started to think about low-band 5G – which is still years away from having a technical definition – let alone the far more exotic possibilities of centimeter-wave 5G or millimeter-wave 5G. Straight Path bulls who expect anything more than marketing and demos in the foreseeable future will be sorely disappointed.

Indeed, it's unclear whether the core value proposition of mmWave 5G – "gigabit mobility," as Straight Path puts it – will even resonate with consumers. In Wi-Fi, for instance, depending on the access point and user device, gigabit speeds are already possible in the 5GHz band using the 802.11ac protocol – but this improvement has hardly caused a step change in Wi-Fi uptake or gotten much mass-market attention. Consider some simple arithmetic. According to Ericsson, in North America, data traffic per active smartphone totaled 2.4 gigabytes per month or approximately 80 megabytes per day. Assuming an average US LTE speed of 10 Mbps (based on OpenSignal data), this implies a total of 63 seconds per day spent downloading mobile data. If speeds rose to 1 Gbps, that time would drop to just 0.6 second per day, thus saving the average users about a minute per day. But even if we value time at a rate of $100,000 per year, a minute is still only worth $0.19; a minute per day would be just $69 per year. To achieve those savings with mmWave 5G would require inventing new radio technology and deploying orders of magnitude more base stations than currently exist, and it would still likely falter in areas with trees, hills, or severe rain, not to mention when going from outdoors to indoors. To be sure, data usage will likely continue to increase, but not at an astronomical rate – Ericsson, for instance, only expects usage to reach 14 GB per month by 2020. Downloading a billion bits in a second is great, but it doesn't do much good when users are only interested in downloading that many bits in a month. Carrier commentary and advertising about the importance of *consistently* good throughput rather than simply exciting-sounding *peak* throughput represent an oblique acknowledgement of this point: today, ever higher download speeds *per se* generate little incremental value for consumers.

Straight Path has happily cast itself as the royal road to 5G, with the move to "gigabit mobility" in the mmWave depicted as thrilling and inevitable. But it will be likely be the 2030s before 5G truly exists on a large scale, and even later, if ever, before the mmWave version of 5G comes into being in the few places where it might make economic sense. With all this "ample lead time," in the words of AT&T, global regulators will have the luxury of studying and rewriting rules for large swaths of high-band spectrum well before it becomes commercially relevant – creating an unprecedented wave of spectrum supply that will dwarf Straight Path's holdings.

IV. Straight Path's Spectrum Is a Small Slice of the Enormous mmWave Pie

The use of millimeter wave bands will open the door to an abundance of spectrum…[*L*]*arge chunks of spectrum are available…*

—Nokia, February 2015

Enormous blocks of spectrum [*are*] *available for short range outdoor or indoor access*

—Alcatel-Lucent, May 2015

The high interest in millimetre wave bands has risen due to the enormous amount of bandwidth that lies in this part of the electromagnetic spectrum. With respect to the present regulatory status, typically V-band offers 7 GHz bandwidth of contiguous spectrum (57 - 64 GHz), extendable to 9 GHz whenever also the 64 - 66 GHz is open for fixed services, and E-band provides two times 5 GHz bandwidth, namely 10 GHz aggregate spectrum (71 - 76 GHz and 81 - 86 GHz). Similarly, at frequency bands above 100 GHz, there are blocks of plentiful spectrum, which could be allowed for extra bandwidth for future broadband wireless transmission services. … The millimetre wave frequency range provides massive and underutilized spectrum…

—European Telecommunications Standards Institute (ETSI) millimetre Wave Transmission Industry Specification Group, August 2015

[*A*]*bove 6 GHz, sharing of the spectrum may become easier due to the limited range of the systems and this could be further improved by the use of advanced antenna techniques with greater directionality.*

—Ofcom, January 2015

The technologies being developed for advanced mobile applications in frequencies above 24 GHz could allow opportunities for reuse of spectrum and for spectrum sharing that are not possible at lower frequencies with current technology. In principle, tightly packed base stations with dynamic beamforming capabilities should be able to share the same channels without causing mutual interference by pointing their beams in non-interfering directions.

—FCC Notice of Inquiry, October 2014

Spectrum bulls often liken spectrum to a natural resource in fixed, finite supply; scarcity, they believe, is what gives it such great value. While this scarcity is as much a product of technology and regulation as of physics, it's true that the low-band spectrum most efficiently used by existing systems is limited in quantity. But mmWave spectrum is a different story altogether. In high bands, regulatory allocations contain hundreds of times more bandwidth than they do in low bands, which helps to compensate for the inherent propagation challenges of higher frequencies. Straight Path's favored 39GHz band is indeed wide, but so are many of the other mmWave bands under consideration for future mobile usage by global policymakers, and these bands in the aggregate are very large indeed.

