The following is a redacted version of the original report. See inside for details.

Goldman Sachs

5G

Moving from the lab to the launchpad

We expect 2019 to be the first year that 5G technology sees material deployment with a focus on fixed wireless broadband in the home. Following this, we expect 5G cellular rollouts for smartphones usage to accelerate in 2020 to accompany the availability of mass market handsets. 5G could help the wireless equipment market (GSe: c$100bn in 2018) to inflect positively after four years of declines. In our view, profound longer term potential disruptions include an edge computing footprint advantage for telcos and scope to power industrial automation given ultra low latency.

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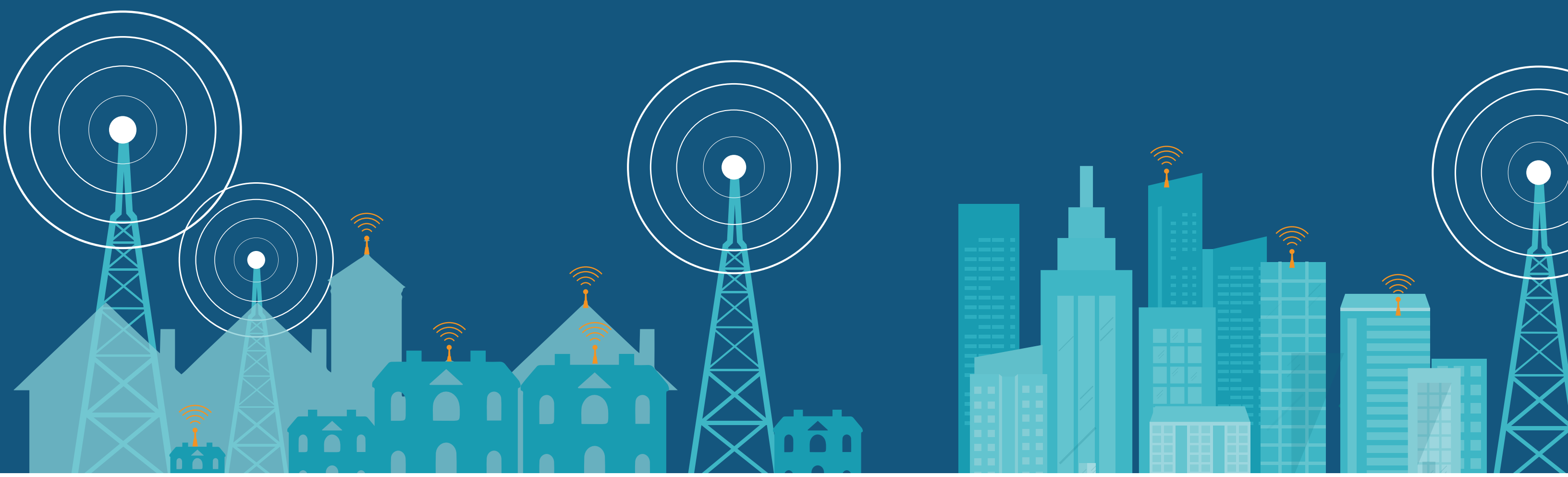

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Note: The following is a redacted version of "5G: Moving from the lab to the launchpad" originally published December 2, 2018 [115pgs]. All company references in this note are for illustrative purposes only and should not be interpreted as investment recommendations.

5G: Moving from the lab to the launchpad

We expect 2019 to be the first year that 5G technology sees material deployment with a focus on fixed wireless broadband in the home. Following this, we expect 5G cellular rollouts for smartphones usage to accelerate in 2020 to accompany the availability of mass market handsets. 5G could help the wireless equipment market (GSe: c$100bn in 2018) to inflect positively after four years of declines. In our view, profound longer term potential disruptions include an edge computing footprint advantage for telcos and scope to power industrial automation given ultra low latency.

Fixed Wireless Access (FWA) is main accelerator of 5G rollout. We believe that fixed wireless broadband access i.e. significantly faster wireless connectivity to the home, based on 5G creates both the most opportunity for incremental wireless carrier revenue and competition. We estimate that 5G provided broadband costs from 13% to 65% lower than FTTH to deploy (assuming 20%-50% market share at a density of 1000 homes/sq. km) and could eventually do away with wired home and small business broadband altogether.

Equipment makers to see a shallower but more sustainable cycle than with prior cellular standards changes and growth recovery. 5G technology for smartphones offers a more evolutionary than revolutionary change to existing LTE technology. However, currently available Non-standalone 5G (4.5G) provides a future proof option to upgrade capacity constrained carrier networks now. Thus, we already see signs of recovery in the c$100bn wireless infrastructure market.

We expect 5G rollout to accelerate in 2019 with mainly FWA and Non-standalone activity. We provide a comprehensive summary of updated carrier plans by region in this report. Most global carriers look set to accelerate rollouts in 2020 to prep for wider 5G device availability in late 2020.

We have seen significant 5G activity since our last report. Since our April 2016 report: "*5G: How 100x faster wireless can shape the future*" we have seen 5G standards for both Non-standalone (NSA) and Standalone (SA) solidify. Carriers can now deploy NSA 4.5G technology to add network capacity that should be fully compatible with full 5G when that equipment/software becomes available with so-called Standalone technology.

5G enables additional disruptions beyond FWA. 5G does bring profound technology shifts in both expected and unexpected ways. As expected, 5G will enable much lower wireless latency that is useful for applications like industrial automation that require very fast network response times. In addition, full 5G supports IoT sensors/devices with long battery life enabling even greater data collection at the edge. Less obviously 5G should also allow carriers to pull through much needed network automation and deploy general purpose compute capacity at the edge of networks as a by-product of automation.

We see some risks to adoption but progress on bottlenecks appears solid. We believe key risks to the adoption of 5G are delays in standardization of 5G protocols and architecture, lack of clarity on further use cases for telcos, spectrum policy and delays in development of device ecosystems. That said we believe there has been marked progress in the last 12 months with accelerating standards setting, clear telco commitments to rollouts, and spectrum auction activity.

5G IN NUMBERS

5G IMPACT

Lower cost

Cost to roll out 5G Fixed Wireless vs Fiber roll out (~$606 cost to pass for Fixed Wireless vs ~$700 for Fiber).

1bn+

Homes globally without a fixed connection could be served with 5G FWA. In addition, potentially 10mn+ industrial sites and 3mn+ warehouses can be addressed by 5G Critical IoT.

$75bn

Total market opportunity for FWA in 2026 is $50bn-$100bn.

SCOPE

3.5bn+

Cellular IoT connections expected by the end of 2023 (vs 1bn+ by YE18). Estimated 14mn base stations required to be built for private IoT networks (vs 7mn base stations today).

10%-35%

Boost to the telco TAM by overall industrial IoT. Massive IoT is expected to drive an incremental TAM of 2%-3%.

c$100bn+

Annual size of the estimated 2018 wireless market including services. This compares to the overall Commtech market (including Fixed Wireless) of $200-300bn.

END MARKET OPPORTUNITY

1/50x

Latency of 5G network vs 4G network. The targeted latency of 5G network is 1 millisecond.

10x

Expected growth of smartphone data traffic in 2017-23. Telcos would need to reduce their cost base by 30% per annum to maintain margins and cater for higher data traffic at the same time.

2500x

Faster download speed with 5G network vs. average LTE download speeds in the US. Estimated average amount of time taken to download a HD movie on a 5G network is sub-10 seconds.

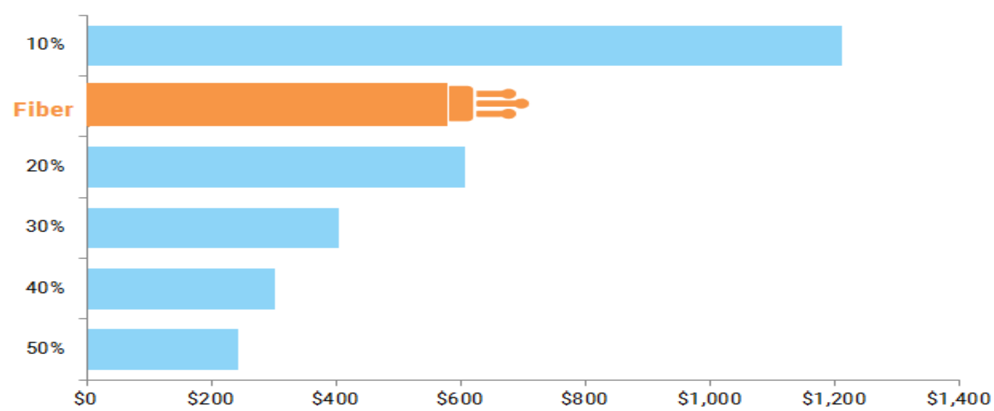
PM Summary

We expect 2019 to be the first year that 5G technology sees material deployment with a focus on fixed wireless broadband in the home. Following this, we expect 5G cellular rollouts for smartphones usage to accelerate in 2020 to accompany the availability of mass market handsets. 5G could help the wireless equipment market (GSe: c$100bn in 2018) to inflect positively after four years of declines. In our view, profound longer term potential disruptions include an edge computing footprint advantage for telcos and scope to power industrial automation given ultra low latency.

5G Fixed Wireless Access driving early deployments

Most carriers report that they see limited scope for 5G cellular rollout (i.e. for smartphones) to drive a step change in revenues. However, 5G technology makes the use of the cellular network for 1Gbps+ home broadband access a reality assuming carriers are able to leverage additional spectrum to support it. This has the effect of materially lowering the cost to reach many homes in less densely populated areas with 1Gbps broadband speeds by 13% to 65%, on our estimates, depending on the assumed uptake rate (20%-50%) and density of 1000 homes/sq. km. It also breaks the dominant position long enjoyed by both telecom and cable MSOs for fixed broadband access. Initially, we would expect this to drive increased competition in the US as many users in less densely populated areas find themselves with a true choice of broadband provider for the first time. In Europe, where population density is higher and countries like the UK have unbundled the local loop we expect slower uptake of FWA and metered rollout of 5G for cellular access. Having said this 5G opens the possibility that wires for home broadband access become a thing of the past just as they have given way to Wifi within the home. This opens the possibility that most users eventually take service from a single wireless carrier who provides both device and home access as well as potentially offers networking and security services that seamlessly link these previously separate realms together.

Exhibit 1: Cost to Pass Under 5G FWA vs. Fiber For Various Market Share of 5G



Source: Goldman Sachs Global Investment Research

Equipment makers expected to see a shallower but more sustainable cycle than with prior cellular standards changes, and growth recovery

5G involves a much more incremental technology change when compared to both 3G and 4G, but with potential upside skews for equipment vendors in certain end applications. We believe this leads to a slower and more elongated cycle for radio vendors globally. It will therefore *not* be a "rising tide lifts all boats" situation for tech vendors, suggesting competitive positioning of vendors will be important. That said, it can nevertheless catalyse a c$100bn 2018 wireless vendor market (GSe) growth inflection (after many years of declines) and we may see less earnings volatility in the latter stages of the cycle. We would caveat this with the potential for fixed wireless access to drive business and for ongoing cycles of capacity addition in mobile networks to continue. In the cases of both 3G and 4G/LTE the fundamental coding system used for communication was changed driving large changes to existing networks. In the case of 5G, OFDMA will continue to be used just as it was for 4G/LTE. We also do not expect the major network shift to IP at the edge the way we saw it with 4G. Having said this 5G looks likely to pull through much more network automation for carriers which should finally begin to materially reduce opex. We also expect 5G to usher in the era of edge computing as the same computing infrastructure being used to run carrier networks is also levered for general purpose workloads closer to the user. This could lead to carriers having a more prominent role in the provision of cloud computing due to their superior real estate and power positions near user locations. Although most of our telco analysts expect 5G to be absorbed into current spending plans without a material increase we believe equipment vendors could see increasing revenue as civil works capex is reduced in favor of higher active 5G equipment spending.

We expect 5G rollout to accelerate in 2019 with mainly FWA and Non-standalone activity

We believe there are two primary drivers of 5G deployment that should begin to gather pace in 2019. First, we expect Verizon to further accelerate its rollout of fixed wireless broadband service based on 5G technology in the US. Second, we believe the availability of forward-compatible "Non-standalone" or NSA 5G (4.5G upgradeable to 5G) is likely to encourage operators running closer to full capacity to spend. In our opinion, this latter driver has already begun and is boosting the results of telecom equipment vendors like Ericsson and Nokia.

Exhibit 2: Telcos/vendors see Non Standalone 5G starting in 2H18, ramping in 2019

Region	Source	Comment
US	**AT&T** (Sep 2018; MWC US)	• Expects to **launch 5G broadband** in **12 cities by end of 2018** & expected to **scale in 2019**
US	**Verizon** (Sep 2018; MWC US)	• Announced launch of residential NSA 5G broadband (fixed wireless) in 4 US cities in October, 2018
US	**Sprint** (Sep 2018; MWC US)	• Expects to deploy **mobile 5G** in **1H19** using 2.5GHz spectrum and **massive MIMO** technology
US	**T-Mobile** (2Q18 results)	• Plans to bring NSA 5G to 30 US cities in 2018 and ready for 5G smartphone in 1H19
US	**Nokia** (Sep 2018; MWC US)	• Expects NSA 5G network deployments to begin by Q3 2018 and accelerate further in Q4 2018
China	**China Mobile** (Mar 2018; press release)	• Expects to launch "**the world's largest 5G trial network**" across **5 Chinese cities later in 2018**
China	**China Unicom** (Aug 2018; BBG article)	• Plans **pre-commercial 5G deployments in 2019** with **commercial deployments in 2020**
China	**China Telecom** (Aug 2018; BBG article)	• Network tests of NSA 5G technology (in 17 cities) by 2018; commercial 5G services in 2020
China	**Nokia** (Sep 2018; MWC US)	• Expects **5G roll-outs in mid-2019 or 1H 2020**
Korea	**SK Telecom** (Sep 2018; press release)	• Expects to **start the commercial operations of its 5G** mobile network in **March 2019**
Korea	**Nokia** (Sep 2018; MWC US)	• Plans to **launch initial rollouts by the end of 2018** with meaningful deployments thereafter
Japan	**NTT DoCoMo** (Oct. 2018; public conference)	• Plans **pre-commercial 5G service in Sepetmber 2019** with **commercial launch in the spring in 2020**
Japan	**KDDI** (Oct. 2018; public conference)	• Plans **pre-commercial 5G service in 2019** with **commercial launch in 2020**
Japan	**Nokia** (Sep 2018; MWC US)	• Expects Japan to get mid-band spectrum in 1Q19; aim to **build in time for 2020 Olympics**
Europe	**Vodafone** (Oct 2018, press release)	• Plans to use the recently bought **700MHz spectrum** in **Italy** for **Industrial IoT, VR/AR**
Europe	**British Telecom** (Sep 2018, press release)	• Prioritising eMBB; expects to **launch 5G in 10 sites in London by 2018** with **acceleration in 2019**
Europe	**Telenor** (2017; press release)	• Expects 5G to be **commercially available in 2020** with focus on Normay, UK, Spain and Greece
ANZ	**Telstra** (Jun 2018, company conference)	• Expects 200 5G sites to be live by end of CY18, and its **5G network to be commercially launched by June 2020.**
ANZ	**Spark** (Aug 2018, company release)	• Is on track to provide **5G services from 2020.**
ASEAN	**Singtel** (Investor Day, June 2018; 2QFY19 results)	• Service to be c**ommercially available in 2019 in Australia**, while looking to **roll out in Singapore in 2020**
ASEAN	**Singapore regulator** (November 2017)	• Looking to hold **26/28GHZ spectrum auction in 2020**
ASEAN	**AIS** (3Q18 results)	• In talks with Thai regulator, expects 5G to be probably **commercially launched in 2020**
ASEAN	**Telkomsel** (Asian games, August 2018)	• Conducted the 5G testing during Asian games in Jakarta; but no clear timeline on commercial launch
ASEAN	**Globe** (June 2018)	• First 5G network service for commercial use to **rolled out by 2Q2019 in Philippines**

Source: Company data

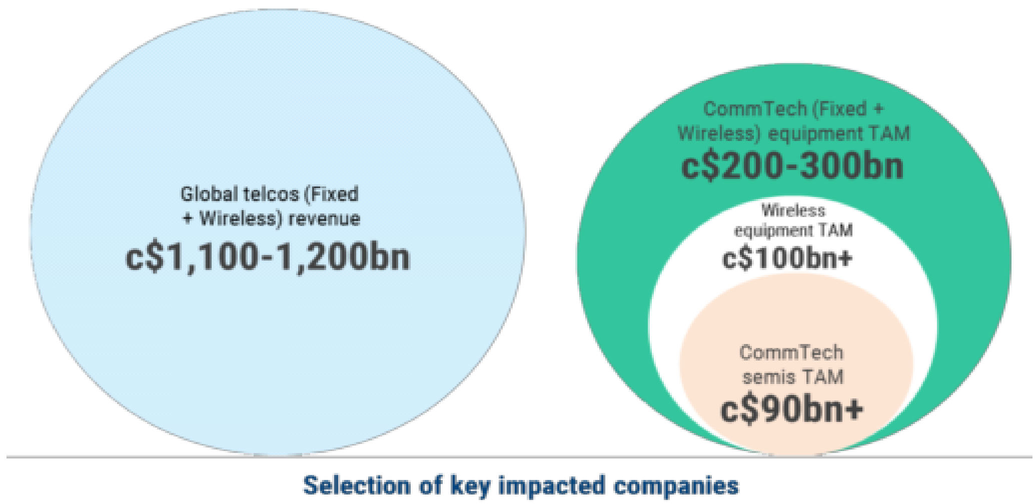
We have seen significant 5G activity since our April 2016 report; Further progress contingent on a few factors

Development on 5G has shifted firmly in the direction of fixed wireless access since we last wrote on the subject in our April 2016 (*"5G: How 100x faster wireless can shape the future"*) report. We also now see real activity around deployment of Non-standalone 5G as equipment has become available and carriers have a way to boost network capacity now that should offer a clear, cost-effective path to 5G technology with only Rf and software upgrades (at least for some suppliers) as opposed to a full forklift network change or addition. In terms of devices, the first silicon is expected to begin shipping in 2019 with the main end products being home routers for fixed wireless access and "puck" style wifi access points. We expect a few mobile devices to begin adopting 5G in early 2020 with mass market products like the iPhone becoming 5G capable by late 2020.

