Networking and Telecom Equipment

Whitebox routing – a transformative disruption, not just a technical evolution

Primer

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Helping carriers to solve their business model issues

We believe the routing market is due for an investment cycle after years of declines, yet we also see a major disruptive technology looming—whitebox routing. Routers make the Internet backbone, with demand driven by 30% annual average growth in data traffic. The COVID-19 pandemic only added fuel to the fire with an additional unprecedented 30-50% traffic growth reported by Telefonica, Orange, Vodafone, Verizon and others, driving Netflix to cut the streaming bit rates (picture quality) to reduce network congestion. The need for routing will only increase over time with new content generated by Media companies, migration to 8k streaming, and the proliferation of video chat/conferencing. However, given flat revenues, Carriers are constantly looking for cheaper alternatives, and this report delves into a looming evolution in the routing market – disaggregated (whitebox) routers. The trend is so disruptive, in our view, that it could potentially change the market in a way that VMware's hypervisor disrupted the server ecosystem. We consider the drivers, the addressable applications, the traditional players' vulnerabilities, and the responses already seen from Cisco and others.

Better scalability, lower costs and greater controls

The whitebox routing transformation mirrors the hypercloud transition from traditional blade servers to generic whitebox servers. Similarly, networking merchant silicon, such as the Broadcom Jericho 2, enables building cost-effective, small standardized routing units, called "pizza boxes," because of their size and shape, that can be added and stacked over time, offering a new type of router - a distributed one. The result is a cost-effective, scalable solution that is simpler to operate, offers lower power consumption, and makes the traditional router chassis a thing of the past. AT&T calls it a Distributed Disaggregated Chassis (DDC), and we see applications at all levels, including Core, Aggregation, Edge, and Access routing.

A few startups leading the pack; yet Cisco joined the race

A few startups have identified the opportunity and developed solutions. At the core, these private companies develop software that runs on generic whiteboxes powered by Broadcom's chip. DriveNets, for example, is unique in its ability to stack a number of whiteboxes into a cluster that acts as a single router, ranging from a single box up to a very large router based on 200 whiteboxes. This eliminates the need for multiple router sizes and models and has the immediate advantage of cost reduction, increased visibility, and control down to the container level. Other private companies like Arrcus, Volta Networks, and RtBrick also offer cloud-native routing software, targeting lower scale routing typically found in Enterprises, Data Centers, or SP Access networks.

The market and implications for Cisco, Juniper, Nokia

Service Provider Routing is a ~$12bn market that accounts for approximately 10% of Cisco's revenues. Cisco recently announced a new line of products addressing this market evolution, offering semiconductors, dubbed Cisco Silicon One; a software only solution, IOS XR7; and a new family of routers, Cisco 8000. We crudely estimate that $5bn of the market is at risk and believe that of the traditional vendors, Cisco is leading the pack in addressing the risk, followed by Nokia. We believe Juniper remains far behind.

Refer to important disclosures on page 17 to 18.

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What's wrong with routing?

Routers are high-end expensive machines. For years, the high-end nature was fueled by Carriers' desire to consolidate all types of services into a single platform for enterprise, wireless, and broadband traffic, and the routers had to deliver a long list of business services like VPN, aggregation, peering and more. However, three factors have pressured the market in the last few years, driving what we think is a long-term secular decline of the routing market. First, the rate of innovation of routers is exceeding the growth in demand, pressuring port pricing by about 20-25% per year. In simple terms, router capacity and port sizes are increasing much faster than demand is growing, resulting in a rapid decline in port cost per bit. Second, customers are looking to replace expensive services, such as MPLS, that are enabled by routers with cheaper alternative solutions. For example, SD-WAN connects branch offices via a cheap $100/month broadband connection, while a dedicated MPLS line offered through a router would cost $1,700/month. Third, there is a new customer - the hypercloud customer - which introduced different needs and different network architectures. Cloud customers do not have a need for wireless or business services support and instead need simpler routers that only support basic connectivity functions at large scale.

These trends had a long-lasting impact on the market, driving demand and pricing down for the past few years. For comparison, total routing revenues grew at a 1.6% CAGR from 2010-2019, with core routing growing at a 2.0% CAGR and edge routing growing at a 1.5% CAGR versus the number of ports growing at a 7.1% CAGR over the same period. If we exclude China from the analysis, total routing revenues declined on average 0.6% from 2010-2019, with core routing declining at a 1.4% CAGR and edge routing declining at a 0.3% CAGR versus ports growing at a 6.0% CAGR over the same period.

Table 1: Total Service Provider Routing Market

Total	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY10-FY19 CAGR
Core Routing	$2,839	$2,975	$2,669	$2,756	$2,629	$2,850	$3,289	$3,471	$3,564	$3,385	2.0%
YoY		4.8%	-10.3%	3.3%	-4.6%	8.4%	15.4%	5.5%	2.7%	-5.0%	
Edge Routing	$8,166	$9,125	$9,206	$9,579	$9,993	$9,896	$9,638	$9,700	$9,206	$9,314	1.5%
YoY		11.7%	0.9%	4.1%	4.3%	-1.0%	-2.6%	0.6%	-5.1%	1.2%	
Total Routing	$11,005	$12,100	$11,874	$12,335	$12,622	$12,746	$12,927	$13,171	$12,770	$12,698	1.6%
YoY		10.0%	-1.9%	3.9%	2.3%	1.0%	1.4%	1.9%	-3.0%	-0.6%	

Source: IHS, BofA Global Research estimates

Table 2: Total Service Provider Routing Market ex-China

	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY10-FY19 CAGR
Core Routing	$2,388	$2,512	$2,258	$2,285	$2,121	$2,358	$2,537	$2,309	$2,223	$2,112	-1.4%
YoY		5.2%	-10.1%	1.2%	-7.2%	11.2%	7.6%	-9.0%	-3.7%	-5.0%	
Edge Routing	$7,070	$7,893	$7,703	$7,805	$7,900	$8,202	$7,712	$7,363	$6,817	$6,880	-0.3%
YoY		11.6%	-2.4%	1.3%	1.2%	3.8%	-6.0%	-4.5%	-7.4%	0.9%	
Total Routing	$9,458	$10,406	$9,961	$10,091	$10,021	$10,560	$10,249	$9,672	$9,040	$8,992	-0.6%
YoY		10.0%	-4.3%	1.3%	-0.7%	5.4%	-2.9%	-5.6%	-6.5%	-0.5%	

Source: IHS, BofA Global Research estimates

Whitebox routers disaggregate software and hardware

The next chapter for the routing market is the disaggregation of standard-based software over commodity hardware, commonly dubbed as "whitebox" routers. We start, first, by explaining the notion of disaggregation. Routers perform two functions: First, they forward incoming packets to the right direction/destination. For example, routers aggregate together all the packets from NYC that are going to Google.com and forward them to Google's servers. Second, routers provide services. The most basic service is related to connectivity. For example the BGP protocol for routing connects multiple routers together and provides the ability to find the lowest cost connection from point to point, or deals with restoration of connectivity in case of disruption.