Consider the bands that the US is proposing for study at WRC-19, according to an August blog post by FCC Chairman Tom Wheeler. Together, they amount to 22 GHz of spectrum, with the largest individual piece by far being the 59.3-71.0GHz band, with almost 12 contiguous GHz:

mmWave Bands Tentatively Proposed by the FCC

Start (GHz)	End (GHz)	Bandwidth (GHz)
27.5	29.5	2.0
37.0	40.5	3.5
47.2	50.2	3.0
50.4	52.6	2.2
59.3	71.0	11.7
	Total	22.2

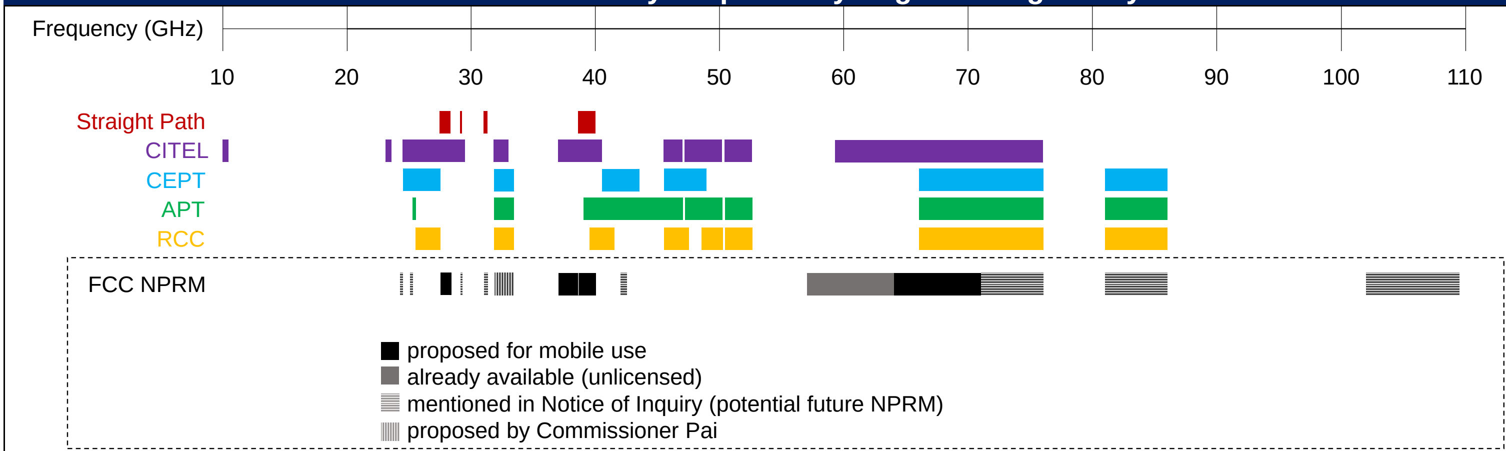
Source: FCC, Kerrisdale analysis

Only a subset of those bands was included in the FCC's recent NPRM, which proposed aggregate bandwidth of 10.85 GHz for mobile use, on top of the 7 GHz already available in the unlicensed 60GHz band. But, in response to complaints from some FCC commissioners that even more spectrum should be considered – at least another 12.5 GHz, according to Commissioner Ajit Pai – Chairman Wheeler has pledged a "follow-on proceeding" in the coming months to go further still.[11]

But the story doesn't stop there. Everyone agrees that the ideal outcome for 5G would be global harmonization of potential mmWave bands, and given how early it is relative to any plausible timeline for commercial deployments of mmWave 5G, international regulatory agencies aim to be open-minded rather than prematurely anoint any one band as the answer. Different regional regulatory groups have devised their own proposals based on different criteria, but in every case they're looking at tens of gigahertz, multiples of what Straight Path has to offer. The chart below illustrates the proposals graphically. (CITEL is the regional organization for telecom regulators in the Americas; CEPT, Europe; APT, the Asia-Pacific region; and RCC, Central Asia/Eurasia, including Russia.)

[11] October 22, 2015, FCC open meeting, ~88:43 ("There are many spectrum alternatives that we can pursue. We will pursue more of them after the WRC meeting, as has been indicated. … It [5G success] requires continued development of other spectrum, which is what we're going to do in the follow-on proceeding").

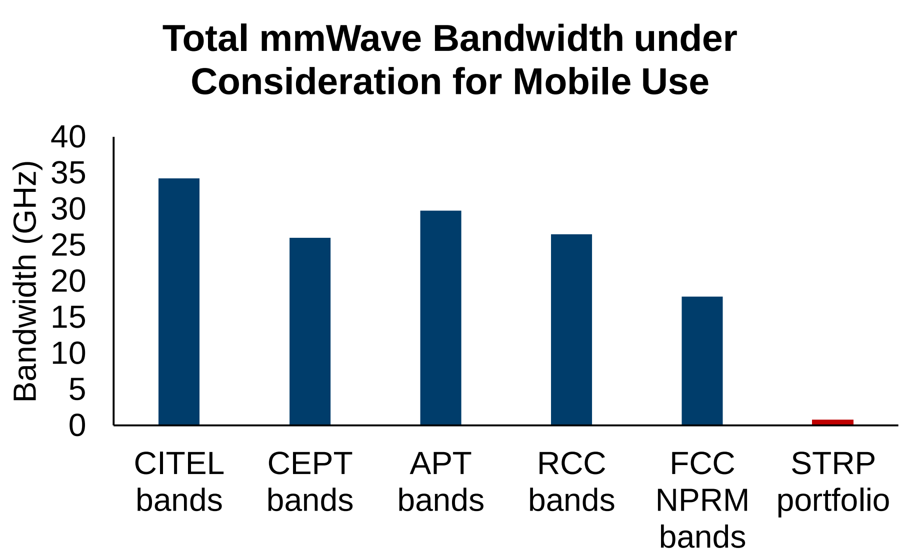
mmWave Bands Tentatively Proposed by Regional Regulatory Bodies