5G enables additional disruptions beyond FWA

The real promise of 5G should begin to become more evident in 2019 as Verizon's fixed wireless access blurs the lines between home broadband and mobile broadband. This opens up a potential disruption of telecom companies who are overly reliant on either fixed or mobile service. By 2020 as 5G architectures pull through more carrier network automation we expect an accompanying expansion of edge computing capacity that could either be operated by carriers or leased to 3rd parties for cloud services that are either edge data intensive or latency sensitive. As full cellular 5G rolls out very long battery life remote sensors become possible with implications for industry that are difficult to predict but likely profound. Ultra low latency 5G also opens up the possibility of even more automated industrial processes though we are unclear whether manufacturers are ready to pay a carrier to network factor equipment. Ultra low latency also should enhance autonomous driving as will edge computing capacity. As always, a ubiquitous, IoT friendly and very high speed wireless network is likely to bring industrial opportunities that are difficult to predict but profound in nature over time.

Exhibit 3: CommTech equipment TAM is estimated to $250bn with wireless market having more than $100bn+ share in it



Source: Company data, Goldman Sachs Global Investment Research, Statista, Gartner

We see some risks to adoption but progress on bottlenecks appears solid

We believe key risks to the adoption of 5G are delays in standardization of 5G protocols and architecture, lack of clarity on further use cases for telcos, spectrum policy and delays in development of device ecosystems (see exhibit including key risks table below). That said we believe there has been marked progress in the last 12 months with accelerating standards setting, clear telco commitments to rollouts, and spectrum auction activity.

Key Risks for the adoption of 5G

Spectrum availability

• **Spectrum auctions progressing** in several geographies; a **delay in auctions can push back 5G deployments**

• **S. Korea, UK, Italy, Finland, Spain and Ireland** have concluded 5G spectrum auctions

• First high-band **US spectrum auctions already launched** in Nov, 2018; another auction of high-band spectrum in 2019

Use case clarity

• **Fixed Wireless Access** appears to have clear **traction in the US**; Verizon launched 5G in 4 US cities in Oct 2018

• **Contingencies** for **Industrial IoT yet to be met;** Germany working on ownership rights for spectrum by the land (industry) owner

• **Clarity on cost-benefits trade-off** (i.e. capex investment vs incremental TAM) for telcos is needed

5G device launch timeline

• **Affordable** and **high performance** device ecosystem is critical for 5G to scale (i.e. dongles/pucks, smartphones)

• 5G dongles expected in 2018; **Samsung** to launch **5G smartphone in 1Q19**; **Apple** timing still **unknown**

• **5G-enabled handsets** are not expected to reach **mass market penetration until 2020-21**

Delay in standardisation

• Delay in setting 5G standards seems to be a **less significant risk** given the progress so far

• **Release 15 5G standard** (Non-Standalone and Standalone) was delivered **ahead of time** by 3GPP

• **Release 16** focusing on 5G applications such as **Industrial IoT;** expected to be finalized by **YE19**

LOW RISK

MEDIUM RISK

HIGH RISK

Source: Company data, Goldman Sachs Global Investment Research

Fixed Wireless the first and largest 5G impact but IoT and Industrial apps also key

Fixed wireless access

5G technology makes the use of the cellular network for home broadband access a reality. This has the effect of materially lowering the cost to reach many homes in less densely populated areas with 1Gbps broadband speeds by 13% to 65%, on our estimates, depending on the assumed uptake rate (20%-50%) and density of 1000 homes/sq. km. Note that this Fixed Wireless Access (FWA) use case also requires the availability of additional, typically higher frequency, spectrum. The cost to pass a home depends on uptake rate of the service, but we expect it to be considerably lower than FTTH even with relatively modest uptake. We estimate $121k per sq.km of total build cost for a coverage radius of 0.6km per base station. Cost to pass a home depends on assumed density. Dense urban areas can range from 2,000 homes per sq.km down to 1,000 homes in a less dense suburban scenario. For context, the top 30 cities in the US had population densities in excess of 3,900 homes/km^2 in 2010. For densities of 1,000-5,000 homes per sq.km, we estimate passing costs would range from $24 to $121 per home assuming 100% uptake of the service. However, we would expect uptake rates to be far lower than 100% given the availability of other broadband service options.

Exhibit 4: FWA Cost to pass sensitivity to density of households and market share

		Market Share				
		10%	20%	30%	40%	50%
Density (homes/sq.km)	500	$2,424	$1,212	$808	$606	$485
	1,000	$1,212	$606	$404	$303	$242
	2,000	$606	$303	$202	$152	$121
	3,000	$404	$202	$135	$101	$81
	4,000	$303	$152	$101	$76	$61
	5,000	$242	$121	$81	$61	$48

Source: Goldman Sachs Global Investment Research, Mobile Experts Inc.

We provide a scenario analysis showing an uptake rate from 10%-50% with a resulting cost to pass a home ranging from $48 to $2,424. As shown in the exhibit above, the cost to pass with FWA is far below the cost to pass with FTTH in most cases, with the cost to pass with FTTH being in the ballpark of $700 with cost to connect $400 for a total of $1,100. Note that in passing costs for FWA, due to the fact that capital is not dedicated to a specific home, churn rates do not affect capital returns in the same way as they do with FTTH deployments. This also raises the interesting point that the effective costs to pass drop as take rates improve. Given this we would expect wireless carriers to experiment with pricing to find the point of optimal return on capital.

Cost to connect materially lowered by self install

We believe total cost to connect a subscriber is $350+ but $200 of that is truck roll which we believe is only required about 50% of the time in early deployments and should be required less and less as technology matures. Self installation would materially reduce installation cost to only CPE equipment. CPE may also be more portable/reuseable. We also believe CPE costs are likely to come down from our initial $150 estimate.

Customer's move to a hybrid wireless usage pattern

With home usage delivered via the same wireless network as mobile usage network deployment economics changes somewhat. Wireless delivery is far less capital intensive and more flexible. It seems unlikely that fixed access remains viable longer term as maintenance capex alone negatively impacts overall service returns. While customers seem likely to continue to use networks in similar patterns to today 5G looks likely to move a lot of home usage over to wireless for the first 200-500 ft and make consumer use of cellular and wifi more amorphous.

Exhibit 5: Fixed Wireless Access (FWA) is a low cost means of providing broadband services to areas with no access to fixed line

	Fixed Wireless Access (FWA) as a use case of 5G
Overview	• Provides internet access to homes using **wireless data connectivity** rather than fixed line (i.e. FTTH) • Means of providing **fast** broadband services even in **areas that do not have ready access to fixed line** • **Low cost solution** as 80% of fixed line cost is in "last mile"; **50% lower cost** vs fiber (i.e. €1k-2k vs €2k-4k for fiber)
Technologies & hardware needed	• Requires significant amount of spectrum; suitable in **less dense** areas where unused spectrum is most prevalent • No engineering works at customer end but require **equipment** that can be **self-installed** by the subscriber • **Beam-forming** and **high-frequency mmWave spectrum** help to boost speed of FWA vs fixed line
Non - Standalone/ Standalone	• Initially can use **existing spectrum** (based on NSA) but does require significant amount of spectrum • FWA is likely to use **SA base station** in the **longer term**
Incremental opportunity	• Nokia sees **10% upside** to telco's **current wireless market** as addressable by Fixed Wireless solutions • As per Ericsson, FWA can result in an incremental market of **10%-15% of wireless service revenues** • **Vodafone** stated it is easier for FWA to be disruptive in US vs EU given fixed line ARPU in US 3x vs Europe
Challenges	• Obtaining the mmWave spectrum given the very **dense deployments of small cells** • It could take **longer time than expected** to install backhaul vs rolling out in locations with exisiting tower space • Partnerships between network providers and telcos to solve **right of way** to put radio up may be a key challenge • NSA version of FWA can be done using existing spectrum; **SA** version of FWA will require **new spectrum**
Timeline	• Standards relating to FWA based on NSA are already frozen (i.e. finalised) by 3GPP in December, 2017 • Fixed Wireless **devices** (i.e. dongles/pucks) for **mid-band** are expected to be out in **2019** and **high-band** in **2020**
Regional adoption	• **More suitable** for the **US** given greater proportion of semi-densely populated areas relative to other countries • Density in **Europe** is higher than US; more useful where **there is cable connection** (25% sites in Europe) • **Less suitable for China** given high penetration of fiber
Use cases	• Fiber equivalent high speed, cheap internet services to homes in sub-dense areas (in place of fixed broadband)

Source: Company data, Goldman Sachs Global Investment Research

Industrial IoT: scope to drive incremental telco TAM and infrastructure vendor revenues but in the longer term

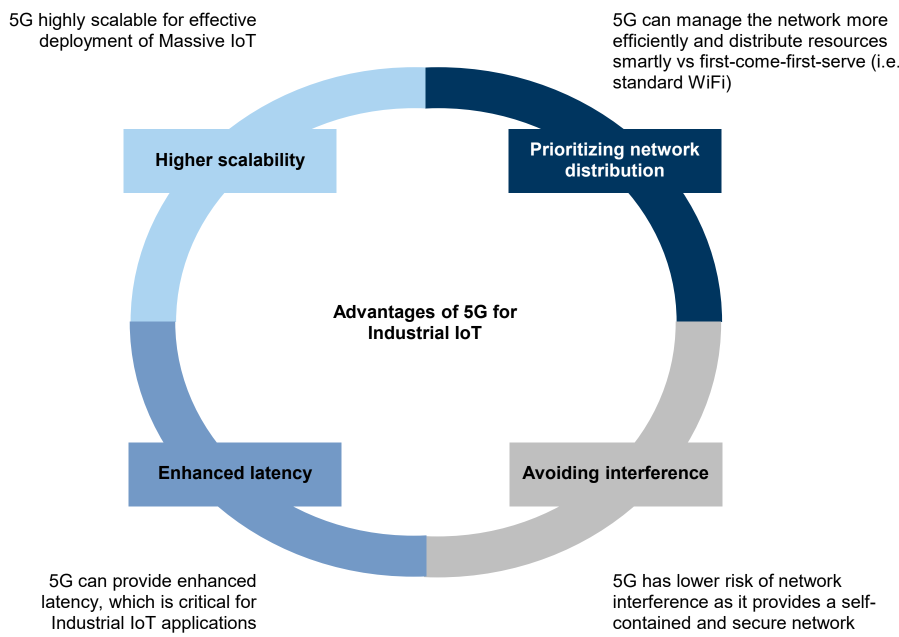
Longer term scope for Industrial IoT to drive incremental telco TAM and infrastructure vendor revenues. The Industrial IoT use case envisages the use of 5G technology to connect machines and processes, benefiting not only from higher speeds but crucial for better latency (responsiveness), facilitating real time feedback loops, and high reliability/security. We see Industrial IoT offering scope to boost the incremental telco TAM, given potential to open up new customer opportunities and various potential use cases. That said, we see this as a longer term dynamic (perhaps towards the middle of the next decade). The use case is more likely to be based on Standalone 5G, rather than NSA. This therefore will require standards to be finalised, as well as spectrum allocation and regulatory issues to be addressed. As such, we see this use case as an opportunity for the mid term. We highlight below the reasons for this and also note areas where upside skews are most likely in the industrial sphere. In addition, we detail bottlenecks in Exhibit 10 which if unblocked could potentially allow this use case to see accelerated traction. In addition, we present a range of potential scenarios in Exhibits 26-35, exploring the potential impact on the wireless vendor market.

We see Industrial IoT offering scope longer term to boost the incremental telco TAM, given potential to open up new customer opportunities and various potential use cases.

- Applications in Industrial IoT can be divided into two categories: mission critical and massive IoT. Typically, these draw on 5G capabilities related to reliability and low latency. The avoidance of network interference is also a potentially important factor we explore below. We see mission critical IoT e.g. for Factory Automation, as the most important end application.
- Mission critical IoT includes critical applications with real time access and control e.g. Factory Automation and Public Safety. Massive IoT includes deployment of massively scaled IoT sensors e.g. Logistics/Track and Trace.
- We see Industrial IoT offering scope to boost the incremental telco TAM, given potential to open up new customer opportunities and various potential use cases. Ericsson stated in its recent CMD in Nov 2018 that potentially 10mn industrial sites and 3mn warehouses globally can be connected by using 5G network.
- Nokia stated that the potential number of private IoT networks that could be built requires 2x the number of base stations (i.e. 14mn vs. 7mn today). Ericsson also stated in their recent CMD in November 2018 that the technology shift to 5G will create a RAN market opportunity of $30bn. As per our industry discussions with Ericsson, the overall IoT opportunity could boost the telco TAM by 10-35%; by contrast we see massive IoT (essentially logistics / Track & Trace) only impacting by 2-3%. We note that in the specific industrial IoT context, out of 4mn manufacturing plants globally, 2mn are 200ft in size and 1mn of these use cable networks and would be addressable using 5G. Given a broad range of potential outcomes, we present a scenario analysis below.

- We see a potential opportunity in public safety related to upgrading the basic communication systems for First Responder networks. This could be meaningful eventually in the broader Industrial IoT category driven by 5G's capability to provide lower latency, higher reliability and more security vs. 4G network, for example AT&T's FirstNet in the US. As per Ericsson, there is a scope to upgrade 120+ First Responder networks globally which are currently based on legacy technology solutions. Ericsson sees public safety use case as potentially providing high ARPUs for telcos but since the government will need a dedicated spectrum band for First Responder agencies, spectrum procurement will take a long time in our view.
- While WiFi is sometimes cited as offering scope to connect up industrial nodes, the advantages of 5G include greater scalability and the ability to ensure there is no network interference, as per Nokia. Nokia also stated that industrial customers are proactively approaching them for 5G based solutions. That said, we see a risk to the industrial IoT use case in the form of further advances in WiFi technology.
- Given the broad array of potential outcomes in both Public safety and Industrial IoT, we present a range of scenarios below (detailed in section "Cycle could be relatively elongated and shallower vs. prior ones given range of timelines").

Exhibit 6: 5G offers benefits for Factory Automation through better latency, efficiency & security



Source: Company data, Goldman Sachs Global Investment Research

We see several technological requirements for Industrial IoT to be a viable use case, alongside the need for Standalone 5G, rather than NSA.

- Standalone 5G will be key for mission critical applications as it is required in order to provide more control and avoid interference e.g. in factories. By contrast for massive sensor IoT (for e.g. logistics / Track & Trace) NSA is sufficient, although this can be upgraded to SA eventually.

- In terms of broader technological requirements, mission critical processes require extremely high radio reliability, with no interference, as well as ultra low latency (and high node availability) so as to provide a high degree of control.

Exhibit 7: Industrial IoT addresses mission critical and massive scale applications (i.e. Factory Automation)

	Industrial IoT as a use case of 5G
Overview	• Applications in Industrial IoT can be divided into 2 categories: **mission critical** and **massive IoT** • **Mission critical IoT** includes **critical applications** with real time access and control e.g. **Factory Automation** and **Public Safety** • **Massive IoT** includes deployment of **massively scaled** IoT sensors e.g. **Logistics/Track and Trace** • Industrial IoT likely to be deployed in 2021/22, **12-18 months** after enhanced mobile broadband (i.e. a 2nd wave of investment)
Technologies needed	• Mission critical processes require extremely high radio access **reliability** with **no interference** • **High node/service availability** and **ultra-low latency** for more control are also important • For massive IoT, **cost effective authentication** of devices on the network is key consideration (embedded SIM)
Non - Standalone/ Standalone	• For **mission critical** IoT, **Standalone (SA) network** is required to have more control and less interference • For **massive sensors** IoT, **Non-standalone (NSA) network** can be used; this can be eventually upgraded to SA network
Incremental TAM opportunity	• Potential number of **private IoT networks** to be built requires **2x** number of **base stations** vs today (i.e. **14mn** vs 7mn) • As per Ericsson, overall industrial IOT can boost **telco TAM by 10%-35%**; massive IoT to drive incremental TAM of 2%-3% • Out of c4mn manufacturing plants globally, **c2mn** are c200 sq ft in size and c1mn of these **use cable networks and are addressable** • There are **>120 first responder networks for public safety** globally based on legacy technology solutions - require upgrades
Challenges	• **Regulatory challenges** exist given the need for dedicated spectrum (i.e. no interference) for mission critical • For example, Germany is working on the regulations to allow the land owner to own the spectrum for industrial IoT
Standards timeline	• **Release 16** focusses on Industrial IoT (i.e. Factory Automation), Vehicle-to-Everything communication, unlicensed spectrum operations • 3GPP submissions gaining traction; **Release 16** expected to be finalised by end of **2019**
Regional adoption	• **China** expected to be the first adopter in 2020 (with focus on Industrial) followed by Japan; Germany also focussing on Industry 4.0 • In North America there is gradual convergence of IoT and 5G with data demand growing
Use cases	• Mission critical IoT: **Factory Automation** and **Public Safety** (and potentially autonomous cars) • **Massive sensor IoT**: monitoring and automation of infrastructure, **Logistics/Track and Trace** etc.