Routers support many networking protocols and services, which are needed for different router functions that are typically based on their location in the network. For example, Core routers will support connectivity protocols such as RSVP or IS-IS at high scale, while Edge routers need to support additional protocols such as BGP, security, and others. In addition to networking protocols, due to their location and role in the network, routers are like Swiss army knives that provide many services to many types of customers/deployments. One of the most important features of routers is the ability for carriers to launch revenue-generating services. For example, network routers are connected to all buildings and all locations, and the software is therefore capable of connecting any two points with an MPLS service (type of connection) to provide additional add-on services like prioritization of certain types traffic over another (Quality of Service- QoS) or security capabilities. Carriers in return lease these MPLS lines to customers for an average cost of $1,700 per month, enabling them to connect branches to data centers over a secure and managed link. Another notable service is a virtual private network (VPN) which creates an encrypted tunnel within the network of routers between two points for a secured point to point connection. Routers, therefore, are services machines, with the embedded software that supports all types of connectivity protocols and enables many types of value-added services.

Disaggregation is the ability to separate the software services from the hardware and enable Carriers to purchase these two parts separately as long as they are compatible with each other. Unlike traditional routers that offer different router sizes and functionality for different locations in the network, this new model enables Carriers to purchase one type of hardware, whiteboxes, for all locations while buying different software elements based on location service needs. Traditional routers are monolithic chassis-based solutions - software and hardware are interdependent and are provided from the same vendor therefore creating a vendor-lock situation. In the disaggregated model, the hardware whiteboxes are based on standard designs and can be sourced from multiple vendors at cost+ pricing. The software can also be sourced from multiple vendors as long as it supports the standard hardware design.

This is where cloud-native software and containers come into play. Various routing protocols and value-added services run in separate containers and are deployed based on need. Multiple service containers can run simultaneously on the same hardware, and therefore multiple network instances and value-added services share a single hardware instance. This model maximizes resource utilization using virtualization. Hardware resources are shared and are fully utilized with any service supported on any port. This level of virtualization efficiency is the basis of the hypercloud architecture and is not supported on traditional routers, only on disaggregated ones. This is why routing disaggregation is defined as "building networks like hyperclouds."

Whiteboxing is not a new concept

Disaggregation of software and hardware is not a new concept. The trend started with hypercloud providers who transitioned from blade servers to whitebox-based servers to lower their data center costs. These big whitebox-based architectures demonstrated that software and hardware could be disaggregated and support very high scale and high availability at a much lower cost.

Cisco, Juniper, and Alcatel have been promoting the concept of disaggregated hardware and software with NFV (Network Function Virtualization) for years. Cisco proudly discussed an architecture of standalone software and services that could be installed on commodity servers and connected to routing hardware that adheres to a certain NVP protocol accepted by the carriers; however, they never discussed the disaggregation of the routing software, itself, from the routing hardware. This new concept is only available with the modern disaggregated routing solutions. To understand the difference between NFV and whiteboxing, we need to take a short trip back in time.

Historically, Carriers' networks had limited ability to mix and match routing vendors due to the proprietary nature of routing software. A Juniper router was able to send packets to a Cisco router, but the Juniper router was not able to pass along the service request to the Cisco router. As a result, Carriers would buy all routers for a certain type of service from the same vendor: all broadband aggregation routers from Nokia (Alcatel), all wireless aggregation routers from Juniper or Cisco, etc. This inflated the price of routers, as the equipment vendors charged a hefty premium for their proprietary solution. Therefore, many Carriers employed the dual-vendor approach for any routing functionality to avoid vendor lock-in. Carriers also pushed for the first wave of standardization with the disaggregation of software and hardware using routers from the leading players, but stripping out the services software, dubbed VNF's (virtual network functions). This first wave of standardization enabled the carriers to mix and match hardware from Cisco, Juniper, Nokia and others, while the services were deployed centrally across all routers from all vendors. This architecture is dubbed Network Function Virtualization or NFV. To put things in perspective, all contracts for routers globally require the need to support NFV, and US carriers like AT&T and Verizon are religious about the migration of the network to NFV based approach.

However, NFV merely changes the way the products are being charged for, as the same components are being purchased from the same vendors with the exception that the ability to mix and match hardware somewhat increases competition. NFV was also expensive, as it utilizes an x86 architecture and requires expensive high-end servers that carry 8-12 cores, for example, resulting in $15,000-20,000 cost per server. As a result, NFV didn't solve the hardware cost issue and didn't solve the basic requirement of hypercloud customers to have basic routers that only support relevant protocols.

Unlike NFV solutions, whiteboxing scales cost-effectively

Whitebox routing is simply the next step in the router's evolution. It brings the value of NFV in a simpler, more scalable way to both high-scale routing as well as traditional services that were deployed in the old NFV way. The disaggregation of hardware from software is done in two levels; first, the routing operating system software runs on standard networking whiteboxes, which represent the router's data plane. And second, the networking and other services run on standard server whiteboxes, which represent the router's control plane. This separation of the control plane and data plane and the scaling of both over standard whiteboxes - server and networking - reduces the cost and increases scalability and control. These disaggregated solutions substitute specialized, expensive hardware with commercial off-the-shelf whiteboxes designed for either networking or NFV, cutting the costs substantially, simplifying the deployment and scale, and giving more control to network operators by leveraging centralized management software and network analytics.