Source: DIGITALEUROPE summary of regional proposals, FCC NPRM, Kerrisdale analysis

By 2019, when the WRC-19 conference takes place, the hope is that, after studying many of these bands, regulators can reach consensus about which are the most plausible targets for 5G developments, taking into account not just technological constraints but also alternative spectrum uses, which vary from country to country. Nonetheless, a few important themes emerge from the work that's already been done:

1) Very large bandwidths are likely to be opened up for mobile services. The graph below summarizes the aggregate size of each regional group's proposed bands, juxtaposed with Straight Path's combined 39GHz and LMDS holdings (measured as a nationwide average). With ~30 GHz on the agenda everywhere, all of Straight Path's MHz-pops no longer look especially impressive.



Source: DIGITALEUROPE summary of regional proposals, FCC NPRM, Kerrisdale analysis

2) Straight Path's bands are not supported by a global consensus. Global harmonization is important in part because of cost: both device makers like Apple and equipment vendors

like Ericsson enjoy economies of scale when they can use the same components across the world, and carriers and consumers enjoy the benefits. Some of the proposed mmWave bands do enjoy global backing already, including (with some small variations from region to region) 31.8-33.4 GHz, ~45-50 GHz, and ~66-76 GHz. By contrast, Straight Path's most important band – 39GHz, which represents 85% of its MHz-pops – is fully included in just one proposal (CITEL's), only partially included in two (APT's and RCC's), and entirely absent from CEPT's. Similarly, one piece of the LMDS band, which is split into three non-contiguous pieces, is not in any region's proposal, while the other two are largely absent outside of CITEL. To be sure, Straight Path's bands could still be designated as global mmWave mobility bands in the future – just as bands missing from the FCC's initial NPRM could easily come into play in follow-up rulemakings – but the fact that many regulatory groups across the world simply don't view Straight Path's bands as compelling priorities gives the lie to the notion that they are somehow essential for 5G. On the contrary, they are at best just one minor piece of the puzzle.

While the exact details of the bands repurposed for mmWave mobility will remain undefined for years to come, it's already clear that regulators are explicitly trying to make this spectrum *abundant,* not scarce, and their initial proposals reflect that intention. With so much competing spectrum supply, Straight Path will have no bargaining power. Why bother negotiating with a rent-seeking incumbent in the 39GHz band when so many other similar bands will be available? Indeed, even in that band, Straight Path won't have a monopoly, since the FCC will likely seek to re-auction the many expired and unused licenses in markets across the country. And with a potential lack of global support, the 39GHz band will be even less attractive.

Furthermore, the raw number of gigahertz in the mmWave bands actually understates the true abundance of spectrum. Current research suggests that, even with complicated techniques like beamforming and adaptive antenna arrays, the practical range of mmWave signals will be on the order of 100 meters. While short ranges and narrow beams present major challenges, they also have a key benefit: the ability to reuse the same spectrum over and over again within a small physical area. In principle, two mmWave base stations operated by two different carriers could be fairly close together and run on the same exact channel without even "noticing" each other.

This state of affairs differs greatly from the lower-band status quo, in which nearby base stations on the same channel *would* greatly interfere with each other, making exclusive control over individual spectrum blocks in particular locations the most natural solution. AT&T and Verizon's networks would not work very well if the cell towers of each were trying to use, say, the 700MHz C Block simultaneously in the same town, especially because they radiate energy in every direction. By contrast, mmWave systems will need to direct energy in a more focused way within a small space, so there's no good reason why AT&T and Verizon couldn't use the same exact frequencies within a region as large as, say, a city, as long as the base stations weren't on top of each other. Such considerations are precisely why regulators are seriously considering making large swaths of mmWave spectrum either unlicensed, lightly licensed, or shared. The physical characteristics of mmWave systems greatly reduce the value of legally guaranteed, wide-area exclusivity and make less conventional models more practical. In the words of

Gerhard Fettweis, a German academic in the field of wireless communications who holds a Vodafone-sponsored professorship and heads 5G Lab Germany:

> Obviously, if we go to these frequencies we can also change the licensing game completely. … We can…go and have Vodafone and Telefónica using exactly the same frequency band. All they need is a certain spacing apart, little more than 10 meters…Then there's no reason why we cannot just have the same frequency band. So forget about frequency auctioning of "your spectrum only." You can then have really shared access. We only need somebody to manage to make sure that the base stations are far enough apart in space.