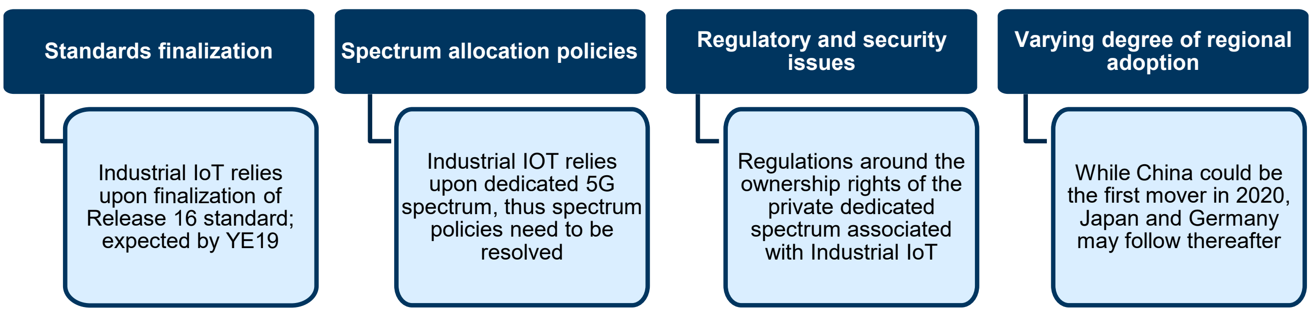
Source: Company data, Goldman Sachs Global Investment Research

...Standards timeline finalisation, spectrum allocation policies and regulatory issues could also be bottlenecks

- The finalisation of standards will be required in our view for take off of Industrial IoT at scale. Given that mission critical IoT is likely to be the most significant use case (i.e. for factory automation) and this relies upon Standalone 5G, specifically that associated with Release 16 standard, which will only be finalised by the end of 2019, this suggests a slower cadence of adoption vs. other use cases.
- We also argue that spectrum allocation policies will need to be settled in the various regions, noting that Standalone 5G, which will be required for large scale industrial IoT (in essence to provide discrete networks that can run on their own spectrum) relies upon dedicated 5G spectrum. We also believe there are regulatory issues that will need to be worked through i.e. Germany is working on regulations to allow the land owner of the industry to own the spectrum for Industrial IoT in Germany.

- Importantly, we see a varying degree of regional adoption. We believe that China will be in the vanguard of Industrial IoT adoption, as part of its 2025 strategy, given scope to further industrial automation as explained in *Cycle could be relatively elongated and shallower vs. prior ones given range of timelines* section.
- We believe that while China could be the first mover in 2020, Japan may follow thereafter as a function of industrial competition, and our industry discussions suggest that Germany could move next. **Our European Industrials analyst discusses some of the potential implications of 5G for factory automation in *Industrial IoT end applications deepdive* section, and our China and Japan Industrials analysts discuss the implications of industrial IoT for their respective regions.**
- Overall, we see Industrial IoT as likely to be deployed in 2021/22, i.e. 12-18 months at least *after* eMBB (i.e. this could represent a second wave of investment, with potential upside skews). However, we do not see it as likely to boost the wireless infrastructure market to any significant degree in the next two years. Indeed it is possible that rollouts more broadly could be most meaningful towards the middle of the next decade.

Exhibit 8: Standards timeline, spectrum policies and regulatory issues are the major bottlenecks in the adoption of 5G for Industrial IoT



Source: Company data, Goldman Sachs Global Investment Research

- We believe there is the potential for **Industrial IoT** to expand the telco TAM *in the medium to long term* and hence our market growth analysis (detailed in exhibits 26-35) suggests that in a positive scenario (if one were to assume that Industrial IoT drives a 10% higher cumulative Wireless spend on 5G vs. 4G) the wireless equipment market could grow at a c.6% CAGR over 2018-22 (vs. 3%-4% in our base case). Our analysis also suggests that if Industrial IoT results in a 15% uplift to the size of the 5G cycle vs. 4G, this would result in the expected wireless market CAGR (2018-22E) to be c.8%.
- We see this as meaningful given scope for further TAM expansion post 2022 as regions such as China and Europe build out their Industrial IoT capabilities at scale. See *Cycle could be relatively elongated and shallower vs. prior ones given range of timelines* section for more detail.

Enhanced Mobile Broadband (eMBB): telco benefits skewed to cost dynamics of data provision rather than differentiation/market share

Telco benefits in the mid-term are skewed to cost of provision in our view rather than long term market share and while commercial rollouts are starting, the cycle could be elongated. Enhanced Mobile Broadband (eMBB), essentially the provision of better connectivity performance to smartphones (theoretically 10x faster speeds), will in our view deliver telcos benefits in the form of continued cost reductions in the provision of data connectivity. That said, we characterise this as essentially in-line with what each generation of wireless technology has typically delivered i.e. a continuation of the cost-down curve for data capacity provision, as opposed to involving a step change in functionality and/or the telco TAM. While eMBB may offer some short term marketing advantages to telcos in our view, we do not see it as something that will deliver *sustainable* differentiation/market share gains. Thus, while its utility is clear, eMBB appears to offer less scope for disruption and/or a step change in the TAM available to telcos (and wireless equipment spending) as compared with other use cases e.g. Fixed Wireless. While eMBB can be delivered using both NSA and SA variants of 5G, and thus rollouts are already occurring using the former, we believe certain associated challenges, alongside the timelines both for regional rollout plans and device ecosystem development, suggest the related revenue profile for technology vendors may be relatively elongated but shallow.

Enhanced Mobile Broadband will in our view deliver telcos benefits in the form of continued cost reductions in the provision of data connectivity

- This use case involves delivering smartphone data connectivity at significantly faster speeds as compared with 4G (theoretically up to 20Gbps vs. LTE at 1Gbps today). Given that data traffic will grow 8x out to 2023 (as per Ericsson Mobility Report June 2018), this offers scope to deal with this phenomenon in a cost effective manner. In other words this allows for the cost of data provision to be lowered each year, which is important given that subscriber growth is broadly speaking flat on a global basis. Ericsson notes that telcos on average need to reduce the cost of data provision by 30% per year just to maintain margins.
- 5G has already been tested for data rates of 5-8Gbps in the eMBB context (vs. up to 1Gbps speeds on 4G). Thus eMBB can deliver greater efficiency in spend in the sense that for a given amount of spending, telcos can provide more data capacity. Nokia/Ericsson have stated that eMBB results in reduced incremental telco capex per extra byte of data delivered (especially as it can be built on top of the existing network using NSA, helping reduce cost, as explained elsewhere in this report).
- Meanwhile, we also see cost benefits in the form of reduced telco opex, as life cycle management costs are reduced (given that 5G networks are designed to leverage AI optimisation and other techniques so as to be more automated). This can also free up extra FCF for equipment capex. Additionally, incremental capex for data delivered is lower, as not only are 5G networks typically built upon existing networks, but also there can be lower testing costs (due to a greater degree of pre-integration) and greater cell tower reuse (in the case of Non-standalone). Nokia cited that the total cost of ownership savings of up to 40% is possible, alongside a

10% improvement in network quality and a reduction of up to 18 months in time to market for new services. However, this is only possible when the entire network is streamlined and upgraded end-to-end.

While there is utility related to the cost of data provision we do not see this offering sustainable differentiation to telcos or an increased TAM

- While its utility is clear we do not see it offering sustainable differentiation to telcos or/and an increased TAM. This suggests it is more likely to be a contributor to sustaining rather than boosting the wireless equipment market, whereas other use cases e.g. Fixed Wireless could offer greater potential to offer upside skews to the wireless equipment market.
- Key use cases include both better connectivity for smartphones (faster data connectivity, alongside VR/AR), but also logistics tracking, and certain applications that use data heavily in indoor environments that require low mobility e.g. smart buildings.
- While we believe that the ability to continue to deliver more data at reduced costs, as explained above, is key to telcos as they seek to preserve FCF margins, we do not see this as a technology that is likely to meaningfully boost the overall telco TAM. In particular, our industry discussions suggest it may offer a short term marketing advantage to the first movers, but we think that similar to 4G, it will not offer scope for any telco to drive longer term market share gains sustainably. We believe that in the long run, it will become more commoditised.

Some 2H18 rollouts on NSA envisage use of eMBB, as it can be delivered on both NSA and SA, but we see it as more of a mid-term dynamic

- Enhanced Mobile broadband can be delivered on both NSA and SA variants of 5G and thus some 2H18 rollouts in the US already envisage use of eMBB eventually (once upgrades are made).
- eMBB is based initially on the NSA networking leveraging the installed base (i.e. the pre existing 4G network). That said, in the longer term, eMBB can be enabled using SA 5G, as this can deliver benefits including easier installation (no complex integration with legacy 4G network) and more control over latency.
- Technologies required to deliver eMBB include not only NSA base stations, but also a self scaling core (i.e. a network that can scale in automated fashion according to the capacity needed). While Massive MiMo (which can multiply the capacity of a wireless connection without requiring more spectrum) may need new in-fill sites to be build (e.g. using lamp posts) which can be costly in terms of capex and opex) it is possible to deploy mmWave on existing macro sites.

Exhibit 9: Enhanced Mobile Broadband serves smartphone data demand and is an evolution of existing 4G architecture with better capacity (and faster speeds)

	Enhanced mobile broadband (eMBB) as a use case of 5G
Overview	• Smartphone use case offering **superior speeds to 4G** to address growing data traffic • Allows **lower cost** for data per GB for telcos (important given subscription growth is flat) • Telcos **need 30% cost reduction** per year to maintain margins; 5G eMBB is more cost efficient vs 4G
Technologies needed	• Non-Standalone (NSA) and Standalone (SA) can deliver enhanced mobile broadband • 5G enhanced mobile broadband requires a **self-scaling core** i.e. network can scale in an automated fashion • Massive MiMo **may need new sites** (e.g. lamp-posts) but can deploy mmWave on existing macro sites
Non - Standalone/ Standalone	• Enhanced mobile broadband is based initially on the **NSA network** leveraging the installed base • **Reduced incremental telco capex** per extra data delivered (as can be build on existing network using NSA)
Initial case for operators	• 5G already been tested for 5-8Gbps (vs up to 1Gbps speed with 4G); can provide a potential 10-40Gbps as well • **Reduced telco opex** as life cycle management cost is reduced (with e.g. cloud native/AI optimisation etc.) • **Incremental capex** for data delivered **reduced** (built on existing network, lower testing cost, cell tower reuse)
Challenges	• Telcos require **more efficient radio access** & **core network** to achieve expected speed and latency of eMBB • Evolution of **5G handsets**; expected to roll out in early **2019**; reach **mass market** penetration in **2020-21** • NSA version of eMBB can be done using existing spectrum; **SA version** of eMBB will require **new spectrum**
Expected rollout time	• Standards relating to eMBB based on **non-standalone** have been **finalised by 3GPP** in June 2018 • **Commercial deployment** of 5G networks for eMBB is expected in **2020 in US** (and Europe thereafter) • 5G compatible smartphones are expected to be launched in 2019
Regional adoption	• More suitable for certain geographies where affluent subscribers can pay for eMBB services e.g. in cities • **US** is expected to be the first adopter of enhanced mobile broadband in 2019, **large scale rollouts in 2020-21** • **Europe** making moves towards 5G with recent spectrum **auctions** in Italy, Spain and Finland concluding in **2018**
Use cases	• **Smartphones**: **Faster data** connectivity and **video**, **AR/VR applications** • Connected devices to follow **logistics tracking, agriculture** and **asset tracking** • Heavy data use in indoor environment that require low mobility e.g. **smart office, smart buildings**

Source: Company data, Goldman Sachs Global Investment Research

- We note Nokia has stated that the main advantage of using 5G in eMBB (once an upgrade to 5G is eventually made in coming years) is the scope for operating cost reduction for telcos. It can be based initially on the NSA network, and later be provided on an SA network once eventual deployment of SA occurs.

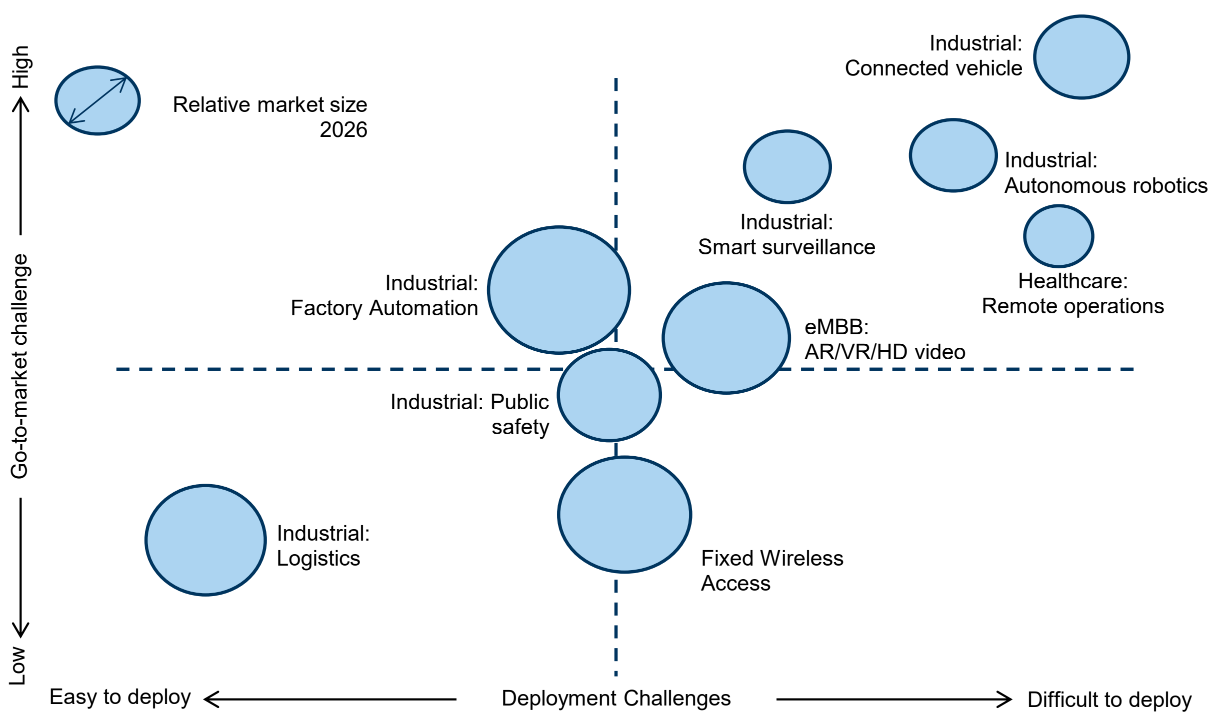
Given certain technical challenges, varying regional rollout plans and device ecosystem timelines, the shape of associated vendor revenues in future years could be elongated but shallow

- We believe certain associated challenges, alongside the timelines both for regional rollout plans and device ecosystem development, suggest the related revenue profile for technology vendors may be relatively elongated but shallow for eMBB.
- Rollouts are already occurring using NSA that is eMBB capable (full capabilities of 5G will be unlocked once hardware/software upgrades are made and spectrum is available, pending which 4.5G technology offers better performance than 4G. We explain it in the Non-standalone section below). That said there are certain

challenges that could slow down adoption. For example, telcos require a more efficient radio access and core network to achieve full speed and latency on eMBB. Further, while the NSA version of eMBB can utilise existing spectrum (4.5G performance), the SA version which will bring benefits like easier installation (no complex integration with legacy 4G network) and higher efficiency in terms of latency will require new spectrum.

- We also note that while some 5G handsets will rollout in 1H2019, mass market proliferation is not expected until 2020-21.
- Further, regional adoption intentions vary greatly, driven by factors including telco competitive intensity but also regulatory priorities. Thus, we note that the US is expected to be the first adopter with initial commercial rollouts in 2019, but with large scale rollouts in 2020-21, with Europe and other geographies following a less rapid cadence of rollout. We also note that the emphasis in China may be biased towards Industrial IoT, with eMBB at scale a year after the US.
- Taken together, we believe these factors may suggest the related revenue profile for technology vendors may be relatively elongated/sustainable but shallower for eMBB. Thus, we believe investors will need to take into account competitive positioning of various tech vendors.