We believe that the rise of disaggregated solutions will take several years, as Service Providers must get comfortable with the new technology and the start-ups that are enabling the technology. The ramp of disaggregated solutions will likely be on a case by case basis and may be accelerated in the post COVID-19 pandemic, first addressing use cases where Service Providers are faced with substantial growth in traffic and service quality needs. For example, in Edge routing, we believe disaggregated routing solutions will be utilized for cell site routers and BNG (Broadband) routers where network operators want more advanced controls, such as subscriber management, authentication,

authorization, and accounting, quality of service, etc. The core of the network, where traffic growth necessitates high speed routing capabilities, is another area where we see disaggregated solutions playing a key role given the superior scaling capabilities.

A key factor that will impact the adoption of disaggregation is the availability of the software and the variety of services. Since whiteboxes can support any networking capability, the more software services deployed over the shared whitebox infrastructure in an SDN fashion, the lower the cost per service and the higher the service profitability. Once service providers deploy Edge, Core, and other routing services over the shared whitebox infrastructure, the greater their incentive is to deploy additional services to further lower their cost. This dynamic will accelerate the adoption of disaggregation.

Our expectation of a slow and steady ramp limits the near-term impact to incumbent networking vendors like Cisco, Juniper, and Arista, and some of the incumbent vendors, like Cisco, have already addressed this new market development (we discuss this in detail in our report). However, longer term, the disaggregation trend has major implications on pricing as well market share dynamics, as companies that are more focused on Access aggregation, like Alcatel, will likely have more exposure than the other routing vendors. In the sections below, we discuss the initiatives of Cisco, Juniper and Nokia, but zoom in on one of the leading startups, DriveNets, that brings innovation and disruption to this market. However, before we delve into vendor specific discussion, we provide an overview of the routing market and the trends in the various sub-markets.

The journey of hypercloud to whiteboxing

We expect hypercloud customers to follow suit and adopt whitebox routing over time. The concept of hardware/software disaggregation is not new for their networks, and Google and Amazon have already followed such architecture inside their data centers, developing their own switching software and building it upon generic Broadcom based switches. We note, however, that not all hypercloud customers are similar. So far, Facebook and Microsoft opted for branded solutions for their switches from Arista, Cisco, and others, yet their innovation and recent announcements all suggest that they will gradually migrate to whitebox switches and routers over time. Second tier cloud vendors, like eBay.com, Netflix, and others, do not have the scale and R&D to participate in the early phases of the market, yet we could see them getting involved later in the cycle when the software matures and is perfected by the larger players. As such, we see different strategies adopted by the vendors for the hypercloud vertical. Cisco started offering its routing semiconductor as a standalone product, addressing mostly hypercloud customers who will develop their own software on top of merchant silicon. DriveNets addresses this market with its standard routing software, and Juniper is working on routing solutions specially developed for the hypercloud market, but the company has not fully disclosed its strategy yet.

The TAM: sizing the opportunity for whitebox providers

Before we define the market, we explain the difference between switches and routers, as whitebox routers will also address parts of the switching market, dubbed Carrier Ethernet switches. In general, and with great caveats on the completeness of the following statement, switches connect computers within a building, while routers connect the buildings. Switches are simple, cheap, have limited software features, and lack depth of service offerings, while routers are the mirror image of these statements. Switches use the simple Ethernet protocol to connect, while routers use the sophisticated IP protocol. In general, and on a like to like basis, switches are half the price of routers, although they have a more limited feature set and capabilities. Sometimes, however, specific applications do not need a fully featured router. For example, a connection between two buildings with deep encryption and guaranteed latency (delay) would typically dictate a router, while a simple aggregation of wireless base station traffic can be done with simple switches, as the needed level of service, beyond simple aggregation, is quite low.

As such, Carriers have dictated that certain types of products will utilize Ethernet protocol and not IP, which enables them to connect these with switches, dubbed Carrier Ethernet switches, instead of routers. Ciena, for example, launched a Carrier Ethernet switch that is mostly addressing the US wireless market. Interestingly, Carriers in Europe do not follow the same strategy and opted for IP protocol for the aggregation of wireless base station traffic, hence the use of routers instead of switches. As a result, Ciena announced recently the introduction of its 5100 router that addresses mainly the wireless aggregation market in Europe. Whitebox routers can address both of these applications and can replace both full featured routers and Carrier Ethernet switches for certain applications. We note that we expect whitebox routers to first address mass volume, simple solutions mainly at the edge of the network, replacing Access routers and Carrier Ethernet switches for Edge applications.

Sizing the opportunity

The Service Provider Routing market is a $12.7bn market dominated by Cisco, Huawei, ZTE, Nokia, and Juniper, and the Carrier Ethernet Switching market is a $2.2bn market dominated by Cisco, Huawei, ZTE, and Ciena. We note that all whitebox vendors exclusively focus on the software portion of the market and also generally only focus on Service Providers, as discussed above. In addition, we do not see any vendor selling in China, given the dominant position of Huawei and ZTE. For the purpose of addressable markets, we therefore remove these portions from the market size, reaching an estimated total addressable market of $5.9bn, between software for Service Provider Routing and for Carrier Ethernet Switches.

Service Provider Routing market

In CY19, the total Service Provider Routing market was $12.7bn, down 0.6% YoY per IHS Markit data. China makes up $3.7bn or ~30% of the total market with Huawei and ZTE capturing ~85% of this market. The Chinese growth has differed significantly from the rest of the world, growing 30.7% and 6.6% YoY in CY17 and CY18, respectively, versus the total market ex-China declining 5.6% and 6.5% YoY, respectively, though the Chinese market was roughly flat in CY19 in-line with the total market ex-China.

The differing growth profiles are in large part due to a strong infrastructure investment cycle in China in 2017. We exclude China from our analysis largely because the China market is +80% served by local players, but we note that the trends in China may suggest that any 5G investment cycle in US may help the routing market growth rates to recover. We also estimate that cloud hyperscalers account for roughly 10%, and we exclude this portion from our analysis as hyperscalers like Amazon have opted to create their own whitebox solutions thus far. We also assume that whitebox software solutions are about 40% cheaper than branded routing (hardware and software integrated) solutions. We therefore crudely estimate the size of the Service Provider Routing market ex-China, ex-hyperscaler, and ex-hardware at ~$4.85bn of revenues per annum.