Multiple gigahertz-wide bands, each of which can likely host multiple operators within a given market (assuming some degree of coordination), are about as far away from spectrum scarcity as one can get, making exclusive control over any individual slice of spectrum – like Straight Path's – relatively unimportant. While carriers have traditionally shied away from unlicensed spectrum, the drumbeat of support for LTE-U and related technologies like LAA – which tie together licensed, low-frequency spectrum and the 5GHz unlicensed band to enhance downlink throughput – demonstrates that carriers are open to different approaches. One compelling option for mmWave 5G would be to tie together reliable baseline coverage in a low band with vast capacity in the unlicensed 60GHz band – currently 7 GHz wide and likely to expand to 14 GHz under the FCC's future rule. With so much bandwidth operating over such short distances, carriers could achieve extremely high throughput while suffering few ill effects from the unplanned interference than can be more problematic in unlicensed bands with better propagation. Straight Path insists that carriers will want the certainty of exclusive, licensed spectrum even in the exotic territory of mmWave, but this low-band logic just doesn't apply with the same force. Even if it did, carriers will likely have a very rich menu of licensed mmWave spectrum to choose from. If scarcity fosters high valuations at low frequencies, then radical abundance will generate *unprecedented cheapness* at high frequencies.

Finally, while the FCC's 5G preparations have focused on mmWave spectrum between 24 and roughly 71 GHz, some researchers also believe that even higher frequencies can work for mobile applications – potentially better than lower-frequency mmWave. For instance, the aforementioned Professor Fettweis has argued that we can harvest *hundreds* of gigahertz above 100 GHz, where propagation is not much worse than it is in the "lower mmWave" but antenna elements can be significantly smaller, enabling easier and more cost-effective miniaturization. Such research is far from commercialization, but it highlights an unfavorable dynamic for Straight Path: by the time mmWave technology is good enough to be economically viable, it's reasonable to expect that it will soon work at 120GHz as well as it works at 39GHz, further obliterating any suggestion of spectrum scarcity.

V. Large-Scale mmWave Networks May Never Be Commercially Viable

After reflecting on the week that I just spent at the Small Cell Forum, it's clear that the view on outdoor small cells really hasn't changed much. Everyone now has a bit of pilot and trial experience under their belt, and we're all still saying mass deployment is 12 months away, just as we have been saying for the past 3 years. However, during this time period no real outdoor volume deployments have occurred, and those few plans that had been announced have largely stalled and been delayed.

—Greg Friesen, DragonWave VP of product management, June 2015

[*W*]*hatever licensing regimes we adopt should take into account the fact that signals from carriers' outdoor base stations will rarely be able to penetrate into the interiors of buildings, where around 75 percent of cellular data usage occurs today.*

—FCC Notice of Inquiry, October 2014

Up through 4G, each generation of mobile technology has been able to balance subscriber growth against the shrinking of inter-site distances and, at the same time, provide increasing data rates to users both individually and in the aggregate. … However, it is not clear that deployments in higher frequency bands, especially those above 24 GHz, can provide the same advantages of capturing ever increasing numbers of users…

—Ericsson, January 2015

Even if mmWave 5G one day becomes widespread, Straight Path's spectrum will still have little value given the massive amount of competing spectrum and the relative ease of sharing the same channel among multiple operators. But it's also important to realize that, notwithstanding the current level of R&D aimed at rendering mmWave bands practically usable for mobile services, it's likely that, even if mmWave mobility is *feasible,* it still won't be economical and thus will never be widely deployed, making Straight Path's potential value negligible.

mmWave optimists have focused on overcoming the challenges of propagation, where the problem is that mmWave signals transmitted between a pair of standard antennas can only travel over very short distances. The usual workaround in backhaul applications, where each endpoint is fixed, is to use highly directional antennas manually aimed straight at each other. But this obviously doesn't work when at least one of the endpoints is small and mobile, like a smartphone. However, by using a sophisticated mixture of hardware and software, researchers have shown with early-stage demos, prototypes, and simulations that multi-antenna arrays can provide a similar degree of directivity. The devices used in these tests are very much not ready for prime time – in one, for instance, the smartphone proxy is a large, bulky trolley – but they serve as a proof of concept, showing that there's at least a chance that this approach could work in mass-market products.

But would it actually make economic sense? Even with complex engineering, mmWave cells are expected to have radii on the order of just 100 meters – dramatically smaller than for conventional cellular systems. Worse still, because usable mmWave signals require narrow beams and tend to reflect rather than diffract, any obstructions would be far more damaging than they would be for lower-frequency signals, calling for high levels of redundancy to mitigate against outages. As a result, mmWave systems demand enormously high cell densities. Base stations need to be packed very close together, and each one needs power, backhaul, computational resources, and permission to use a given physical location, all at the mercy of local stakeholders including, in particular, a patchwork of municipal governments and utility companies.