Exhibit 10: 5G use cases expected to increase the TAM for telcos



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 13: We see Fixed Wireless Access and Enhanced Mobile Broadband as the most important near term use cases, with Industrial IoT a mid term driver

Use case evolution and supporting technology

		4G/Current	On the road to 5G	5G experience	Level of traction
Fixed Wireless Access		1bn+ homes without regular broadband	Wireless data connectivity in place of fixed line	Internet with speed greater than cable	✓✓✓
Enhanced Mobile Broadband		Smartphones based	New tools to enhance user experience	Full Immersive experience e.g. VR	✓✓
Industrial IoT	Factory Automation	Process automation	Flow management and remote supervision	Cloud robotics and remote control	✓✓
Industrial IoT	Public Safety	Voice-based legacy technology	Enhanced speed of response	Real-time mission critical communication	✓✓
Industrial IoT	Energy, Utilities & Logistics	Metering and smart grid	Resource management and automation	Machine intelligence and real-time control	✓
Healthcare		Connected doctors & patients	Monitoring and medication e-care	Remote operations	✓
Automotive		On demand in-vehicle information	Real-time Information vehicle-to-vehicle	Autonomous driving	?
Technologies		• Multi-standard network • Cat-M1/NB - IoT[1] • Cloud optimized functions • VNF[2] orchestration	• Gigabit LTE[3] • Massive MIMO • Network slicing • Predictive analytics for telcos	• 5G NR and 5G Core • Virtualized RAN • Federated network • Distributed cloud • Real-time machine learning/AI	

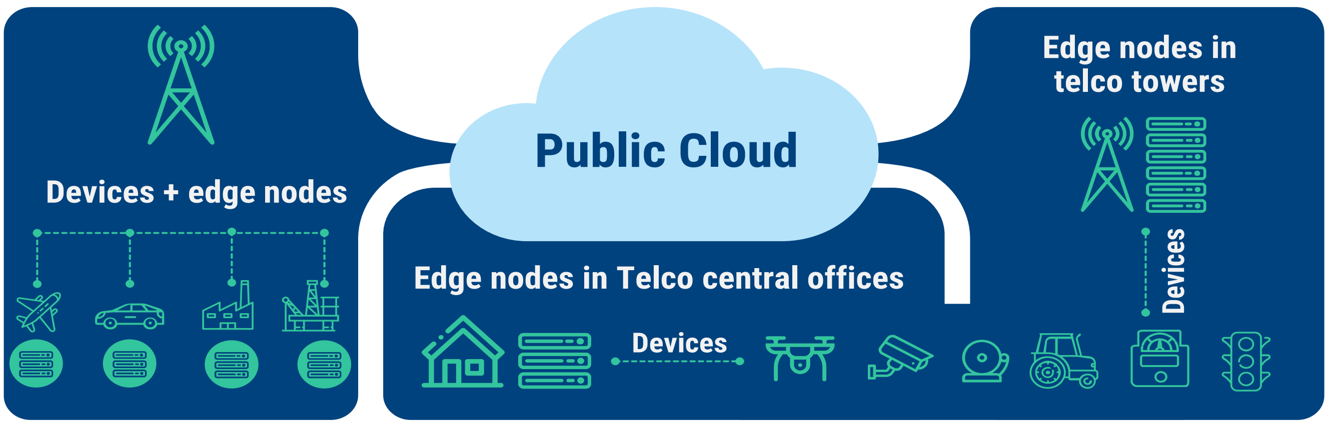
[1] *Cat-M1/NB – IoT: Category M1 (Cat-M1) and/or Narrowband IoT (NB-IoT) LTE - based technology to enable massive IoT use cases*
[2] *VNF: Virtual Network Function; automated procedures to onboard software-based network functions for multiple vendors*
[3] *Gigabit LTE: LTE Advanced for much higher peak rates*

Source: Company data, Goldman Sachs Global Investment Research

Edge Computing

Why do we need it? Network capacity and the speed of light limit both how much data can be transmitted over distance and how fast various workloads can respond to stimulus at the edge of the network. Placing computing infrastructure closer to users allows this infrastructure to pre-process large datasets and only send extracts of this data back through constrained networks. Edge compute also reduces latency between the applications running and users or IoT devices at access end of the network.

Implications for infrastructure. We believe that edge computing is likely to be mainly deployed by telcos who have needed real estate in strategic edge locations. To the extent that cloud players attempt to deploy their own edge compute we would see material upside for infrastructure vendors who might supply that build.



Source: Goldman Sachs Global Investment Research

Perspectives on 5G from **Börje Ekholm**, President and CEO of Ericsson

Q. What is your vision for 5G? What are the most innovative things that could potentially be done with this technology?
A. 5G is a platform for innovation. Previous generations were centered around consumer and personal communications. 5G will serve consumers, enterprises and take the internet of things to a next level, where superior connectivity is a prerequisite. We see 5G to be used primarily in three areas: Initially, 5G will be a capacity enhancer in metropolitan areas. We predict mobile data traffic growth will increase more than five times until 2024. Enhanced mobile broadband will be a way for operators to manage the cost and the quality for end users. This is in line with what consumers want. More than 70% of consumers expect 5G to provide better performance such as faster speed, better reliability and lower latency, according to Ericsson Consumer Lab study. That will enable consumer offerings around gaming, video and AR/VR.

For many telecom operators, it will make sense to build out fixed-wireless access as an access technology for broadband using 5G. Specially for households or small enterprises in the underserved areas where the cost to build fiber to the home is high. Over time, new, exciting innovation for 5G will come with IoT use cases. We will likely find the most transformative use cases in critical IoT, where the speed, latency and security of the 5G network will be key. Here we can see 5G's potential to transform industries and society at large – with use cases such as smart manufacturing, smart cities, self-driving cars and advanced healthcare applications just to mention a few.

Q. What is the justification for telcos using 5G, both for Non-Standalone and Standalone, across smartphone, fixed wireless, industrial and other areas? How should we think about revenue generated or cost saved that would justify them making the investment? To what extent have telcos made progress defining the business case for these?
A. The initial payback for 5G to telecom operators is lower cost to address traffic growth. These cost efficiencies will be enough to cover spectrum licenses and upgrades to 5G. For operators to prevent spiraling costs or having to degrade performance for end users in the network, they will have to lower the cost per gigabyte. This can be done first by adding more radio spectrum (carriers) to a 4G network, adding advanced antenna technology such as MIMO and eventually upgrade to 5G especially in densely populated areas with high capacity needs in the networks. According to our economic study of enhanced mobile broadband, 5G will enable 10 times lower cost per gigabyte than current 4G technology.

Non-standalone (NSA) enables operators to leverage existing installed base of 4G networks to launch 5G new radio (NR) sooner. Most operators will start with NSA and then, after NR coverage has been established, deploy also standalone (SA). All 5G base stations will support both NSA and SA. SA requires an upgrade to a more modern core network, 5G core. The specifications for 5G SA standard were concluded about half a year after NSA. The 5G core network has been standardized with a service-based architecture that facilitates new service introductions, such as more advanced network slicing. It is also defined to be the same core network for mobile and fixed services.

On top of the cost efficiency payback, telecom operators have options to address new incremental revenue opportunities based on their market specifics. For some, fixed wireless access will be a key growth opportunity to address a new market or underserved customers. We have also done an economic study of fixed wireless access and investments payback time is less than two years. Fixed wireless access is starting in North America, but we see it gaining momentum also in other parts of the world.

As mentioned earlier, another opportunity is massive and critical IoT. Industry digitalization and 5G open up new material revenue opportunities for telecom operators. We see many progressive operators already starting to experiment and address these opportunities, based on 4G, with a mindset on the opportunities that 5G will offer. To better understand new use cases, support our customers and build an ecosystem, we are collaborating with leading telecom operators worldwide, more than 40 universities and technology institutes and 20 industry partners.

Q. How do you think China will approach 5G – it seems as though the focus will be more standalone vs non-standalone? How important is Industrial IoT for the region?
A. In China, we see increasing 5G field trials, which will be ongoing until mid-2019. We expect commercial network deployments in China to start second half of next year, with broader commercial deployment expected from 2020. China is a special market when it comes to scale. Each Chinese operator has millions of LTE base stations compared to hundreds of thousands for the biggest networks in other parts of the world. To put the 5G field trials in China into perspective, they are almost the size of a network in a small European country. The ambition of 5G network deployments in China is expected to be high, both in scale as well as with earlier adoption of standalone (SA) compared to other parts of the world. There is a strong drive in China for 5G industrial applications, for example smart manufacturing and connected vehicles.

Q. What are the key swing factors for 5G which could make the upgrade a "big" cycle vs. what could make it a disappointment?
A. First, it is critical to have radio spectrum available for 5G and we have seen many countries already concluding spectrum allocations. Moreover, a major difference with previous generation shifts is that telecom operators will be able to migrate existing 4G spectrum to 5G in a much easier and more efficient way than ever before. We call it spectrum sharing, and it essentially means that an operator can run 4G and 5G devices on the same carrier. This means that operators will be able to re-use existing spectrum, e.g. lower bands, and thereby roll-out 5G coverage smoothly.

Second, the 5G adoption will depend on the speed and scale of 5G network launches. For instance, in the US, 4G network launches were spread from 2010 to 2012 (over 30 months). For 5G, the launches are expected be closer and all four big operators have already released 5G launch plans. It is important to watch resolution on M&A transactions and new entrants (e.g. Cable). China launched 4G at the end of 2013 which was relatively late compared with other markets such as the US. For 5G, only the future will tell, but launches of 5G networks in China are likely to come sooner than with 4G. The size and scale of 5G roll out in China is an important swing factor. For Europe, we had various spectrum auctions in 2018 and a few operators being public about their 5G launch plans in 2019.

Third, there need to be 5G devices available not only for launch but broadly available. More importantly, we need to see how fast device prices will decline for 5G. In general, we have seen a 5G momentum accelerating faster than in other generations with, for example, standardization being concluded earlier than expected. We are closing 2018 with continued good momentum on 5G and concrete prospects for launches in 2019.

Significant 5G progress since our 2016 report

5G activity has picked up in the last 6-12 months; contingencies for full Standalone (SA) rollout yet to be met but progress underway. We believe that activity on 5G and related technologies has picked up meaningfully in the last 12 months, driven by several key factors. While we perceive there was increasing investor scepticism about the technology in the 18-24 months period after we wrote our 5G roadmap report in 2016, momentum has increased more recently, and near term we see potential acceleration related to Fixed Wireless. We note that overall 5G trial activity has increased, standard setting has progressed markedly, and commitments to rollouts (especially in N. America) are being made, with initial Non-standalone buildouts (NSA; i.e. 4.5G upgradable in future years to full 5G) occurring already, as evidenced in equipment suppliers' financials. While Standalone rollouts (5G that works as such at the point of installation) remain at an extremely early stage even in the most advanced markets, we note vendors have increased their 5G R&D spend. Indeed, spectrum auctions are also progressing in several geographies. It is also important to note that the existence of NSA 4.5G/5G offers telcos with capacity shortages an immediate ability to add cellular capacity that is effectively future proof. Overall, while we believe there are still key contingencies to be met for full-blown commercial Standalone 5G rollouts, progress is underway with meaningful rollouts starting in the US in 2019. Even if we do not necessarily see a step change in the size of the 5G cycle vs. the prior 4G cycle, the wireless equipment market is starting to grow off a low base, after four straight years of declines.

Exhibit 12: Contingencies for 5G adoption yet to be met but progress under
Standards, business model clarity, device ecosystem are key bottlenecks

Source: Company data, Goldman Sachs Global Investment Research

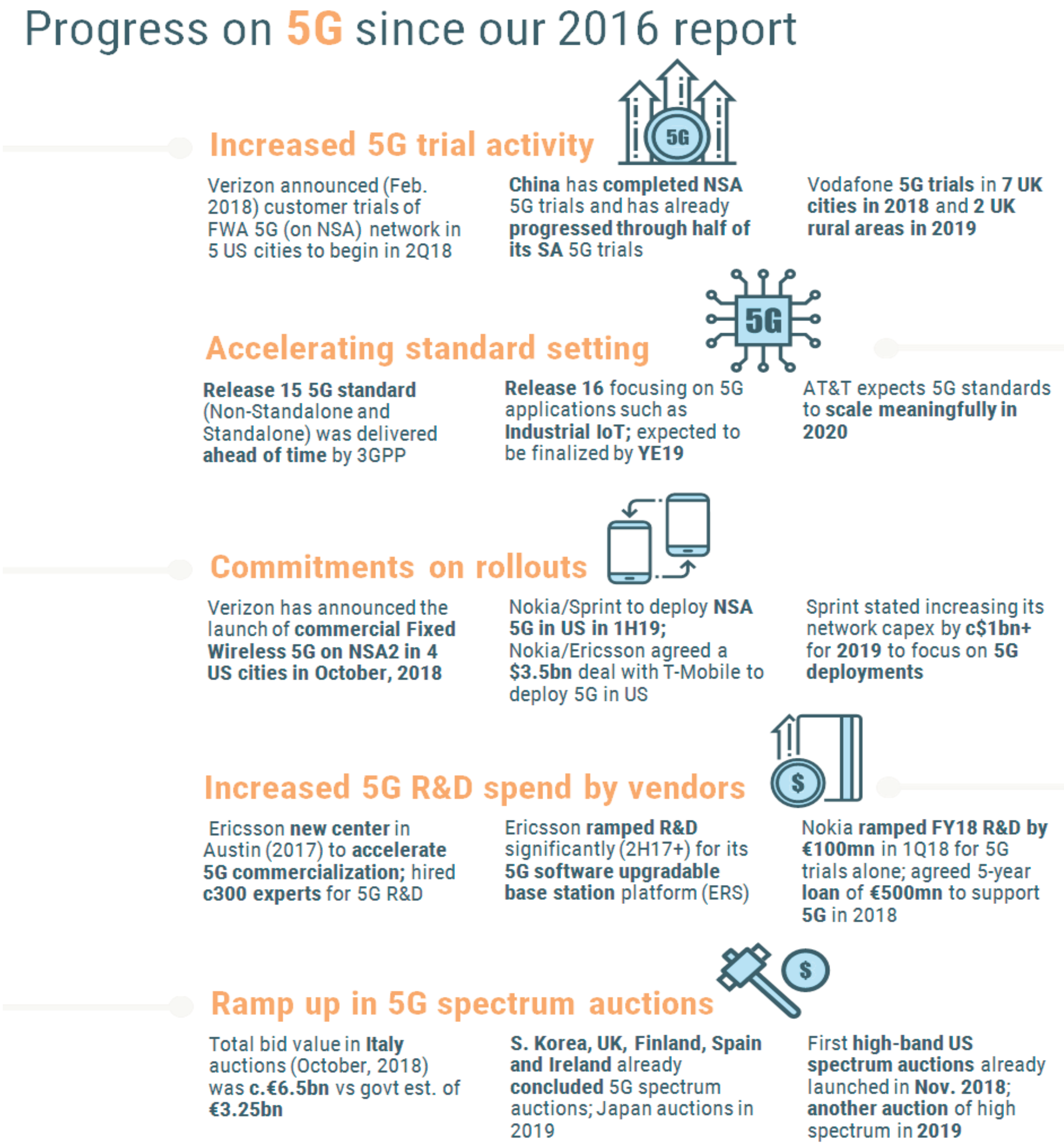
While there are meaningful geographic variations, we note overall 5G trial activity has accelerated

- We believe that different geographies are proceeding at different paces, with the US and other countries in the lead. This is to some extent a function of different economic conditions for telcos in certain regions (i.e. competitive intensity / profitability) but also to some degree due to different regional approaches to pursuing the use cases enabled by 5G (enabled by faster speed, better latency and higher reliability). For example, the Fixed Wireless use case, discussed in detail elsewhere in this report, looks likely to be adopted more aggressively in the US than in other developed regions. Nevertheless, we believe that trial activity has begun in earnest in the key regions, especially those that are normally the earlier adopters of new wireless technology.
- Verizon conducted customer trials on fixed wireless 5G (leveraging Non-standalone 5G technology) in five cities, including Houston and Sacramento in 2Q18. This preceded its commercial launch in four cities on 1 October 2018.
- Moreover, China has completed Non-standalone 5G trials and has already progressed through half of its Standalone 5G trials.
- We see Europe as likely to be slower than other regions to adopt this new technology, but note that Vodafone targets seven UK cities this year, with two rural area trials planned for next year.

...And standard setting activity has progressed markedly, with releases ahead of target

- We note that key standards have actually been released *ahead* of initially envisaged timelines. Given that the setting of standards involves an intensive level of engagement by infrastructure vendors, we believe this would tend to indicate a certain degree of progress by the technology ecosystem.
- Importantly, we note that the Release 15 5G standard was delivered a year ahead of the timeline initially targeted by the 3GPP (the standard setting body). This was finalized in two phases; the first phase encapsulated standards related to Non-standalone base stations in December 2017 (i.e. 4.5G upgradable later to 5G once spectrum etc is finalized in a given telco's territory) and the second phase involved standards for Standalone base stations in June 2018 (i.e. base stations that work on 5G as soon as they are installed). Thus Non-standalone 5G standards have been completed and the main base standard for Standalone 5G is already finalized.
- Standards related to certain (more mid term) applications of 5G remain to be settled, for example those relating to Industrial IoT use cases will be contained in Release 16. However, this is currently in progress, and is expected to be finalised by YE19.
- We detail the 3GPP (the standard setting body) timelines in more detail in our *Cycle coule be relatively elongated and shallower vs prior ones given range of timelines s*ection, and a summary is presented in Exhibit 21.