Table 3: Total Service Provider Routing market (IP Core + IP Edge)

	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Total revenue (mn's)	$11,005	$12,100	$11,874	$12,335	$12,622	$12,746	$12,927	$13,171	$12,770	$12,698
YoY		10.0%	-1.9%	3.9%	2.3%	1.0%	1.4%	1.9%	-3.0%	-0.6%
Total ports (mn's)	4.35	5.42	5.67	5.93	6.79	7.07	8.31	8.32	8.22	8.08
YoY		24.6%	4.7%	4.6%	14.5%	4.0%	17.7%	0.1%	-1.2%	-1.6%
ASPs	$2,531	$2,234	$2,094	$2,079	$1,858	$1,804	$1,555	$1,583	$1,554	$1,571
YoY		-11.8%	-6.3%	-0.7%	-10.7%	-2.9%	-13.8%	1.8%	-1.8%	1.1%
REVENUE MARKET SHARE										
Cisco	39.5%	37.3%	37.5%	35.4%	35.2%	34.3%	31.0%	29.7%	29.4%	27.4%
Huawei	13.3%	14.5%	16.9%	19.6%	20.0%	19.9%	24.0%	26.9%	30.0%	31.0%
ZTE	1.5%	1.9%	1.7%	2.1%	3.1%	3.9%	3.8%	6.6%	6.2%	7.4%
Nokia/ALU	15.4%	16.2%	16.8%	17.1%	18.1%	17.1%	17.2%	16.3%	17.2%	19.1%
Juniper	19.4%	18.9%	17.1%	18.8%	17.6%	18.5%	18.2%	16.6%	14.4%	12.8%
Other	10.8%	11.3%	10.0%	7.1%	5.9%	6.3%	5.7%	4.0%	2.8%	2.3%

Source: IHS, BofA Global Research estimates

Table 4: Total Service Provider Routing market ex-China

	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Total revenue (mn's)	$9,458	$10,406	$9,961	$10,091	$10,021	$10,560	$10,249	$9,672	$9,040	$8,992
YoY		10.0%	-4.3%	1.3%	-0.7%	5.4%	-2.9%	-5.6%	-6.5%	-0.5%
Total ports (mn's)	3.64	4.63	4.68	4.76	5.21	5.75	6.75	6.41	6.25	6.14
YoY		27.1%	1.2%	1.6%	9.3%	10.5%	17.3%	-5.1%	-2.4%	-1.7%
ASPs	$2,598	$2,248	$2,127	$2,120	$1,925	$1,835	$1,519	$1,510	$1,446	$1,463
YoY		-13.4%	-5.4%	-0.3%	-9.2%	-4.7%	-17.2%	-0.6%	-4.3%	1.2%
REVENUE MARKET SHARE										
Cisco	41.3%	38.9%	40.3%	39.7%	40.9%	39.7%	37.7%	38.8%	40.0%	37.5%
Huawei	8.3%	10.5%	10.9%	11.4%	8.4%	10.4%	11.6%	11.5%	13.4%	15.3%
ZTE	0.8%	1.0%	0.7%	1.0%	1.5%	2.0%	1.7%	2.9%	1.6%	2.3%
Nokia/ALU	16.9%	17.7%	18.4%	19.0%	21.7%	20.1%	21.0%	21.1%	22.7%	25.3%
Juniper	21.1%	20.6%	19.3%	21.8%	21.2%	21.4%	22.0%	21.5%	19.6%	17.9%
Other	11.4%	11.3%	10.4%	7.1%	6.3%	6.3%	5.9%	4.1%	2.7%	1.8%

Source: IHS, BofA Global Research estimates

We estimate the Core Service Provider Routing market ex-China to be roughly $2.1bn using IHS data (see Table 5), with 10% of the market, or $211mn, dedicated to Data Center Interconnect solutions sold to cloud providers. We then apply a 40% discount to reflect lower pricing for software vs. fully fledged router, bringing the addressable market to $1.14bn. The Core Routing market represents ~25% of the total market with growth driven by network traffic increases. The need for increased network capacity and 400G upgrades will likely catalyze a Core Routing investment cycle, though this cycle will likely not begin until late 2020 timeframe and will not meaningfully impact the market until 2021 and we expect the net result to be low-single-digit growth through CY23. Current demand for routers due to COVID-19 changes could drive higher growth in the intermediate term, and some market players believe the growth could be as high as double digits through 2023.

Table 5: Core Routing market ex-China

	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Total revenue (mn's)	$2,388	$2,512	$2,258	$2,285	$2,121	$2,358	$2,537	$2,309	$2,223	$2,112
YoY		5.2%	-10.1%	1.2%	-7.2%	11.2%	7.6%	-9.0%	-3.7%	-5.0%
Total ports (mn's)	0.33	0.39	0.36	0.38	0.40	0.38	0.52	0.45	0.45	0.41
YoY		17.9%	-7.1%	3.7%	7.0%	-6.5%	37.3%	-12.6%	-1.4%	-7.0%
ASPs	$7,203	$6,426	$6,214	$6,064	$5,259	$6,254	$4,903	$5,107	$4,985	$5,095
YoY		-10.8%	-3.3%	-2.4%	-13.3%	18.9%	-21.6%	4.2%	-2.4%	2.2%
REVENUE MARKET SHARE										
Cisco	58.6%	58.1%	59.8%	57.6%	59.9%	56.5%	49.8%	46.2%	44.1%	45.0%
Huawei	4.5%	3.8%	4.7%	4.8%	3.3%	4.0%	9.1%	11.9%	13.3%	16.3%
ZTE	0.4%	0.6%	0.4%	0.4%	0.7%	1.8%	1.1%	2.6%	1.6%	1.9%
Nokia/ALU	0.7%	1.0%	0.7%	3.1%	4.4%	8.1%	7.7%	7.0%	7.6%	8.8%
Juniper	31.2%	28.9%	26.6%	28.7%	29.6%	28.4%	31.7%	31.9%	33.0%	27.5%
Other	4.6%	7.6%	7.7%	5.4%	2.1%	1.1%	0.6%	0.5%	0.5%	0.4%

Source: IHS, BofA Global Research estimates

The Edge Routing market ex-China is roughly $6.9bn, with about 10% of the market dedicated to Data Center Interconnect solutions sold to cloud providers. Excluding this portion of the market, we estimate the Edge Routing market to be roughly $6.2bn, with $3.72bn addressable by whitebox software solutions. Edge router growth is driven by Edge services like wireless and broadband aggregation, business services, etc. We expect this market to remain stable with NFV, SD-WAN, and other initiatives shifting the demand to alternative technologies.