In other words, mmWave takes the laundry list of problems that have prevented *normal* small cells from ever living up to expectations and tacks on many more. Wireless industry observers have long predicted that cellular networks, which are today heavily reliant on traditional large ("macro") towers, will evolve toward a small-cell architecture, with compact radio equipment located on sites like lamp posts and utility poles, greatly enhancing capacity *while using normal low-band frequencies.* In 2012, AT&T even announced that it would deploy 40,000 small cells by the end of 2014. In reality, though, AT&T quietly gave up on that plan after deploying, according to industry experts, only a few thousand. Finding and getting rights to 40,000 usable locations at a low enough cost in a short enough time to justify the investment – especially relative to more conventional macro capex – proved to be impossible.

To be sure, the small-cell approach hasn't been abandoned, but few regard earlier projections of millions of cells across the country as realistic for the foreseeable future, and even Sprint's more recent plan to roll out tens of thousands of sites has been dubbed "very aggressive, even in a three-year period."[12] But while dense small-cell deployments *complement* macro sites to add capacity in conventional frequencies, they're non-negotiable *necessities* in mmWave, where macro-style wide-area propagation is impossible. If carriers can't make the math work to deploy large numbers of small cells using familiar bands with relatively good propagation, how can they possibly justify even larger numbers using exotic frequencies and complex, likely costly equipment (which doesn't even exist in commercial form today)? For mmWave to work, a small-cell architecture must already be in place – but once such an architecture is in place in lower bands, it will significantly improve network performance on its own, further calling into question any incremental ROI on adding mmWave on top.

But the cost associated with high cell densities is just one of the practical problems with mmWave. One of the best summaries comes from Ericsson, the world's largest telecom equipment vendor and hence a firm with about as much mobile-network expertise as anyone in the world. Ericsson's detailed comments on the FCC's mmWave Notice of Inquiry read like a horror story for mobile-operator CFOs:

[12] Source: Dave Jones, SVP of mobile infrastructure at Zayo Group, at the 2015 Tower & Small Cell Summit (~51:00).

[I]n the nearer term, the Commission should focus on spectrum above 10 GHz (rather than above 24 GHz) as today's evolving technology can more easily transition to these frequencies. The radio environment at higher frequencies is simply very different, and it gets more "different" as the frequency increases. …

A much denser site grid may be needed, limiting the economic benefits of deployment within areas that are capable of generating traffic. …

Propagation limitations will greatly limit non-line-of-sight ("NLOS") coverage, especially between indoor and outdoor locations and in rural and suburban areas…LOS coverage will be possible, but obstructions and vegetation will pose difficulties in reception. …

High directivity for mobile antenna systems will have to be achieved by arrays of many elements. This is by no means a trivial task, and current research and development efforts are just beginning. …

[T]he random orientation of handheld user equipment, limits on EIRP [i.e. power levels] in proximity to the human body, and blockage of the signal by parts of the human body require compensation at the base station's receive antenna. …

In outdoor environments, the system is unlikely to provide ubiquitous coverage—for example, it will be difficult to account for losses through vehicles…Even communications through a window may require higher power than an outdoor-to-outdoor link because of high attenuation through windows as well as wells. In addition, commercial buildings often have windows that are metallized, which will further attenuate signals. …

Handsets, to some degree, can overcome obstacles in their path by finding other signal paths to close the link; however, outage probabilities for high data rates will likely be significant, because buildings, foliage and atmospheric conditions can affect propagation characteristics with significant attenuation in comparison to bands below 3 GHz. …

There are fundamental physical differences that require completely different approaches rather than tweaks, such as the path loss, which is proportional to the square of the frequency. As a result, when the frequency is increased by a factor of ten or more, the design of the circuity and antennas is not simply scaled up or down a bit, as may be the case when there is a more moderate increase in frequency; the design needs to be fundamentally reexamined. …

NLOS outdoor to indoor coverage cannot be obtained in a satisfactory manner at frequency bands above 24 GHz. …

Obstructions can cause problems with coverage, for example down side streets, behind large trees, inside a car, or behind a large truck or bus. Nomadic obstructions such a

> parked truck will cause sporadic dropouts…[A] single building, some trees or a truck or bus obstructing the path might break the connection. …
>
> Coverage over and beyond a hill will likely not be possible. …

In sum, in addition to requiring a dense small-cell architecture that has not proven to be economically compelling using *conventional* cellular bands, mmWave networks will face severe difficulties achieving things that users today largely take for granted, like providing service irrespective of how they hold their phones, whether they're standing behind a hill, or whether there's a truck or bush nearby. Perhaps most fatally, while existing cellular systems almost entirely provide coverage to indoor users via outdoor cell towers, mmWave signals generally won't be able to penetrate walls or even common types of glass, narrowly circumscribing their usefulness or requiring costly building-by-building indoor deployments, a model that cannot scale to large areas. Beyond a small handful of high-density outdoor events like the recent papal visit in Philadelphia – which was well-served by conventional cellular and Wi-Fi systems – the vast majority of cellular data consumption occurs indoors. The entire rationale for traveling down the long, difficult path of fundamentally reexamining all aspects of radio engineering to enable mmWave mobile networks is to provide very high data rates – but those data rates will fizzle out and often drop to zero in precisely the places they're needed.