Exhibit 15: 5G activity is picking up with progress on timelines, R&D, and standards; Fixed Wireless rollouts near term



Source: Company data, Goldman Sachs Global Investment Research

Further, vendors have increased their 5G R&D spend, with spectrum auctions also progressing in several geographies.

- Another indication of continued progress on 5G is the increased R&D spend specifically targeted towards it by leading base station suppliers.
- We note that Ericsson, for example, ramped R&D significantly in 2H17 onwards, so as to deliver various iterations of its 5G software upgradable base station platform (ERS), and continues to maintain high levels of 5G development spending with a view towards progressive Standalone 5G rollouts. It also hired 300 engineers in Austin at a new centre dedicated towards accelerating commercialisation of 5G.
- Meanwhile, Nokia at 1Q18 results stated it had increased R&D spend by €100mn for 5G trials alone, and one of the reasons cited for its latest cost savings program (announced at 3Q18 results) was to allow for investment in R&D (for such technologies).

… and commitments to commercial rollouts (especially in N. America) have been solidified, with the very first Non-standalone commercial build-outs already occurring and high profile Fixed Wireless rollouts in the US

- While this year full Standalone 5G rollouts will be a very small part of the wireless infrastructure picture (and associated revenues for wireless vendors in 3Q18 were de minimis), we note that there is already momentum behind Non-standalone rollouts, with impacts already visible in supplier's financials related to N. America.
- In particular, Verizon already launched its commercial Fixed wireless 5G offering based on Non-standalone technology in four US cities on 1 October 2018. Sprint and T-Mobile meanwhile will ramp 5G offerings in 2019.
- While Non-standalone technology (i.e. 4.5G that is upgradable to 5G in the next 1-2 years) is currently larger in the mix (vs. Standalone), we see this as coming under the broader 5G umbrella. While the rollouts are arguably to a significant extent driven by the requirement for extra capacity *now* at reasonable cost (independent of 5G features), the motivation to invest in these now is driven at least to some extent by certain benefits that will be unlocked *in future* by 5G functionality being switched on (i.e. in the next years), even if the most prominent use cases are the subject of debate. Further, we see the US, as one of the early adopter markets, as likely to start to build out Standalone 5G in 2H19, as explained in Exhibit 25, albeit we would stress that other regions will likely see more meaningful critical mass of Standalone rollouts more towards 2H20 (Korea/Japan) or even 2021 (Europe).

…and while certain key contingencies must be met for full-blown commercial Standalone 5G rollouts we believe progress is being made

- Whereas we believe there are still key contingencies to be met for full-blown commercial Standalone 5G rollouts (i.e spectrum policy and device ecosystem readiness), we believe progress is underway in these areas.
- As explained in Exhibit 14, further progress is required to deliver a coherent spectrum policy in key regions. That said, even in Europe, where we believe the

ramp could be slower than other regions, there have been 5 spectrum auctions completed in the last 6-12months. While the spectrum auction in Italy led to bids valued at €6.5bn, 2x the initial estimate, we believe that this was to some degree due to idiosyncratic features (albeit it would seem to some extent to underline a meaningful level of interest in 5G even in one of the less advanced regions). Further, while our industry discussions suggest a need for the US to accelerate the crystallisation of spectrum policy for the 3.5GHz band, the first high-band US spectrum auctions launched on 14 November, 2018 and another auction of high-band spectrum planned in 2019. Japan auctions are also scheduled in 2019. The FCC, led by chairman Ajit Pai, is currently making a concerted effort to make substantial amounts of spectrum available for 5G deployment over the next few years.

- We also see evolution of an affordable and high performance device ecosystem as a key bottleneck to broader adoption of Standalone 5G, albeit we do not see this as insurmountable. While 5G Dongles/pucks are expected to launch in 2018 (key for Fixed Wireless Access as a use case), initial 5G handsets are only expected to be released in early 2019, and then only in small volumes. We see the timeline for rollouts of mass market smartphones as key to the feasibility of the Enhanced Mobile Broadband use case (which we see as more mid term). We expect mass market rollouts beginning in late 2020, with Apple's timeline a key swing factor.

Exhibit 14: 5G ecosystem is accelerating with Fixed Wireless the most differentiating use case

Fixed Wireless incremental telco TAM

- **1bn+ homes worldwide** without a regular broadband connection can potentially be served with 5G Fixed Wireless
- **Fixed Wireless Access** can drive an **incremental TAM** of **10%-15%** of telco's wireless service revenues
- 5G Fixed Wireless **costs 50% less to roll out** vs fiber (i.e. €1k-2k for Fixed Wireless vs €2k-4k for fiber roll out in rural areas)

Smartphone use case cost reduction

- Smartphone **data traffic** expected to grow **10x in 2015-21**; telcos need to **reduce costs by 30% p.a.** to maintain margins
- eMBB **reduces** telco's **deployment opex** (sharing current assets) and **run rate opex** (automation of software and network functions)
- 5G can offer **enhanced speed, latency, capacity** as compared to 4G

Serve new end markets (e.g. Industrial)

- Increased demand for Industrial IoT as 5G can provide **better latency, reliability** and **security**
- Potential no. of private IoT networks to be built requires **2x no. of base stations vs today** (i.e. 14mn vs 7mn)
- Globally **>120 first responder networks** (mainly based on legacy technology) - **require upgrades**

5G as a competitive tool for telcos?

- 5G could be used as a **competitive marketing tool** by telcos, especially in the early phase of rollouts
- Vendors have **increased** their **5G R&D spend** to accelerate 5G deployment e.g. Nokia increased FY18 R&D spend by **€100mn** for 5G trials alone.
- However, while there is evidence that **'first-movers'** in 4G made higher ARPUs, this **advantage tends to normalize over time**

Source: Company data, Goldman Sachs Global Investment Research

Perspectives on 5G from **Rajeev Suri**, President and CEO of Nokia

Q. What is your vision for 5G? What are the most innovative things that could potentially be done with this technology?
A. Even before 5G is commonplace, one thing is abundantly clear: it will transform both the consumer experience and a wide range of industries, from manufacturing to mining to healthcare. It is ten times faster than even the fastest 4G networks, it possesses one millisecond latency and it can support one million connected devices per square kilometre. 5G will mean products, services and experiences that today's networks are simply unable to support. We are particularly excited about what 5G will bring for enterprises and the public sector. It will open the door to the Fourth Industrial Revolution, with mass automation, machine learning embedded within every network element and massive machine-to-machine communications, all with only light-touch human oversight. The factories of a few years' time will be unrecognisable from today's.

We can see tantalizing glimpses of this today in Nokia's own 'conscious factory' facility in Oulu, Finland. It runs on 4G, so its potential hasn't been fully realized yet. But even now, it provides a blueprint for highly predictable manufacturing. Waste has gone down, productivity has gone up. This is partly down to the precision of the machines themselves, but it also relies on the intense use of data which is characteristic of Fourth Industrial Revolution technology.Whatever 5G's most innovative application is, my prediction is that it will be built on an end-to-end network – in other words, a network in which every element is designed to work with every other element, with efficiency and security built in. Nokia is the best vendor to help, given our end-to-end portfolio, market leading positions in each domain, and strength in services.

Q. What is the justification for telcos using 5G, both for Non-Standalone and Standalone, across smartphone, fixed wireless, industrial and other areas? How should we think about revenue generated or cost saved that would justify them making the investment? To what extent have telcos made progress defining the business case for these?
A. The justification is this: 5G will make telcos money. That is why they are excited about 5G and are taking steps to roll it out early. Consumers and industry are hungry for new capabilities that are better, faster and more reliable than those we have today. In order to capitalize, telcos must be in a position to sell these new capabilities. They must evolve beyond the limits of a communications service provider, or CSP – a provider of SIM cards and connectivity – and become a DSP, or digital service provider – selling services and products specific to each customer. It means moving beyond transporting data from point to point, and adding some value to that data on the way.

For example, a smart factory needs far more than just access to a core network. It needs inbuilt AI, repair data and drones to use it, AR equipment for staff and so on. Some businesses might want to procure and maintain all of this in-house, but many will want trusted telco partners to provide it for them. They will be willing to pay for the additional value unlocked by these services. So the onus is on the telcos to become capable of selling what their customers want. This will require significant capex, yes, but the resulting revenue and profit growth opportunities are game changing. For telcos who leverage next-generation digital communication networks that go beyond connectivity – such as network slicing and massive MIMO, edge cloud, or new enterprise-focused digital applications – we predict a jump of approximately 150% in revenue and 200% in EBITDA for the enterprise segments of these businesses between 2018 and 2028.

Game changing indeed. And there is yet another game changing opportunity which we don't think has been sufficiently explored. This is the potential for our telcos to drive large opex savings for themselves through network automation. We believe total cost of ownership savings of up to 40% is possible, alongside a 10% improvement in network quality and a reduction of up to 18 months in time to market for new services. But this is only possible when the entire network is streamlined and upgraded end-to-end. This is encapsulated in Nokia's 'Future X' blueprint, and we have already worked with dozens of customers who want to apply this blueprint to their own network evolution plans. In terms of Standalone and Non-Standalone, we expect initial 5G networks to be deployed on the 5G Non-Standalone standard, which utilises an existing 4G core network to set up connections and then aggregates in 5G radio bearers to add capacity and speeds. Countries that prioritize the industrial productivity opportunity will make more aggressive 5G core investments in order to support the 5G Standalone standard, which is much more flexible and high performance.

Q. How do you think China will approach 5G – it seems as though the focus will be more standalone vs non-standalone? How important is Industrial IoT for the region?
A. Not so much 'China will' as 'China is'. Their approach to 5G has been fast, coordinated and extremely impressive. Widespread commercial rollout of 5G is a central pillar of their latest Five-Year plan. The Chinese government's approach to spectrum, both mid- and high-band, has been particularly proactive: the regulator has promised to release at least 100 MHz of mid-band spectrum and 2 GHz of high-band spectrum for each wireless provider. And unlike their counterparts in U.S. and elsewhere, Chinese telcos face far fewer delays when applying for wireless infrastructure sites.

This approach means China isn't choosing between Standalone and Non-standalone – in other words, they aren't choosing between either bolting on 5G to their existing LTE networks, or building entirely new 5G networks from the ground up. They are doing both. The mid-band availability means that nationwide Non-standalone availability is just around the corner, enhancing existing LTE infrastructure. But the high-band availability means that they will be equally well-placed for Standalone services, with a strong focus on Industrial IoT.

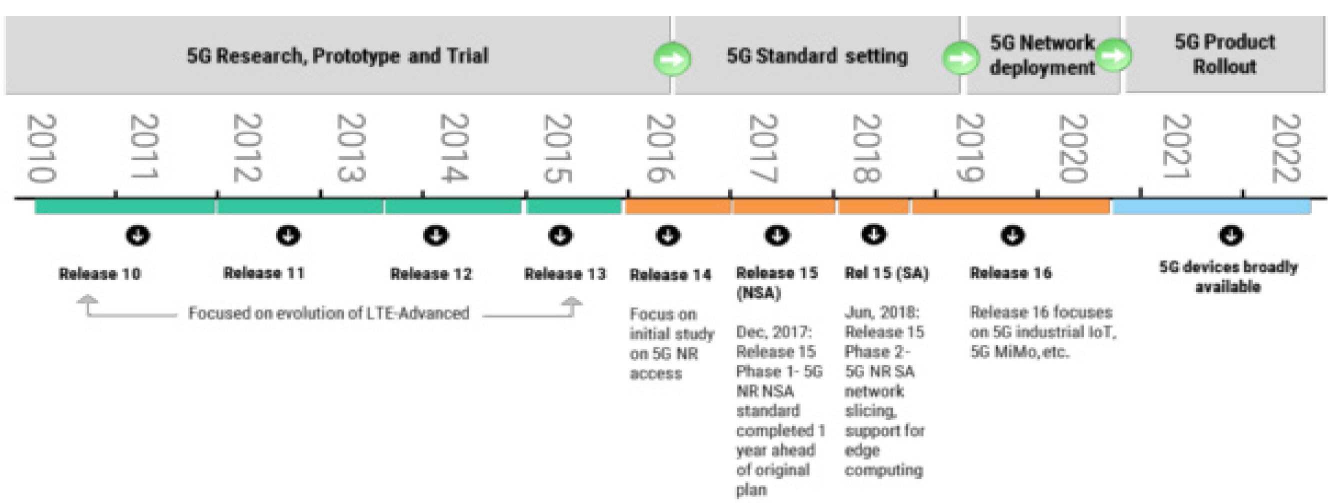
Q. What are the key swing factors for 5G which could make the upgrade a "big" cycle vs. what could make it a smaller cycle?
A. As I see it, the chance of 5G precipitating a smaller cycle is nil. It is much more than just another radio technology upgrade. Everything we have seen, from the technology itself to the enthusiasm with which governments are pursuing the first-mover advantage, points to 5G being a momentous development with multiple cycles of investment and significant potential for disruption.

There are two reasons why. First, an unprecedented amount of spectrum will be deployed on 5G. Low, mid, and high band spectrum will all be utilized. This points to the range of applications that will utilize 5G. Second, the new industrial opportunities created by 5G will unlock a huge amount of previously dormant value. I have already mentioned increased automation, AI, and several other industrial use cases. Companies are willing to pay in order to leverage 5G and improve productivity, just as consumers are willing to pay in order to access new, faster and more immersive services.

Cycle could be relatively elongated and shallower vs. prior ones given range of timelines

Timelines for 3GPP standards, Non-standalone vs. Standalone adoption, device ecosystem and different use cases by region suggest the equipment spending cycle could be relatively elongated vs. prior cycles. We believe the timeline for 3GPP standards releases, Non-standalone vs. Standalone adoption, ecosystem development and regional telco rollouts suggests the overall 5G cycle could be relatively elongated (and shallower) vs. prior cycles from a wireless infrastructure perspective. This is likely exacerbated by a fairly consistent theme of carriers saying they see no real shorter term revenue opportunity with 5G outside of fixed wireless. However, currently available Non-standalone 5G (4.5G) provides a future proof option to upgrade capacity constrained carrier networks now. Thus, we already see signs of recovery in the c$100bn wireless infrastructure market. While 3GPP standards progress has already been significant, we note that releases are staggered between Non-standalone (4.5G upgradable to 5G) and Standalone releases, with different releases for different use cases at different times. Moreover, the dichotomy between Non-Standalone technology and Standalone 5G technology could also lead to the slope of the ramp being shallower, as demand for the latter is to some extent pulled into 2018/19 in our view. Meanwhile, whereas early devices for 5G e.g. home routers and dongles, are available this year, we believe release schedules for some devices (e.g. mass-market smartphones mainly starting in late 2020) suggest certain use cases e.g. Enhanced Mobile Broadband are unlikely to be materially adopted in the next two years. Finally, we anticipate 5G potentially could exaggerate the regionalization dynamic in communication equipment, given that different key geographies (e.g. China) target to adopt the various use cases at different times.

Exhibit 15: 5G standards already set for FWA, eMBB; Industrial IoT standards set by 2019/20



Source: Company data, Goldman Sachs Global Investment Research

Progress on 3GPP standards has already been significant, meaning initial rollouts for certain use cases can proceed, but remaining releases will be staggered...

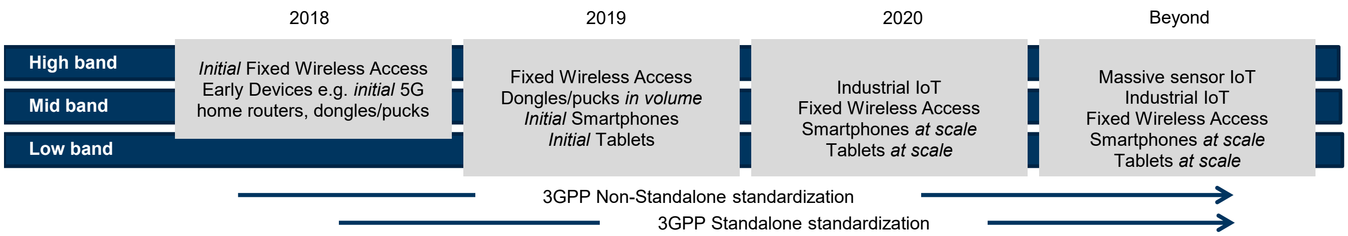
- While 3GPP standards progress has already been significant, we note that releases are staggered between Non-standalone and Standalone releases, with different releases for different use cases at different times. We see these dynamics as suggesting potential for a more elongated cycle.
- We note that Release 15 Phase 1 was already completed in December 2017, which finalized the standards related to Non-standalone base stations (i.e. those that ship as 4.5G but then are upgradable with software and/or hardware plug-ins).
- That said, release 15 phase 2 was completed in June 2018, as illustrated in Exhibit 21, and pertains to the broad architecture for Standalone 5G, thus enabling its application to use cases such as Fixed wireless and Enhanced Mobile broadband. We see commercial rollouts in select geographies in 2019, but a larger scale of ramp will not be until 2020 in our view (with some regions only proceeding to scale rollouts beyond that as per Exhibit 25).
- However, we note that Release 16, which focuses more on the Industrial IoT application of Standalone 5G (amongst other things), is not due until mid 2020, suggesting that this application of 5G is more likely to be seen in the longer term in most geographies (i.e. beyond 2020).