Table 6: Edge Routing market ex-China

	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Total revenue (mn's)	$7,070	$7,893	$7,703	$7,805	$7,900	$8,202	$7,712	$7,363	$6,817	$6,880
YoY		11.6%	-2.4%	1.3%	1.2%	3.8%	-6.0%	-4.5%	-7.4%	0.9%
Total ports (mn's)	3.31	4.24	4.32	4.38	4.80	5.38	6.23	5.95	5.81	5.73
YoY		28.0%	2.0%	1.5%	9.6%	12.0%	15.9%	-4.5%	-2.4%	-1.3%
ASPs	$2,136	$1,863	$1,783	$1,780	$1,645	$1,525	$1,238	$1,237	$1,174	$1,201
YoY		-12.8%	-4.3%	-0.1%	-7.6%	-7.3%	-18.8%	-0.1%	-5.1%	2.3%
REVENUE MARKET SHARE										
Cisco	35.5%	32.9%	34.6%	34.5%	35.8%	34.9%	33.8%	36.5%	38.7%	35.2%
Huawei	9.6%	12.6%	12.8%	13.3%	9.8%	12.2%	12.5%	11.4%	13.4%	15.0%
ZTE	1.0%	1.1%	0.8%	1.2%	1.7%	2.0%	1.9%	3.0%	1.6%	2.4%
Nokia/ALU	22.4%	23.0%	23.5%	23.6%	26.4%	23.6%	25.4%	25.6%	27.7%	30.3%
Juniper	17.7%	18.0%	17.2%	19.8%	19.0%	19.4%	18.8%	18.2%	15.3%	14.9%
Ericsson	2.2%	2.3%	3.5%	2.8%	2.7%	2.9%	3.1%	2.1%	1.3%	0.8%
Other	11.6%	10.1%	7.6%	4.8%	4.7%	4.9%	4.6%	3.1%	2.1%	1.4%

Source: IHS, BofA Global Research estimates

Carrier Ethernet Switching

We estimate the Carrier Ethernet Switching market ex-China is roughly $1.8bn, solely addressed to Service Providers versus the Core and Edge Routing markets that also include hyperscalers. Of the total market, we estimate that 40% of the market is hardware, leaving $1.1bn addressable to disaggregated solutions. The market has been declining for a few years, given the stagnancy in broadband and wireless investments, yet we could see some recovery once 5G basestation deployments gain momentum in the US.

Table 7: Carrier Ethernet market ex-China

	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Total revenue (mn's)	$2,502	$2,312	$2,204	$2,152	$1,858	$1,910	$1,681	$1,702	$1,648	$1,768
YoY		-7.6%	-4.6%	-2.4%	-13.6%	2.8%	-12.0%	1.2%	-3.1%	7.3%
Total ports (mn's)	4.37	4.17	4.25	4.07	4.67	6.00	6.24	6.93	7.42	7.53
YoY		-4.6%	2.0%	-4.2%	14.7%	28.4%	4.0%	10.9%	7.2%	1.5%
ASPs	$573	$555	$519	$528	$398	$318	$269	$246	$222	$235
YoY		-3.2%	-6.5%	1.9%	-24.7%	-20.0%	-15.4%	-8.7%	-9.6%	5.7%
REVENUE MARKET SHARE										
Cisco	55.3%	49.8%	49.2%	51.6%	57.9%	59.5%	62.5%	63.7%	71.0%	65.6%
Huawei	12.1%	14.4%	7.3%	2.2%	3.4%	6.0%	12.3%	11.7%	11.2%	13.6%
ZTE	5.9%	6.6%	6.7%	5.5%	6.3%	10.4%	6.6%	5.3%	1.8%	2.2%
Ciena	0.0%	0.4%	0.7%	0.9%	0.4%	0.9%	1.7%	3.5%	5.4%	10.3%
Ericsson	0.2%	0.3%	0.3%	0.5%	0.5%	0.5%	0.3%	0.1%	0.1%	0.0%
Other	26.5%	28.5%	35.8%	39.3%	31.5%	22.8%	16.5%	15.7%	10.5%	8.3%

Source: IHS, BofA Global Research estimates

Digging deeper through the lens of private companies

All of the private whitebox routing companies are software companies that are looking to change the Service Provider networking space by disaggregating the network infrastructure, from Core to Edge, in the same way hyperscalers disaggregated Cloud infrastructure. At their core, the solutions aim to change the operational and economic model of the network, allowing networking equipment to scale much faster while increasing Service Providers' profitability. DriveNets, one of the leading startups in the space, enables cost savings as well as very granular control over traffic. The company's software enables the use of standard x86 servers and networking whitebox hardware, which are sold directly to service providers by multiple ODM providers. While the specific names are not disclosed, we believe DriveNets works with all Tier 1 Carriers and major cable operators in the US, and similar customers in Europe and Asia.

Most private companies are still very small, and they currently address only a few routing services. DriveNets started from high-end applications in Core and Aggregation and is pushing downstream to Edge and Access, while several other vendors, such as Arrcus, Volta Networks, and RtBrick, target standard whitebox switches or single whitebox solutions, focusing on lower scale routing typically found in enterprises, data centers, or Service Provider access networks. We believe disaggregated routers will expand in the future into adjacent markets, including access networks, such as SD-WAN, enterprise WLAN equipment, enterprise routing, campus switching, and data center switching.