It's easy to dismiss these profound limitations by just asserting that R&D will address them somehow down the road. But while the basic outlines of how to compensate for weak mmWave propagation in free space are already known – use a lot of coordinated antenna elements – the failure of mmWave signals to penetrate most building materials is simply a physical fact, as is the likelihood that a user's head or fingers will disrupt narrow mmWave beams. There are no practical, ready-to-hand solutions to these problems, and they are so fundamental that it's difficult to imagine any. At the recent Texas Wireless Summit in mid-October, leading mmWave expert Robert W. Heath, Jr., a professor of electrical and computer engineering at the University of Texas at Austin, spoke frankly about these issues (starting at ~10:25):

> [T]hat main signal path…can be blocked by buildings. You know, you're in Manhattan? There's a lot of buildings around! … Boy, people can block the signal too, depending on which frequency you're operating at. We tend to either scatter or absorb a ton of mmWave frequency. It actually even depends on clothing – I mean, wearing a wool sweater is hugely different than a synthetic shirt. But anyways, basically people block the signal. So if you have, like, a low transmitter/receiver, people walking around: your signal's going to be blocked, like, all the time.
>
> By the way, we block the signal ourselves. I could be communicating with this base station right here, I turn my back to talk to someone over here – I just blocked my best propagation path. My SNR [signal-to-noise ratio] goes down 25 dB [decibels]. I get nothing now. So. We block our own signal. And then it goes to the extreme that in fact we can even block the antenna elements on our hand. Everyone remembers this Apple "antenna-gate," but this is a big issue at mmWave because, even though you have an

> array of antennas, that array is not very big. You could very easily just happen to cover it with your thumb. …
>
> So what can you do here? The Samsung approach…is to actually have two arrays, and that's a great idea. … Of course, if you turn that [device] landscape to watch a YouTube video, you just blocked both antennas. [*Audience laughter.*] So what are the other solutions here? The one I was thinking about recently is this…You could have a little, like, shock, or a buzzer or something, that tells the user, "Get your finger off the antenna!" [*Audience laughter.*] I mean, I don't know! But, in all seriousness, this is going to affect a lot of how we use the technology, because no more can we kind of use it everywhere – now we have to be mindful of where our fingers are, where the base station is. I mean, something silly like this – this could kill it. If the typical user…can't figure out how to get the iPad working, man, it's going to be dead.

What rational actor would have the appetite to spend enormous sums of money building out a large-scale mmWave network using completely new, untested technology to provide at best inconsistent and unreliable – and at worse nonexistent – service indoors, in suburbs, near trees, or in cities with too many or too few buildings? With such a daunting, operationally difficult, and expensive project, how much room would there be in the budget to pay for spectrum? To achieve any economic return, the underlying spectrum has to be trivial in cost, undercutting the purported value of Straight Path's licenses.

The bull case for Straight Path is built entirely on the success of mmWave 5G. But 5G is likely decades away from peak deployment and has no inherent need for mmWave, which in turn faces so many staggering economic and technological limitations that it may never come to fruition at all, like so many other hyped-up concepts in telecom. Even if mmWave 5G does succeed, there will be so much available spectrum that incumbents like Straight Path will have no bargaining power and little to offer.

VI. Valuation Precedents and Benchmarks Demonstrate that Straight Path Is Worth Very Little

The typical bull case for Straight Path takes the company's 256 billion MHz-pops – the sum of bandwidth times population for each market for which it holds a license – and applies some price per MHz-pop derived from cellular bands, less an arbitrary discount. The dream is that, although such high-frequency spectrum has typically traded for prices per MHz-pop that are several orders of magnitude lower than what carriers have paid for lower-band spectrum, that's just because mmWave bands weren't yet authorized for mobile use and didn't have the right technology. Now that regulators are moving toward favorable rules and researchers are developing new kinds of equipment, Straight Path bulls contend, mmWave spectrum prices will begin to converge with those of conventional bands.

By seeking to map the value of normal cellular bands onto Straight Path, bulls are applying a radically incorrect model, ignoring basic first principles. But before explaining why, it's worth reviewing just how inexpensive mmWave spectrum is. In 2008, for example, the United Kingdom auctioned off three GHz of spectrum in the 40.5-43.5GHz band – similar to Straight Path's 39GHz band, but with roughly twice the bandwidth. A firm called UK Broadband purchased rights to 2 GHz in this band for just £120,000. Not £120 million -- £120 *thousand.* Nor was this price an incredible bargain; by 2009, the firm, which had sought to use the spectrum for wireless broadband, had already given up on much of its plans.

Similarly, in 2012, as noted in the Company Overview section above, Level 3 Communications, the large telecom infrastructure firm, sold its portfolio of mmWave spectrum, inherited via an acquisition, to Spectrum Holdings Technologies, an entity controlled by the former head of IDT Spectrum, the unit that later became the core of Straight Path. These licenses account for almost a third of Straight Path's total holdings today. The price, revealed in legal documents filed as part of litigation between IDT and the former executive,[13] was just $203,000 for licenses covering, according to our license-by-license calculations, 32 billion MHz-pops in the 39GHz band and 14 billion in the LMDS band, for a total of 46 billion MHz-pops. The arithmetic is as simple as it is striking – $203,000 divided by 46 billion MHz-pops implies a price per MHz-pop of $0.000004. Obviously, applying such a low benchmark to Straight Path indicates that its portfolio is worth very little. To be precise, 256 billion MHz-pops x $0.000004 yields an aggregate value of just over $1 million. Even if this calculation were off by a factor of 10, Straight Path's stock would still have 98% downside.