…while the dichotomy between Non-Standalone and Standalone 5G technology could also lead to the ramp being shallower

- The dichotomy between Non-Standalone (NSA) technology and Standalone (SA) 5G technology could also lead to the slope of the cycle being shallower as demand for the latter is to some extent pulled into 2018/19 in our view.
- NSA technology is effectively 4.5G hardware that is sold now that will be upgradable to 5G later via a software upgrade (and or hardware modifications). We explain the difference between NSA and SA 5G, as well as the path to upgradability of the former, and the motivation of telcos to use NSA hardware, in our *Non-Standalone offers eventual upgrade path to full 5G with capacity benefits now* section.
- In the long run, e.g. 3-5 years from now, it will make more sense for telcos to buy a greater proportion of SA 5G hardware from the outset, as by then the standards will be set for use cases like industrial IoT/public safety where there is more benefit to using SA, but also because more spectrum will be available for SA and finally because the SA technology will have come down in price somewhat vs. NSA.
- However, near term telcos are rolling out NSA technology under the broader 5G umbrella with a view to gain an eventual upgrade to full 5G capabilities and use cases later. By utilizing NSA now (effectively 4.5G), telcos can improve their current 4G networks now and leverage existing infrastructure when it comes to upgrading to 5G using upgrades later.
- This should help the wireless equipment market in 2018/19 as carriers can go ahead and increase air capacity and be confident that there is a smooth migration path to full 5G as standards evolve. Indeed this is already benefiting vendor financials.

- However, it could also lead to demand for SA 5G hardware effectively being pulled in, and thus the shape of the broader 5G wireless cycle being shallower. Our scenarios in Exhibits 26-35 aim to illustrate a range of potential outcomes. We note that although several of our Telco analysts for various regions believe overall Telco capex may not be significantly impacted near term, the share of wireless capex may rise on 5G vs. 4G as a result of less need incrementally for new macro sites (as compared with prior cycles) given that the network can be built around the existing installed base. This could mean less civil works and so may therefore free up capex for equipment based capacity spending in our view.

Exhibit 16: Initial devices expected to serve Fixed Wireless Access use cases (routers/pucks, etc.)

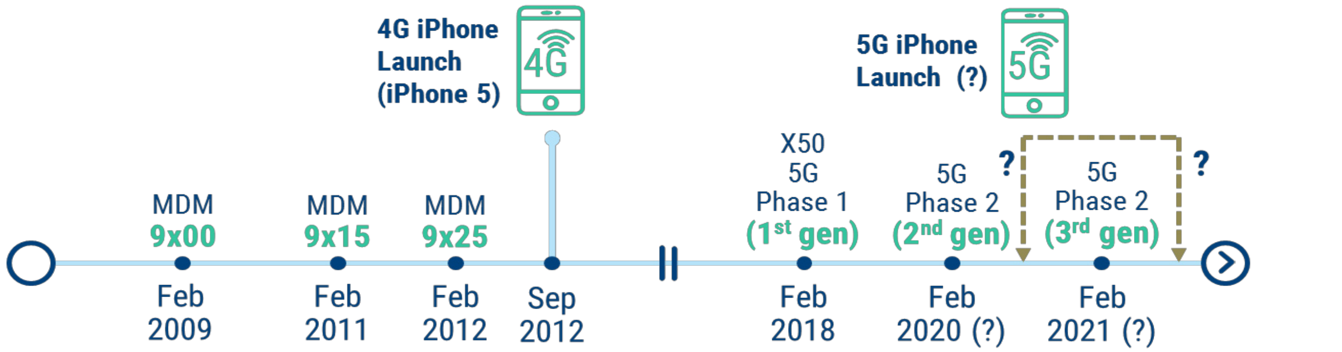


Source: Company data, Goldman Sachs Global Investment Research

We also note that device roadmaps suggest certain key use cases on 5G are unlikely to be seen at scale until 2020 onwards...

- Some early devices for Standalone 5G e.g. home routers and dongles, are already available this year. This will enable proliferation of use cases such as Fixed Wireless in some regions, e.g. the US. Verizon has stated it plans to pass 30mn homes in the US with its 5G network in the next few years. By contrast, T-Mobile US has targeted 10mn homes passed a few years after its launch in 1H19.
- That said, smartphones will only launch in small volumes in 1H19, and mass-market smartphones will mainly start in late 2020 based on our discussions with key vendors like Qualcomm. This suggests certain use cases e.g. cellular coverage (Enhanced Mobile Broadband or EMB) are unlikely to reach full scale adoption in the next two years.
- We see the timeline for rollouts of mass market smartphones as key to the feasibility of the Enhanced Mobile Broadband use case. We expect mass market rollouts in late 2020, with Apple's timeline/intentions a key driver.
- As illustrated in Exhibit 23, devices relevant to certain other 5G use cases e.g. devices required for massive sensor IoT/Industrial IoT may also not be available until 2020. Taken together, we believe this is yet another factor that could drive a more elongated wireless equipment cycle as compared with prior cycles.

Exhibit 17: Chip roadmap critical for device availability



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 18: Market commentary around device availability

Samsung	• Unveiled pre-commercial version of **5G home routers** at MWC 2018 • FCC (regulatory body) approved production of commercial router in May 2018
Huawei	• Introduced **5G customer-premises router** in Mar 2018 • Plans to launch **5G mobile in 3Q19** and **5G autonomous vehicles** (with Audi) by **2020**
Qualcomm	• Working with multiple telcos/manufacturers on **5G devices** and **conducting trials** • Expects **dongles/pucks** to be available by **2018** and first **5G phones in 2019**
Ericsson	• Expects **5G compatible handsets** to be available to consumers **in 2019** • Believes **5G smartphones** will only reach **mass market in 2020-21**
Nokia	• Expects **5G dongles to launch in 2018** and **5G smartphones in early 2019** • Believes smartphone ecosystem evolution will take **some years to be mass market**

Source: Company data

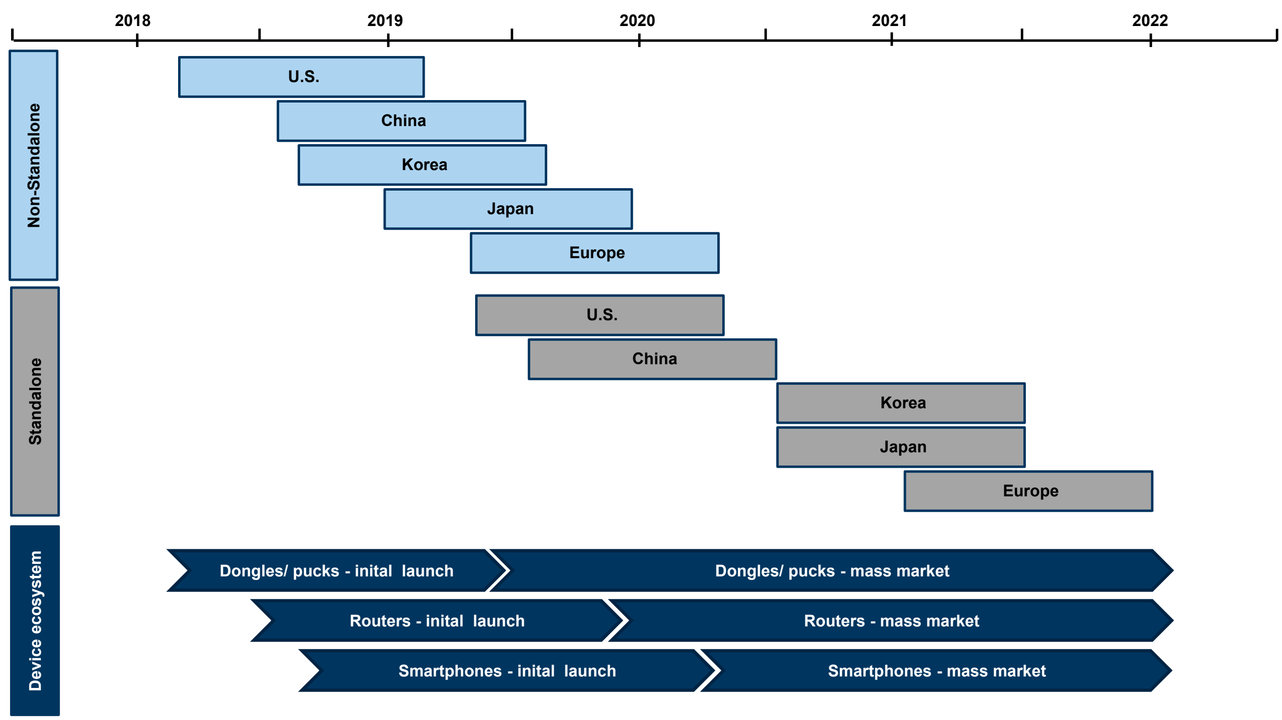
...while different regions e.g. China will focus on different use cases at different times, underscoring the scope for a more elongated but shallower cycle

- Given that different regions will focus on implementing different use cases at different times, we believe that this could lead to the cycle being more sustained than prior wireless equipment cycles, but with peak equipment vendor revenues being less elevated. In other words, we see a shallower cycle as it seems less likely that multiple regions will see peak equipment revenues all at once. In particular, we note that some regions target to implement certain use cases which will only be possible to deliver once certain standards are finalised (e.g. related to latency, network slicing etc.). Thus, **China** (20% of the global market) will likely start to ramp SA meaningfully in 2020-21, with a focus on industrial applications, e.g. smart manufacturing and connected vehicles. These applications will rely on standards that will only be crystallised by YE2019, with rollout thus only likely thereafter. By contrast, the **US** (30% of the global wireless infrastructure market) is already starting to adopt NSA this year (with a bias towards Fixed Wireless Access and Enhanced Mobile Broadband) whereas SA is then likely to ramp in mid to late 2019 (with less of an emphasis on the industrial use case, and more of a reliance therefore on the basic SA standards that were already finished in June 2018). **Europe** (20% of the global market) will most likely ramp NSA in 2019 with SA deployments not likely before 2021. Europe is focusing mainly on the Enhanced

Mobile Broadband and Industrial IoT use cases (albeit again, there will be a phased multi year timeline in our view).

- Meanwhile, **Japan** is focused on NSA currently with focus on Enhanced Mobile Broadband, and Industrial IoT in the longer run. Japan is likely to see pre-commercial mid-band roll outs in 1Q19 to support the Rugby World Cup in 2019 and Tokyo Olympics in 2020. However, major deployments are not likely until 2H 2020/21. This timeline has been shifted out by 1 year due to spectrum constraints (given overlap with satellite services). On the other hand, small-scale NSA deployments are likely in South Korea in early 2019 with large scale SA rollouts likely in 2021.

Exhibit 19: Non Standalone 5G is already being rolled out, with Standalone likely in 2019 and beyond



Source: Company data, Goldman Sachs Global Investment Research

Given a broad array of potential outcomes on 5G cycle evolution, we present a sensitivity analysis; our base case is underpinned by what we view as conservative assumptions vs. prior cycles

- Our base case assumes the *cumulative* overall size of the 5G cycle will be the same as that seen in 4G. Although we believe there could be upside skews to this given the potential for FWA and Industrial IoT to increase the TAM, we do not see Enhanced Mobile Broadband as a game changer in terms of functionality (and see it more as a continuation of capacity enhancement for lower costs as has been seen in each prior cycle). Hence, we think this is a prudent approach.
- We also assume in our base case that the upcoming 5G cycle will see a more elongated trajectory with a more *shallow* slope in the early years. We note initial spending on NSA has already begun, and we expect growth to continue into 2018/19 in the wireless market. We incorporate this longer trajectory into our analysis by assuming the peak of the 5G cycle is two years after the peak seen in the prior 4G

cycle. Hence, our base case assumes we reach peak wireless spending in Year 6 (vs. Year 4 as seen with 4G). As such we assume c3% growth p.a. in 2019/20 which compares to a range of annual growth of high single digits in the initial years of past cycles (i.e. we assume a shallower ramp).

- The eventual size and shape of the 5G cycle is yet to be established, and telco business models for different use cases are yet to be finalised. As such, we present scenarios below on 1) the potential size of the cumulative spending on the 5G cycle vs. 4G, alongside 2) scenarios on the potential impact were there to be a more elongated cycle than was seen in 4G; and 3) potential upside to our base case related to Industrial IoT expanding the market TAM for telcos (note we see this as more of a longer term upside skew).

Our scenarios suggest that in a bull case, the wireless equipment market could grow at c10% CAGR 2018-20 vs. c3% CAGR 2018-20 in our base case...

- While we do not believe eMBB offers meaningful potential to grow the overall *cumulative* size of the 5G cycle vs. 4G, we do however note that **Fixed Wireless Access** is an incremental opportunity for telcos. Thus, we show that in our bull case, if FWA results in the cumulative size of the 5G cycle increasing 10% vs. 4G, this would result in the expected wireless market CAGR (2018-20E) to be c.9% (vs. 3% in our base case). Note this compares to high single digit growth in prior cycles.
- Further, while in our base case scenario we expect wireless capex to peak in 2025 (six years after the expected initial rollouts in 2019), we also sensitise scenarios where capex peaks earlier (i.e. a faster/sharper ramp). Whereas our base case assumes a peak after 6 years (whereas 4G peaked after 4 years), our bull case with this factor assumes a peak after 5 years. Thus, in a scenario where capex peaks one year earlier than assumed in our base case (i.e. in 2024), this would accelerate capex growth in the earlier years of the cycle, thereby raising the expected wireless market CAGR (2018-20E) to c.4% (vs. 3% in our base case).
- In our most positive scenario (bottom right of sensitivity table), one would have to assume that both the cumulative spending on 5G cycle is 10% higher than the 4G one *and* that capex in this cycle peaks one year earlier than our base case (i.e. in 2024). Such a scenario would result in a 10% CAGR for the wireless capex market in 2018-20 (i.e. in the initial two years of build outs where the market is coming off of a low base following years of declines in preceding years).

Exhibit 20: Wireless capex to grow at a c.3% CAGR in 2018-20E (assuming capex peaking in 2025); sensitivities around peak capex year and cumulative spend
Wireless spend CAGR 2018-20E; Black box (Base Case; GSe)

Wireless capex CAGR (2018-20E)						
		Cumulative Wireless spend in 5G cycle vs 4G cycle				
		-10%	-5%	0%	5%	10%
Peak capex	2026	-3%	0%	2%	5%	7%
	2025	-2%	1%	3%	6%	9%
	2024	-1%	2%	4%	7%	10%

Source: Goldman Sachs Global Investment Research

Exhibit 21: A 10% uplift to the 5G cycle vs. 4G driven by Industrial IoT could drive a c3pp higher wireless capex CAGR in 2018-21E (assuming base case capex peak in 2025)
Wireless spend CAGR 2018-22E

Wireless capex CAGR (2018-22E)						
		Cumulative Wireless spend in 5G cycle vs 4G cycle				
		5.0%	7.5%	10.0%	12.5%	15.0%
Peak capex	2025	5%	6%	6%	7%	8%