The whitebox building blocks of the Network Cloud

To better understand the components of a disaggregated routing solution, we explore the innovation through the lens of the DriveNets solution, which demonstrates how better controls and lower costs are achieved. The DriveNets solution uses two hardware building blocks in the form of generic "pizza boxes." The first element is called a Network Cloud Packet Forwarder (NCP), and it is a whitebox router with port speeds of 100Gb/s and 400Gb/s and total per box capacity of 4Tb/s. The second element is dubbed Network Cloud Fabric (NCF) and enables customers to connect multiple NCPs into a cluster. Both a single whitebox or a cluster of many whiteboxes (up to 200) can act as a single routing entity. This model enables the disaggregated router to be distributed over many whiteboxes and grow as needed, while still acting as a single router and substantially simplifying operations. This new distributed, disaggregated router architecture can scale linearly from a single whitebox router of 4 Tbps to a cluster of hundreds of white boxes (up to 768 Tbps).

DriveNets' management claims that its distributed disaggregated routing model is the largest cloud-native disaggregated Core and Edge router on the market, scaling up to 7680 ports of 100G. The company works with multiple partners, including merchant silicon vendors (Broadcom and Intel), ODMs for assembly, optical transceiver vendors like Lumentum and Credo for the optical pluggables, Value Added Resellers (VARs) and System Integrators like KGPCo (Sis) for installation into the customers' networks. The whitebox hardware is sold to operators directly from the manufacturers, providing Carriers the ability to fully customize the specs, ranging from high-end to low-end components depending on the target applications.

According to ACG Research, DriveNets' Network Cloud Core and Edge networking solution delivers the lowest TCO in the industry with an average of 50% cost savings over traditional routing solutions. These results are due to four key elements: open whiteboxes available by multiple ODMs, operational simplicity driven by the use of only two types of whitebox building blocks and flexible router clusters, new software-based licensing, and the infrastructure virtualization that enables any service on any port.

Disaggregated routers are software-based solutions

As noted, traditional routers are monolithic chassis-based solutions, meaning the software and the hardware are interdependent and are provided from the same vendor, therefore creating a vendor-lock situation. In the disaggregated model, the software is hosted in a cloud, which provides better control of the hardware units deployed in the field. As such, all startups in the space are software vendors. Again, we analyze the DriveNets software architecture to better understand what such a software package entails.

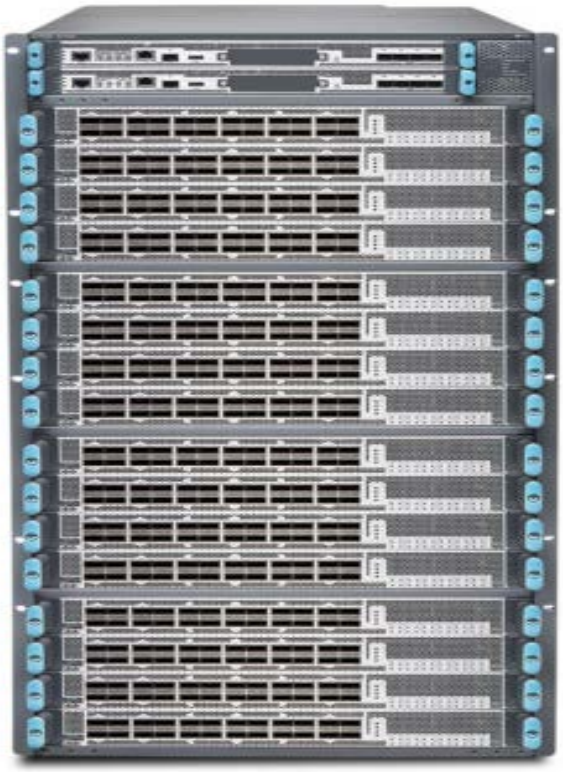
DriveNets Network Cloud solution has two main components: DriveNets Operating System (DNOS), and an orchestrator, dubbed DriveNets Orchestrator (DNOR). The operating system, DNOS, is a cloud-native networking stack software that is built on containerized microservices. DNOS is a distributed NOS (Network Operating System), creating a unified, shared infrastructure over a distributed architecture, supporting multiple service offerings including Core, Aggregation/Peering, Edge and Access routing capabilities. DNOS is able to run on any Cloud networking whitebox that is based on the Distributed Disaggregated Chassis (DDC) designed hardware, and the software leverages open APIs for automation, configuration, and telemetry. The software is installed on X86 servers and acts as the brain of the Network Cloud by dictating how the NCP and NCF hardware (the data plane) should behave in order to create one virtual router. DNOS enables any routing service to run on unified, shared infrastructure and dynamically attach to any port on the platform. For example, if a customer wants a certain cluster to perform aggregation, DNOS will apply the relevant routing protocols for aggregation to the specified ports and then will tell the NCP and NCF hardware where and how to route the packets in order to complete the aggregation function.

DNOR is the central orchestration layer of the DriveNets platform. The software enables the various containerized, microservices software elements, as well as hardware from multiple providers, to act as one synchronized routing solution by automating the backend orchestration processes. DNOR enables customers to manage all whiteboxes with zero-touch installation, decommissioning, and updating. It also provides network visibility including performance metrics and traffic data, and we believe the next logical evolution would be to add AI/ML capabilities to predict faults and congestion, optimize performance of the network, and provide self-service capabilities where customers can order and provision services on the fly.

Disaggregated routers' scalability is a major differentiator versus legacy networking chassis