Bulls will insist that such a comparison is unfair, even though it involves a relatively recent and relatively large transaction between knowledgeable parties. After all, that price likely only contemplated the niche use cases of fixed wireless broadband and wireless backhaul, not the much larger market for *mobile* broadband that regulators might ultimately open up for Straight Path. Spectrum for mobile broadband changes hands for prices measured in dollars per MHz-pop, not tiny fractions of a cent. Why shouldn't the same ultimately apply to Straight Path's spectrum?

The answer is that a band's frequency has a large impact on its cost of deployment, with the number of required infrastructure nodes rising exponentially with frequency. As a result, operators historically pay less for high-frequency spectrum than for low-frequency spectrum, because it's cheaper, less difficult, and less time-consuming to build out low-frequency networks. A recent real-world example of this effect comes from Canada. In March 2015, the Canadian operator Telus purchased spectrum in the AWS-3 band – centered roughly at 2 GHz – for ~$2/MHz-pop at auction. Very shortly thereafter, in May, the same company purchased spectrum in the 2.5GHz band – centered roughly at 2.6GHz – for just $0.36 per MHz-pop at auction. The frequency was only 30% higher, *yet the price was more than 80% lower.* What

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[13] See e.g. *IDT Corporation et al.* v. *Rapaport et al.,* Case 2:13-cv-00634, Document 1 (IDT complaint) p. 30 (reference to "the $203,000 [he] paid to Level 3").

would the price have been for mobile spectrum whose frequency was not 30% but *20 times* higher? Almost zero.

Even if we charitably assume that antenna arrays and beamforming can overcome the enormous challenges of mmWave propagation, it's clear that mmWave networks will need huge numbers of nodes even to cover small areas with the multi-Gbps throughputs expected of 5G. One of the most useful analyses in this regard comes from Nokia's comments on the FCC's NOI, which include, in Table 2, estimates (derived from a simulation) of the relationship between radio node density per unit area, average user throughput, cell-edge throughput, and outage probability, factoring in the presence or absence of *foliage,* which has a large impact of system performance. With foliage, achieving a high cell-edge throughput and a low probability of service interruption – consistent with the widely discussed 5G design principle of creating a more consistent and uniform user experience – would require approximately 187 radio nodes per square kilometer. By contrast, based on CTIA data, the US has 298,055 cell sites covering an area of 9.8 million square kilometers, for a density of just 0.03 nodes per square kilometer. In other words, mmWave could require a network *more than 6,000x denser* (187 / 0.03 = 6,233) than existing cellular networks. If we assume a benchmark valuation of $1/MHz-pop for non-standard cellular spectrum at ~2GHz – in line with what Verizon has reportedly been willing to pay – then we estimate that a best-case valuation of Straight Path's portfolio, at a much higher frequency and requiring a much more dense network, not to mention a fundamental rethinking of many aspects of mobile technology, would be only a few tens of millions of dollars *in the future* – more than 90% lower than where it trades today.

Illustrative Valuation of Straight Path's Spectrum Based on Cellular Benchmarks	
STRP MHz-pops (B)	255.7
Assumed price per MHz-pop @ 2 GHz	$ 1.00
Network density adjustment factor	6,233.3
Adjusted price per MHz-pop @ 39 GHz	$ 0.00016
STRP illustrative valuation ($mm)	$ 41.0
Equity downside	***-93%***

Source: company filings, Kerrisdale analysis

Of course, this valuation only factors in the decreased utility of any similarly high-frequency band relative to conventional cellular bands. It makes no adjustment for the availability of large swaths of competing spectrum, much of it unlicensed, or the incremental cost of using exotic hardware and software to cope with the challenges of mmWave. Nor does it adjust for the impracticality of covering indoor locations via outdoor cell sites – the standard model for almost all existing network deployments – which would imply a *dramatically higher* node density than that assumed above, given that the 187 nodes/sq. km. figure was based on a simulated *outdoor* network. Thus we regard this valuation as highly generous on multiple fronts – even if we ignore the high probability that Straight Path's spectrum will simply never be used for mobile service at all.

We also neglect an important Straight Path–specific issue: its lack of large blocks of *contiguous* spectrum. Many industry participants have highlighted the importance of contiguous spectrum in mmWave bands, since, again, the only rationale for engaging in the necessary R&D is to obtain large bandwidths of many hundreds of megahertz; some even call for gigahertz-wide channels, as already exist in the 60GHz band. While Straight Path's holdings in its favored 39GHz band do add up to hundreds of megahertz in total, the band plan consists of paired 50MHz units separated by 700 MHz from each other. While the details vary from market to market, Straight Path generally does *not* have rights to large, contiguous blocks. Instead, it has scattered bits and pieces, often separated by channels formerly owned by companies that are now defunct.