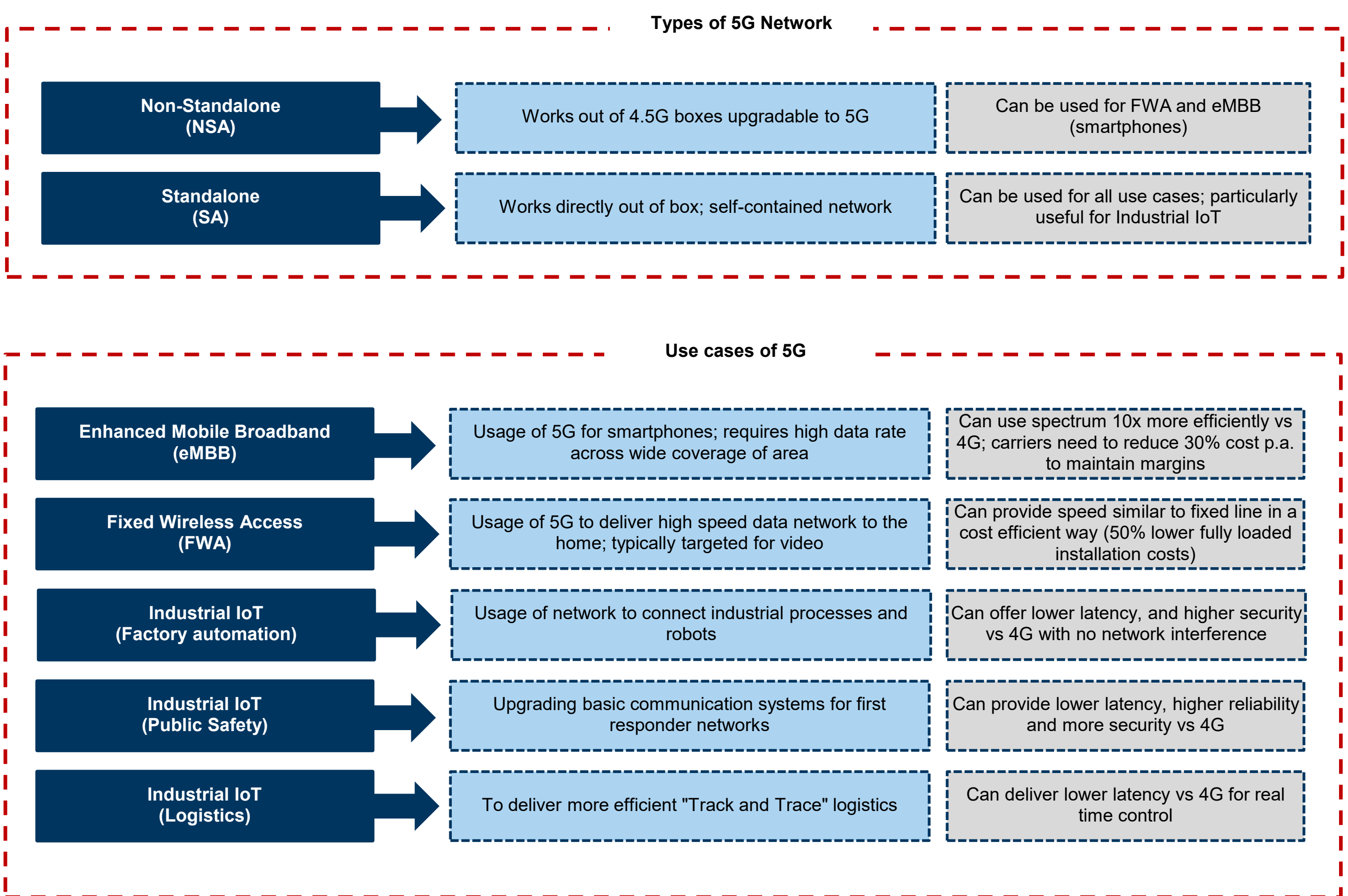
Source: Goldman Sachs Global Investment Research

- We believe there is the potential for **Industrial IoT** to expand the telco TAM *in the medium to long term* (but not before, given standards for this application have yet to be finalised) and hence we extend our market growth analysis out to 2022 and show the impact that larger cumulative spending on 5G vs. 4G could have on our base case. Our sensitivities assume that in a positive scenario, the telco TAM (and therefore implicitly cumulative capex spend) could be up to 15% higher than we assume in our base case. For context, we note that Ericsson has stated that it believes there is scope for Industrial IoT to expand the telco TAM by 10%-35%. Hence, we believe our bull case is justifiable. Our analysis suggests that the market achieves c40%-50% of this incremental uplift by 2022 given that we see China and potentially Europe as regions where Industrial IoT will proliferate first (with other regions to follow thereafter).

- Thus, if one were to assume that Industrial IoT drives a 10% higher cumulative Wireless spend on 5G vs. 4G, the wireless equipment market could grow at a c.6% CAGR over 2018-22 (vs. 3%-4% in our base case). Our analysis also suggests that if Industrial IoT results in a 15% uplift to the size of the 5G cycle vs. 4G, this would result in the expected wireless market CAGR (2018-22E) to be c.8%.

Exhibit 22: Non-Standalone uses 5G upgradable core, whereas Standalone uses new infrastructure

Variety of use cases for Non-Standalone and Standalone 5G



Source: Goldman Sachs Global Investment Research

5G needs spectrum within three key frequency ranges to deliver widespread coverage and support all use cases

5G will extend the range of frequencies used for cellular communication (ranging from below 1GHz up to approximately 300GHz), in order to be able to handle increased traffic capacity and enable bandwidths required for very high data rates involved in use cases such as high quality video streaming. The spectrum is broken up into bands, each with unique features as you move up into higher frequencies. 5G needs spectrum within three key frequency ranges to deliver widespread coverage and support all use cases. The three ranges are **1) Sub-1 GHz, 2) 1-6 GHz and 3) above 6 GHz.**

- **Sub-1GHz is unlicensed spectrum used to provide high speed 5G mobile broadband coverage across urban, suburban and rural areas and to help support massive scale IoT services.** The range of this spectrum is longer vs. mid-band and high-band spectrum. Thus, it will enable the 5G network to reach beyond urban centers and across the walls of the buildings. It provides the widest coverage but latency is higher vs. mid and high bands. The European Commission supports the use of the 700 MHz band for 5G services and in the United States the 600 MHz band has been assigned and T-Mobile has announced plans to use it for 5G.
- **Spectrum from 1-6 GHz offers wider bandwidths** and a good mixture of coverage and capacity for 5G services. This spectrum is important to provide **wider bandwidth Enhanced Mobile Broadband services and support mission critical IoT use case**. The latency of mid-band is lower vs. low-band spectrum. European telcos are currently focusing on mid-band adding significant capacity for eMBB.
- **Spectrum above 6 GHz is licensed spectrum and is used for extreme bandwidths eMBB in dense urban areas.** This spectrum is critical for delivering the fastest data speeds with 5G services. The latency for high-band is lower than the other two bands but the coverage is lesser relatively. The 26 GHz and 28 GHz bands have especially strong momentum and as they are adjacent they support spectrum harmonization and therefore lower handset complexity, economies of scale and early equipment availability.

Exhibit 23: 5G spectrum is divided into 3 bands - low, mid and high

Bands	Characteristics	Applications
High bands (mmWave) above 6 GHz	Licensed spectrum	Exclusive use: extreme bandwidths
Mid bands between 1-6 GHz	Shared spectrum	Wider bandwidths for e.g. eMBB and mission-critical
Low bands below 1 GHz	Unlicensed spectrum	Shared use & longer range for e.g. MBB and massive IOT

Source: Company data, Goldman Sachs Global Investment Research

Regional updates: North America

5G itself not generally impacting capex near term but Fixed Wireless an interesting development with 2019 capex to see growth

AT&T deploying cellular 5G in a limited way with acceleration in 2020

AT&T expects to initially roll out its 5G network in 12 cities by the end of 2018. However, the company will launch its first equipment in the form of a "puck" or a mobile 5G hotspot that will receive the signal and allow mobile devices to connect. This is largely due to the near-term lack of commercially available handsets and chipsets in the market. AT&T expects standards compliant 5G deployment to roll out 1) in 12 cities in the latter part of 2018, 2) in 19 select markets on millimeter wave in 2019 and 3) on a much larger scale with greater handset availability in 2020.

Verizon moving ahead with fixed wireless 5G but 2019 progress expected to be measured

Verizon's current strategy is to build out adoption of its 5G fixed wireless network and continue to densify its network for mobile 5G which is expected to begin to scale in 2020.

Fixed 5G

Verizon launched its "5G Home" fixed wireless service in four markets in October 2018. For greater detail on its expected rollout and timeline.

Mobile 5G

Verizon has not provided a detailed timeline on its plans for mobile 5G but sees initial deployment of the service in 2019 along with a more meaningful nationwide deployment in 2020. From a build-out perspective, the company is currently working on densifying major urban centers, including deploying small cells and fiber, in order to support mobile 5G on its millimeter spectrum. After that, the company will continue to densify semi-urban areas with small cells.

Verizon sees the biggest impediment to scaled mobile 5G as the availability of chipsets and handsets which its expects in 1H19 with the launch of the "5G moto mod" a Verizon exclusive accessory available for Moto Z3 smartphone. This accessory will enable access to Verizon's 5G network making it one of the first 5G enabled handsets. For higher volume products like the iPhone, we do not expect availability of 5G device until late 2020.

T-Mobile deploying 5G on both high- and low-band spectrum with the goal of a full mobile network by 2020

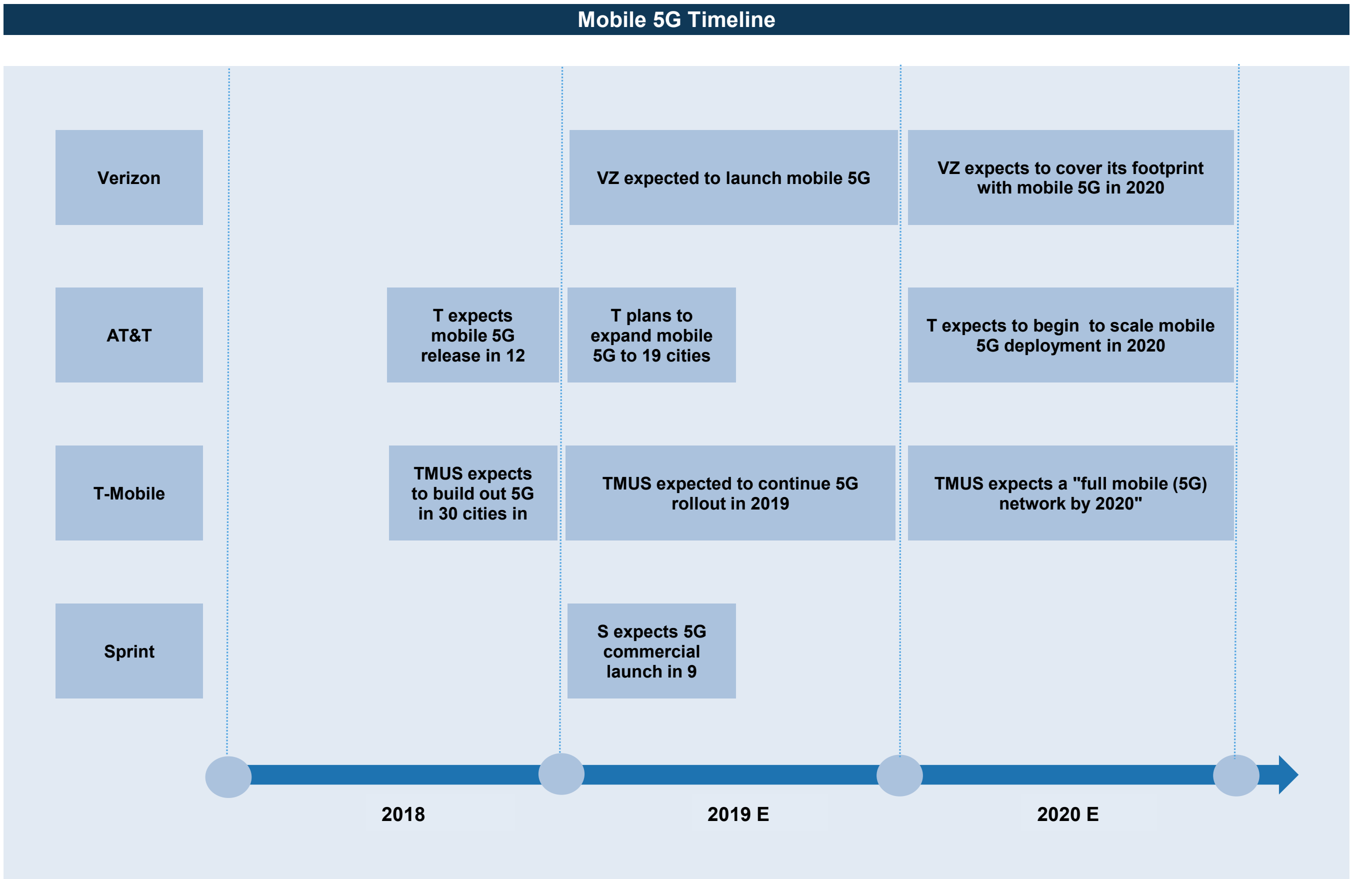
T-Mobile is focused on building out mobile 5G over the next few years. T-Mobile plans on readying its network for 5G by 1) deploying 5G-capable equipment today, 2) readying its backhaul from a fiber perspective, 3) deploying its 600 MHz spectrum, which it expects to form the basis of its 5G network, and 4) building-out 25,000 small cells to add speed and capacity in order to prepare the network for 5G traffic. T-Mobile has an eventual goal of a "full mobile network by 2020," according to CFO Braxton Carter at our Communacopia Conference in September. Although T-Mobile has made comments that its initial 5G build-out will be on millimeter wave spectrum in 2018, the bulk of the nationwide 5G network will utilize its low-band (600 MHz) spectrum holdings as the company believes this is the most economical method of deploying 5G on a nationwide basis. However, T-Mobile has described its spectrum strategy as the "layer cake approach" in which it will utilize all types of spectrum in order to achieve 5G coverage and capacity. The company's long-term 5G goals include delivering over 100 Mbps service to 2/3rds of the US by 2021 and 90% of the US by 2024.

Sprint limited launch in 1H19 but scaled 5G roll out timing less clear

Sprint aims to initially launch its 5G network in nine markets in 1H19, including New York, Dallas and Los Angeles. Its initial 5G launch aims to cover a large portion of each trial city but will not guarantee total coverage. Additionally, Sprint is working alongside LG to deliver a handset compatible with Sprint's 5G network by 1H19. Although Sprint has not clarified when it will begin to scale its mobile 5G network, we assume it will occur in 2020 alongside the other major carriers.

At our Communacopia Conference, CEO Michel Combes remarked that Sprint's 5G strategy is to take advantage of (1) its ability to deploy massive MIMO technology, which will allow it to run LTE and 5G simultaneously, and (2) its large portfolio of 2.5 GHz spectrum, which will provide capacity in dense urban areas.

Exhibit 24: The major US carriers will begin limited mobile 5G deployments in 2018, with widespread coverage expected in the 2020 time frame
Mobile 5G timeline for major US carriers

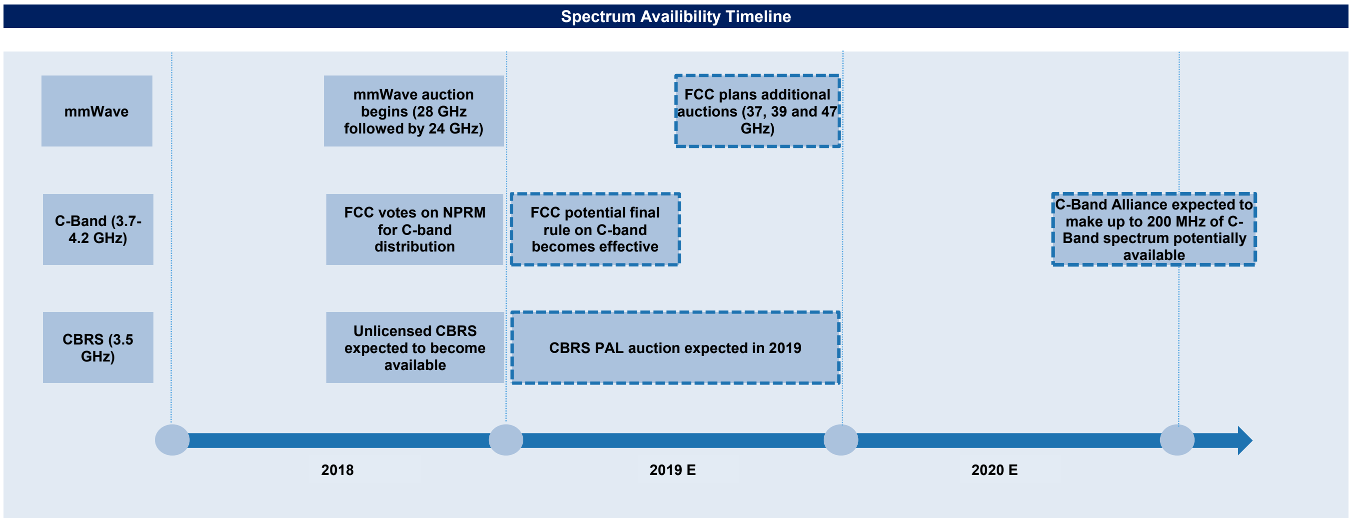


Source: Company Press Releases, Goldman Sachs Communacopia Conference 2018

5G Spectrum Spending

The Federal Communications Commission, led by Chairman Ajit Pai, has made it priority to increase the amount of spectrum available to support 5G. This includes a combination of new licensed bands as well as unlicensed bands. Most of the additional spectrum that the FCC is looking to free-up for 5G is within millimeter wave frequencies that the Commission intends to make available through auctions. However, it has also prioritized certain "mid-bands" including CBRS (3.5 GHz) and C-Band (3.7GHz to 4.2 GHz) that could come to market through novel processes. These include Priority Access Licenses (CBRS) that are effectively spectrum bands shared by carriers and government agencies and potentially privately negotiated license transfers from satellite operators to wireless carriers (C-Band). We summarize approximate timelines for various spectrum proceedings in Exhibit 40.