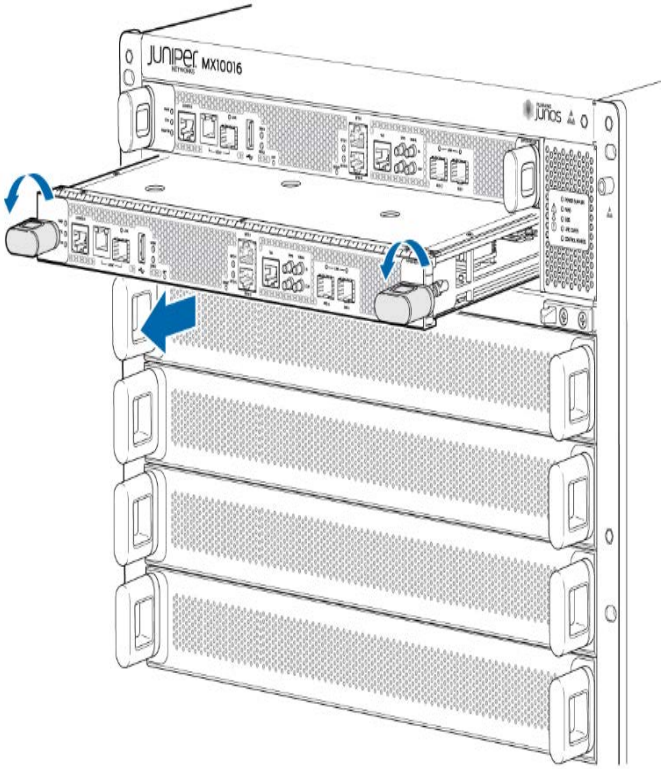
In a traditional routing architecture, Service Providers purchase large, proprietary routing chassis from Cisco and/or Juniper, filling them with line cards to add capacity as network traffic scales. The chassis is a simple rack/mounting hardware that stores the actual routing devices and acts as the connecting control plane for the individual routing line cards. The chassis also serves to protect and cool the equipment and provide power for the routing devices. Large chassis are very expensive, as they contain all of the power, cooling fans, and backbone necessary to run an entire chassis of line cards. The physical constraints and cost of the chassis make scaling very difficult. Once a chassis is filled, service providers need to purchase an additional chassis in order to add capacity, even if the Service Provider needs just one more line card of capacity.

Exhibit 1: Full routing chassis



Source: Cisco

Exhibit 2: Line cards are added to the chassis to add more capacity



Source: Juniper

In a disaggregated routing architechture, scaling is much easier. Customers buy generic pizza boxes (NCP and NCF) rather than large, expensive proprietary chassis and line cards. A single "pizza box" can function as a single router or can be clustered to deliver scalable routing capacity, combining all the routing capacity into a single clustered pool from which capacity can be provisioned on as-needed basis.

Exhibit 3: Clusters scale linearly like cloud compute

	STANDALONE	CLUSTERS			
		Small	Medium	Large	Extra Large
Max capacity	4Tb	16Tb	96Tb	192Tb	768Tb
Ports	40x100G	160x100G	960x100G	1,920x100G	7,680x100G
	10X400G	40x400G	240x400G	480x400G	1920x400G
	80x10G/25G	320x10G/25G	1,920x10G/25G	3,840x10G/25G	15,360x10G/25G
NCPs	1	4	24	48	192
NCFs	-	2	7	13	13

Source: DriveNets

Furthermore, the platform's control and data planes are disaggregated such that the data plane runs on these pizza box routers, NCP and NCF, while the control plane runs on x86 servers or virtual machines. By disaggregating the control plane from the data plane, the data plane can scale independently. Similarly, by leveraging containerized microservices, the operating system allows the networking services to run in

independent containers. Each service can therefore scale and operate independently from the others, and the various services, like core-routing, aggregation, etc. can then be attached to any port within the shared infrastructure. The ability to scale the data, control plane, and services separately provides the customer with greater flexibility, economically and physically, than purchasing a typical routing chassis and filling it with line cards.

Routers also differ depending upon their location in the network. For example, a core router is different than an aggregation router. However, disaggregated routers enable customers to utilize a single, standardized hardware for all types of routing applications. In the DriveNets model, for example, all of the hardware boxes are the same throughout the Network Cloud, and Service Providers can purchase more boxes in anticipation of traffic increases without worrying about where in the network they need the capacity, as all of the hardware boxes are the same regardless of network location. The separation of the control plane and data plan and the ability to scale services separately also provides a new and improved network function virtualization, or NFV, solution. The cloud-native software built with containerized microservices enables the support of any service, on any port, at any scale over the shared virtualized network infrastructure, supporting both network services and external third-party services.

Traditional competitors slower to move

Service Providers are increasingly looking for disaggregated networking solutions, and incumbent vendors are beginning to respond to the trend. To date, one approach to disaggregating hardware from software is through network function virtualization, or NFV. With NFV, network function software is ported off the proprietary hardware and placed into virtual machines. In theory, this allows operators to scale the network functions; however, the costs are prohibitive. The servers used to deliver the services, VNFs (VPN, aggregation, etc) are high end servers that cost as much as $15,000 to $20,000 and the routing hardware remains a version of the proprietary hardware based on proprietary semiconductors. Whitebox routing takes the same concept to a higher level, bringing anywhere from 50% to 10x cost reduction, depending on the vantage point.

Cisco entering the whitebox market

The disaggregation of hardware and software has been a trend that incumbent vendors have danced around carefully for years. In many cases, vendors were reluctant to cannibalize their own market and only added some centralized management and analytics capabilities. For example, up until recently, Cisco sold its Digital Network Architecture (DNA) technologies and Cisco ONE software separate from its hardware; however, the actual routing software had always remained integrated with the hardware itself.

The next step in the disaggregated journey for Cisco was their recent announcement at their Internet for the Future event in December 2019. At the event, Cisco unveiled Cisco Silicon One, a clean sheet custom silicon architecture designed for both switching and routing use cases versus traditional silicon architectures that address one or the other. In conjunction with the new silicon architecture, Cisco announced a custom ASIC dubbed Cisco Silicon One Q100, a routing platform dubbed Cisco 8000 series, and a disaggregated software operating system dubbed IOS-XR7. All new products will be supported by new flexible consumption models where customers have the choice of buying components and software a la carte or as part of fully integrated systems. For example, Cisco is offering pay as you grow licenses that lower the initial costs, as well as right-to-use license pooling to consume software licenses as desired and add capacity where needed.

Cisco noted that the new ASIC, Silicon One, is expected to ship in the second half of 2020 and will support third-party networking whiteboxes. It is yet to be seen if Cisco Silicon One will be able to match the capabilities of Broadcom's chipsets.

In our view, Cisco's Future of the Internet event and the related product announcements were a direct response to the rising competitive threats from disaggregated solutions by companies like DriveNets, Arrcus, Volta Networks or RtBrick. With the new products and consumption models, Cisco will enable and participate in the networking disaggregation trend by allowing customers to buy components or disaggregated software, IOS XR7, for whitebox architectures. The new architecture reduces the operational complexity and cost of networking with the vendor itself and other vendors who will offer hardware solutions based on Silicon One, by enabling one ASIC and one software management system for all routing and switching functions. Silicon One also provides consistent feature development and consistent telemetry across all routing and switching use cases to provide a unified management experience, reduce OpEx, and reduce time to value.