The table below provides a summary of the top 30 markets, ranked by population. While Samsung has called for at least 500 MHz of contiguous mmWave bandwidth to achieve targeted 5G performance, and the regional telecom regulatory body in the Americas, CITEL, has noted that "[c]ontiguous wide system bandwidth (approximately 500 MHz to 1 GHz or more) will be considered as a critical factor for efficient delivery of ultra-high end user bit rates," Straight Path has, on average, less than 200 MHz of contiguous bandwidth in the largest markets.

Straight Path 39GHz Portfolio: Maximum Contiguous Bandwidth by Market

Pop. rank	Market	39GHz bandwidth Total	39GHz bandwidth Max. contiguous
1	NYC-Long Is. NY-NJ-CT-PA-MA-VT	800	150
2	LA-Riverside-Orange Cnty CA-AZ	800	150
3	Chicago-Gary-Kenosha IL-IN-WI	1,000	200
4	San Fran.-Oakland-San Jose CA	600	100
5	Wash.-Balt. DC-MD-VA-WV-PA	1,000	200
6	Dallas-Fort Worth TX-AR-OK	900	250
7	Boston-Worcester MA-NH-RI-VT	800	200
8	Phil.-Atl. City PA-NJ-DE-MD	700	150
9	Houston-Galveston-Brazoria TX	900	200
10	Detroit-Ann Arbor-Flint MI	800	150
11	Atlanta GA-AL-NC	800	150
12	Miami-Fort Lauderdale FL	1,000	300
13	Minneapolis-St. Paul MN-WI-IA	1,000	200
14	Seattle-Tacoma-Bremerton WA	900	350
15	Denver-Boulder CO-KS-NE	900	250
16	Cleveland-Akron OH-PA	800	150
17	Orlando FL	700	200
18	Phoenix-Mesa AZ-NM	900	200
19	Puerto Rico-US Virgin Islands	700	200
20	St. Louis MO-IL	1,100	300
21	Indianapolis IN-IL	900	350
22	Portland-Salem OR-WA	900	150
23	San Diego CA	800	150
24	Pittsburgh PA-WV	700	200
25	Nashville TN-KY	600	250
26	Tampa-St. Petersburg FL	1,000	200
27	Sacramento-Yolo CA	500	100
28	Kansas City MO-KS	800	150
29	San Antonio TX	900	150
30	Columbus OH	800	150

Source: FCC Universal Licensing System, Kerrisdale analysis

Although few equity-market participants have noticed that Straight Path's lack of large, contiguous bandwidth could render it useless for 5G mobile service, *Straight Path* has certainly noticed. As a result, it's hoping to convince the FCC to let it engage in a reshuffling of the licenses in each market in order to make its holdings more contiguous. It's far too early to know whether the FCC will prove amenable to this request for special treatment – effectively a subsidy for a legacy license holder whose aspirational business model is to hoard unused spectrum in hopes of cornering the market. But the risk is asymmetrically negative for Straight Path. If it *does* get permission to reshuffle its licenses and assemble as much contiguous bandwidth as it can, it still faces all the other problems we've examined, from the enormous supply of other mmWave spectrum to the great practical difficulties of building an effective mmWave network to the simple fact that operators are nowhere near considering major 5G build-outs, let alone anything as exotic as mmWave 5G. But if Straight Path does *not* get special favors from the FCC, then its hopes of being the poster child for mmWave 5G are simply doomed from the start; its contiguous bandwidth is wholly inadequate. Straight Path will certainly be very busy lobbying for years to come.

VII. Conclusion

The notion that a company as silly as Straight Path – a 7-person patent troll *cum* spectrum play, with the former role having already run its course and the latter premised on an exotic frequency band that has driven almost everyone who ever touched it into bankruptcy or failure – is worth almost $600 million defies common sense. Investors have been swept up in 5G hype that is, in reality, a mixture of marketing fluff and regulatory lobbying, much of which has nothing to do with mmWave bands at all. In all the excitement, they have overlooked the utter lack of mmWave spectrum scarcity, the enormous barriers to cost-effective mmWave networks (going beyond merely weak propagation and extending to issues as fundamental as being able to access indoor locations from outdoor cell sites), and the entire concept that network operators are not going to completely overhaul the status quo at enormous cost unless that strategy presents a compelling return on investment. Looking at prices per MHz-pop as if all frequencies behaved the same way violates economic logic. To repeat Ericsson's basic point, "The radio environment at higher frequencies is simply very different," and with orders-of-magnitude differences in basic network parameters, like cell density, there will naturally be orders-of-magnitude differences in spectrum prices.

At an even more fundamental level, supply and demand govern the price of spectrum as surely as they govern the price of any commodity. With low demand, given the great difficulties of practical mmWave deployments, and extremely high supply, given all the spectrum that will be available in the next several years and beyond, mmWave spectrum will never fetch a high price. Straight Path's valuation is irrational and unsustainable.

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