The software, IOS XR7, has also been simplified and modernized to reduce required resources, as previous ported software versions were too heavy. The software also integrates with Cisco Crosswork Cloud, a SaaS platform for network monitoring and analytics, as Cisco will likely try to attach platform value-add services to limit the deflationary impact of network disaggregation. We question though the ability of Cisco to take a legacy routing software, based on years of development by hundreds of engineers, and fully transform it to become cloud-native and support software containers.

Though large incumbent vendors, like Cisco, are well aware of their customers' desires to switch to software-oriented solutions and will likely work with and cater to their top customers with future software releases, incumbents ultimately do not have the incentive to disrupt their business models. Legacy networking products still comprise the vast majority of their revenue bases and a transition to a DriveNets-type model would ultimately be deflationary. As such, we believe certain parts of the market will adopt whitebox routing before other parts. Access routing and aggregation solutions, where cost and granular control are important, will be the first applications to get targeted by whitebox routers, in our view. We also believe some core networks may as well be targeted due to the cost efficiencies of the fully virtualized infrastructure and standardization. We believe Nokia (old Alcatel routing) is more vulnerable in these markets, given its dominance of these applications, and note that Juniper seems a bit out of sync with these market trends.

Juniper also in the whitebox market, though not merchant silicon market

Juniper, like Cisco, has slowly embraced the concept of disaggregation and has been selling various versions of its software separate from its hardware for many years. Unlike Cisco, however, Juniper mainly sees software-only routing solutions in the low-end of the routing market where bandwidth demands are minimal and sees little traction in the high-end of the market due to the limitations of general purpose compute at packet processing.

Juniper's routing solutions leverage merchant chips at the lower end and custom chips at the higher-end and for complicated use cases. While Cisco has begun to sell its chips as merchant solutions, Juniper does not see customer interest in buying standalone high-end chips given the complexity and cost of developing software for the silicon. Instead, Juniper has focused its efforts on 400G silicon photonics. As the cost of routers declines consistently, the proportional cost of silicon photonics in routing solutions rises, and Juniper is looking to leverage its Aurrion asset and its ability to integrate photonic elements, like lasers and detectors, on the silicon wafer to gain a cost advantage versus competitors who are still leveraging manual labor processes to integrate the photonic elements onto the chip.

The business model behind Disaggregated Routers

Grow capacity first, then migrate everything

Customers typically begin the journey with whitebox routing by supplementing existing routing capacity, using whiteboxes to handle new "growth traffic." As the customers

gain comfort with the model, the use of standard whiteboxes, and the new software, they can seamlessly scale the whitebox routing platform to support more services and traffic by adding additional whiteboxes to the router. At a later stage, customers are able to migrate legacy traffic over without interfering with the network operations.

Fixed-price term licenses for software disaggregates cost from traffic growth
Historically, Service Providers purchased physical routing solutions by paying up-front for a chassis and paying for individual line cards which are added on as network traffic increases. DriveNets for example, has a much different go-to-market, offering a disaggregated solution at a lower price – often 40-50% cheaper. With DriveNets, customers buy the software through a fixed-price 3-5 year term based licenses that allow them to consume as much capacity as needed, pay out of the OpEx budgets, and simplify capacity growth planning, as customers can then purchase the generic hardware directly from ODMs.

With this model, for example, a large Tier 1 Service Provider would buy software for $10mn a year and purchase its hardware at a fraction of the cost of competitors' proprietary hardware. Once the software and hardware are purchased, the Service Provider can then activate as many ports as needed, which serves to detach the network growth from the network cost structure. The only cost that scales with capacity is the cost of the generic whitebox hardware. Lastly, by virtue of the smaller cloud-based software footprint, Service Providers are typically able to cut down on the amount of hardware necessary to support their networks, further reducing costs.

The startups typically charge according to two main growth vectors. First, the software licenses are per function licenses. If a Service Provider needs both Core and Aggregation routing, then two licenses would be purchased. The second vector for growth is attached services, such as security functions, analytics, artificial intelligence, and others.

Friction with the sales motion by virtue of being a disruptor
Despite the clear cost savings provided by the private companies, there are still several points of friction in the sales motion, which is natural for small disruptive start-ups. First, customers are accustomed to working with giants like Cisco, Nokia and Juniper, and these incumbent vendors have established themselves as trusted technology partners. Meanwhile, buying from a small start-up comes with many inherent risks, both execution and technology risks.

Second, part of the cost benefit of the disaggregated solutions stems from the need for less headcount to manage the platform versus the headcount necessary to manage a proprietary system. Naturally, the engineering teams will question the disaggregated solution closely, knowing that the decision could put jobs in jeopardy. Third, the cost of introducing a new vendor into the network can be high. Service Provider customers do extensive testing of new solutions in their labs, and the cost of onboarding a disaggregated solution can be high because many Service Providers have not worked with the new solutions at scale. When faced with large initiation or onboarding costs, customers sometimes lose sight of the TCO savings and negotiations can stall.

Current state of the disaggregated solution market
Today, there are generally two types of RFPs in the market: there are new RFPs for disaggregated solutions, and there are RFPs for routing solutions in general, where disaggregated solutions compete among integrated solutions. The market for disaggregated solutions is still very nascent, and in many cases, Service Providers are still grappling with how the technology can fit in their networks. Evidently, 96% of routing market is still controlled by four incumbent vendors, Cisco, Huawei, Nokia, and Juniper. Competition includes legacy vendors with physical solutions, legacy vendors with new disaggregated solutions, and smaller startups that we noted like Rtbrick, Volta Networks, Arrcus and DriveNets.

Huawei scrutiny could open some doors for startups

Huawei sells products at low prices, competing with the large routing players like Cisco and Juniper. Due to its low price point, Huawei has been able to gain share outside the US versus the other vendors. In our view, recent scrutiny of Huawei by Governments and Service Providers could open the door for new low cost solutions in the form of disaggregated routing solutions. Ex-China, Huawei represents ~13% of the total routing market, behind Cisco, Nokia, and Juniper.

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