Exhibit 25:
We expect substantial amounts of spectrum to be made available over the next few years

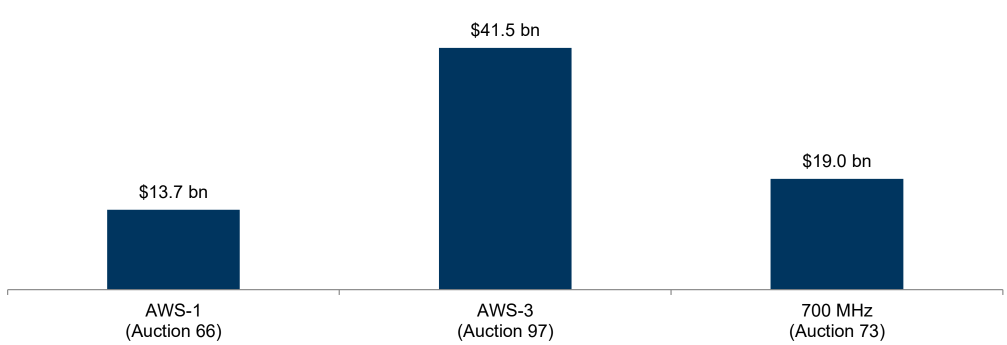


* According to FCC's auction factsheets, the 28 GHz auction's bidding will start on Nov 14th; the 24 GHz auction's bidding will start after the 28 GHz bidding concludes.
*FCC Chairman Pai: "As Part of our strategy to extend U.S. leadership in 5G, we intend to hld a single auction of the upper 37 GHz, 39 GHz, and 47 GHz spectrum bands in the second half of 2019."
* FCC voted on July 12th on the NPRM for C-band and unanimously approved it.
* FCC published the NPRM on the Federal Register on August 29th; comments are due on or before October 29, 2018; reply comments are due on or before November 27, 2018.
* Thereafter the FCC will seek to issue an order, which we estimate will take at least until 1H19 as this then needs to be filed with a 60-day comment period.
* C-Band alliance data, according to Intelsat's 3Q18 Earnings Call
* There are two portions of CBRS spectrum: Licensed and Unlicensed. The Unlicensed portion will become available in 4Q 2018, according to CBRS Alliance website. The licensed portion is expected in 2019.

Source: FCC, CBRS Alliance

We do not have an estimate for how much money the major wireless carriers may spend on spectrum during their 5G upgrades. However, we note that the primary spectrum bands used to support 4G LTE networks (700 MHz, AWS-1 and AWS-3) sold at auction for a combined $74 billion. This equates to little more than half of the total wireless capex spent by the four major wireless carriers during the peak period of 4G investment in the US (2012-2015). As such, 5G-related spectrum spending could be material. However, we should note that some of the spectrum bands that we expect the carriers to use to support their 5G roll-outs have already been purchased. This includes 600 MHz (T-Mobile), 28 GHz and 39 GHz (Verizon), 39 GHz (AT&T) and 2.5 GHz (Sprint). So, incremental spending on spectrum to support 5G is likely manageable, in our view.

Exhibit 26: Wireless carriers spent roughly $74 billion on 4G LTE spectrum across three primary auctions



Source: FCC Filings

Impact on Industry Dynamics

Mobile: No immediate impact from 5G. We do not expect the roll-out of mobile 5G to have a material impact on industry dynamics in the US. This is because the initial benefit of mobile 5G will likely be enhanced capacity. So, 5G should enable all of the major wireless carriers to sustain their unlimited plans as usage grows, but we do not see it providing any carrier with a unique opportunity to drive a share shift that is materially different from their current momentum.

Regional updates: EMEA

Europe – 5G unlikely to change capex or competitive dynamics; have we seen 'peak capex' for some EU operators?

5G will have a more muted impact on European telecoms than in the US, in our view. Similar to the US we do not expect mobile capex to rise for most operators in Europe (or indeed to rise at all for most of them). Unlike the US we do not expect as material a disruption in competitive dynamics. The key reason is that 5G fixed wireless (FWA) makes less economic sense in Europe given much higher population densities and better overall broadband infrastructure than in the US. **5G is unlikely to raise European mobile capex intensity over time, but neither will it drive a wall of capex near-term**, in our view. We do not expect material 5G capex to start in Europe much before 2020 and even then we do not expect it to come at an extreme cadence. Most operators question the incremental use cases for 5G, with autonomous driving still a number of years away. Even industrial internet of things (IoT) usage is relatively niche in the near-term and is likely to take a long time to play out. In addition, operators are waiting for customer equipment including smartphones and routers to be ready before pursuing a scale roll-out. These will start to launch in 2019 but are unlikely to drive meaningful demand before 2020/21.

Have we reached 'peak capex'? Yes, for some - European capex intensity is at 15 year highs both in absolute and relative terms when compared to other regions. Capex hikes to pay for fixed-line investments have been the key driver of negative sector earnings momentum and falling returns, along with regulatory uncertainties and headwinds. European returns have seen the most markedly negative trends of global telecom peers. Removing the risk of 5G driving higher capex could drive meaningful investment opportunities in Europe. It raises confidence that we have reached 'peak capex' for those stocks nearing the end of their fiber investments in fixed.

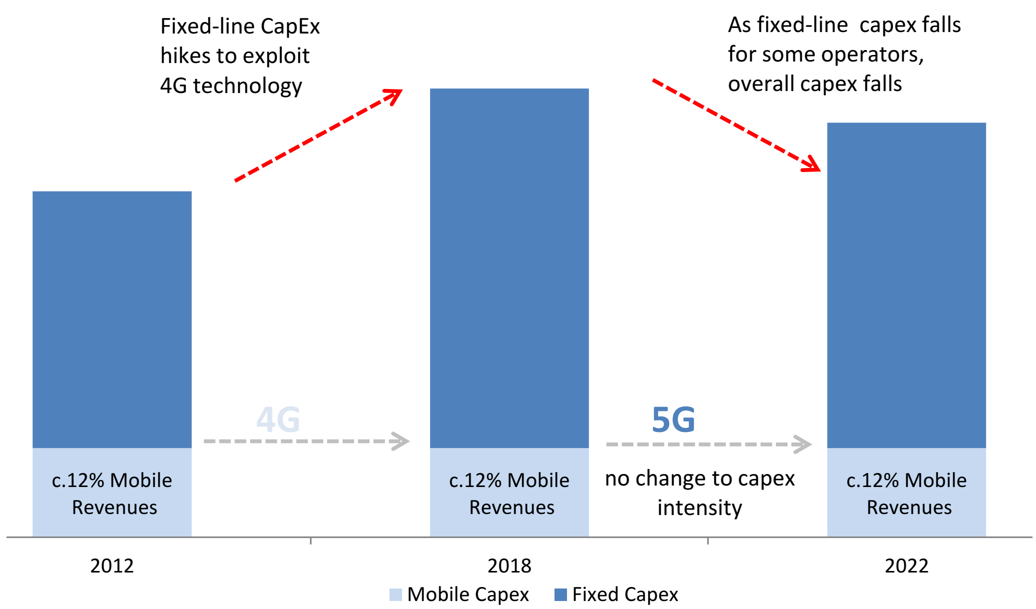
Why is the 5G impact different in Europe vs. the US? The key difference is that US operators will deploy FWA to a much greater proportion of the population than European operators will. European operators will focus mainly on the Enhanced Mobile Broadband (EMB) form of 5G which involves similar capex to the 4G cycle and is nowhere near as disruptive. This is particularly true given 5G utilizes the same OFDMA coding technology used in LTE as opposed to the wholesale change in core technology that occurred with LTE. In FWA, 5G tech is used as a way to deliver guaranteed service similar to ultrafast broadband fixed-line speeds. In EMB, 5G offers superior peak speeds to 4G but cannot deliver guaranteed speeds in densely populated areas. We view FWA as potentially cannibalistic to fixed-line services and would place further pressure on mobile capex budgets. EMB will likely be a companion product to fixed, as 4G is today, and will replace 4G capex without an expected spike. **The opportunity to deploy FWA is much lower in Europe than it is in the US** due to 1) less suitable population densities meaning FWA is widely seen as suitable for <25% of households compared to c.40% in the US; 2) there is less scope for a mobile operator to undercut fixed-line pricing and steal fixed-line customers in Europe given US fixed-line ARPUs (ex-content) are 3x European ARPUS; 3) also existing fixed infrastructure is far superior in Europe (given fiber has been rolled out to at least the street cabinet to over 85% of the population and cable covers more than two-thirds of households) vs. the US (given fiber has been rolled out to fewer than 25% of households while cable covers c.80% of the population) meaning FWA is less attractive relative.

5G impact in Europe - all you need to know

Timeline: significant roll-outs not expected before 2020/21 – Europe will launch 5G slower than in the US and Asia partly because most European CEO's question the near-term use-cases for consumer 5G (e.g. autonomous driving etc, which more than one operator notes is 'always 5 years away'). In addition, operators are waiting for customer equipment including smartphones and routers to be ready before pursuing a scale roll-out. These will start to launch in 2019 but are unlikely to drive meaningful demand before 2020/21. Importantly, as a scale player in four of the five largest European markets, we note that Vodafone has stated it will be a fast-follower on 5G. Vodafone is keen to be the "co-lead" on 5G roll-out in each market to avoid an "arms race" on 5G spend but also because it sees limited scope to monetise advanced 5G spend vs. its peers. It will only roll-out 5G when it has to, i.e. when its competing incumbent does. We do expect industrial IoT 5G investments to come a little sooner, in markets including Germany, but these are less material investments and this theme is likely to take a longer time to play out in our view. We also do not expect a wall of 5G capex at any point, it is more likely to be a smooth transition between 4G capex intensity transferred into 5G. Many will therefore invest in 4.5G equipment and then upgrade to 5G over time, rather than immediate, larger 5G investments.

- **Capex: mobile capex intensity unlikely to rise** – because European operator 5G focus is on Enhanced Mobile broadband 5G rather than fixed wireless. Put simply, as a technology and as an investment, 5G is to 4G what 4G was to 3G. Therefore 5G capex will just represent a continuation of the capex currently being spent on 4G – as 4G investment rolls off 5G investment should roll on. European telecoms operators expect 5G spend to supplant 4G capex and keep mobile capex intensity broadly stable rather than raise it. Within this capex mix, we note that 5G may involve greater equipment spend than civils works and testing spend when compared to 4G. We also note that there is greater spend typically at the start of a network upgrade cycle.

Exhibit 27: Sizing the 5G capex opportunity
5G capex (GSe)



Source: Goldman Sachs Global Investment Research

- **<u>Spectrum spend:</u> expected to be similar to 4G spectrum costs** – we have now seen 5G spectrum auctions in many markets including Italy, UK, Spain, Finland amongst others. While the Italian 5G auction fees of over €6bn were more than 2x consensus expectations and materially higher than 4G spectrum fees, we view this as an anomaly due to the design of the auction. Italian authorities structured the spectrum availability to two large bundles and two smaller ones - for four scale operators. This scarcity of large spectrum slices drove the inflated prices. We do not see this price inflating auction structure in other markets. So far, in all other markets the 5G spend has been the same or lower than the 4G equivalent. We continue to forecast spectrum fees at c.2% of mobile revenues on a smoothed basis, just as we modeled during the 4G upgrade cycle.
- **<u>Impact on industry dynamics:</u> Unlikely to be materially disruptive** – most importantly, with less utilisation of FWA technology, the scope for 5G to help mobile operators disrupt and take share from fixed-line operators is much smaller in Europe. While this will still be possible in some regions in some markets, overall we do not expect 5G to materially hinder the fixed-line growth outlook across Europe. On average, across our coverage we forecast fixed-line revenues +1.5% 5-year CAGR vs. mobile revenues +0.8%. This reflects the greater market concentration of fixed-line networks and operators compared to mobile. It also reflects our view that 5G networks will not be viewed by most as a serious replacement for fixed-line service – a scenario which would essentially dilute fixed-line market concentration. In terms of industry cost economics, 5G is a continuation of trends rather than a material shift. 5G is needed to keep costs down as data usage rises: in Europe, fixed-line usage is c.50x that of mobile (at 200Mb/s per month average vs. mobile at 4Mb/s). As usage continues to rise, operators need the more cost efficient 5G

spectrum and technology so that costs don't ramp. Operators expect fixed-line usage (in the home) to continue to vastly exceed that of mobile usage (out of the home), meaning that without FWA, 5G on an Enhanced Mobile Broadband basis is unlikely to replace the need for a fixed-line service offering dedicated capacity. That said, a long term opportunity could be Industrial IoT where there could be scope for telcos to gain new business. However we see this as unlikely to impact the industry in the next 2+ years especially given that this would need to be based on new discrete Standalone 5G networks and dedicated spectrum which will not be available for some years (with regulations and even technology standards also yet to be crystallised).

Regional updates: APAC

China - Capex to turn around in 2019 with 5G, but ramp slower than 4G

Telcos target 5G commercial launch in 2020

All three major operators in China (China Mobile, China Unicom and China Telecom) announced plans for 5G network trials in 2018, pre-commercial launch in 2019, and commercial launch in 2020. Since China has over 80% FTTx penetration, 5G will mainly be used for eMBB and industrial applications. In terms of technology, the telcos have historically expressed preference for SA network over NSA. We expect Chinese telcos to roll out 5G as they see opportunities for a positive return on investment given 4G spending achieved good mobile data coverage. On the other hand, it is important to keep in mind the SOE nature of the telcos and their role in helping the government achieve its goal of industry transformation which could be relevant to the Industrial IoT use case.

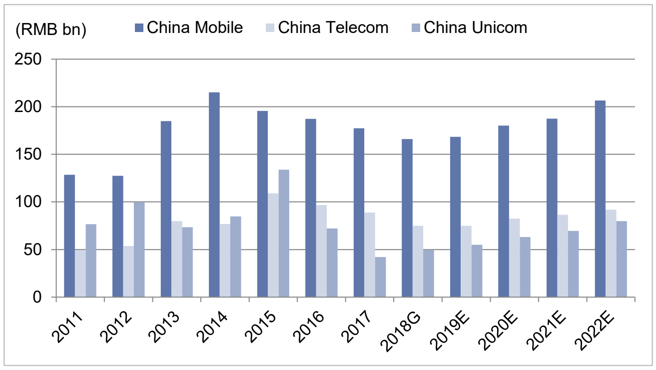
We expect China's 5G capex ramp to be slower than 4G

Overall, we believe the rollout of 5G in China is likely to be more incremental compared with 4G, and focused on key applications as opposed to the focus on coverage that was the main driver with 4G. As a result, we think China's 5G capex ramp is likely to be slower than that of 4G. China's three major telcos have all indicated that their 5G business models are yet to be finalised and that 5G network rollouts are likely to track the development of 5G applications, in contrast to the rapid rollout of full coverage with 4G. In 2020-21, we expect the Chinese telcos to focus initially on 5G outdoor coverage, along roads and areas specializing in industrial IoT as well as edge computing activities, with indoor coverage rollouts to come after 2021. As such, our capex estimates are 4%-13% below consensus for 2019E-20E.

China's 4G network rollout cycle (2013-2015) was quite concentrated with wireless capex increasing c.40%-70% per year. CM had a head-start with its TD-LTE license and was trying to gain back subscribers it lost in the 3G period. Meanwhile, CT/CU obtained their FDD-LTE licenses one year later and were then trying to catch up with CM in 4G. Industry capex declined sharply post 2015 as the telcos deployed a total of roughly 2 million 4G base stations in three years' time.

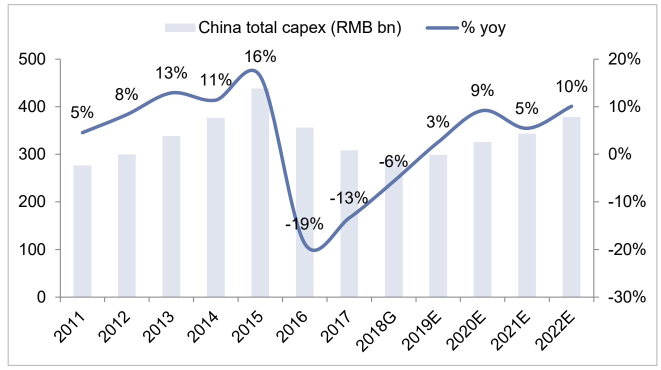
Since there will only be one global standard on 5G, we expect the Big Three telcos to receive their licenses at the same time this time around. In addition, we do not expect CM to be in a rush as it already has China's leading 4G network in terms of coverage and service. As a result, we expect wireless capex to turn positive to 3% yoy in 2019E and accelerate to double-digit growth in 2020E-22E with the commercial launch target in 2020E and device ecosystems becoming mature likely post 2020E. As such China may see less earnings volatility in the latter stages of the cycle this time around i.e. the slope of the cycle may be shallower but spending may be more sustained.

Exhibit 28: We expect total China telco capex to turn around in 2019 with 5G...



Source: Company data (2018 data company guidance), Gao Hua Securities Research

Exhibit 29: ... while the capex ramp will likely be slower and steadier than 4G



Source: Company data (2018 data company guidance), Gao Hua Securities Research

We expect spectrum allocation to be announced by end 2018 and 5G license to be issued in 1H19

The Chinese government allocates spectrum to telcos at no cost so the issue in China is the timing of allocation rather than the cost. We view the 5G spectrum allocation, 5G license issuance, and 5G pre-commercial rollouts as the three main milestones preceding the commercial launch of 5G in 2020. According to C114 (a leading Chinese telco news portal), China's government will make 5G spectrum allocations in 2H18. C114 has reported that, CM is likely to get 100MHz at 2.6GHz and 200MHz at 4.9GHz, while CT and CU are likely to get 100MHz each at 3.5GHz. We expect China to wait for full Standalone 5G standards before moving toward rollout which likely pushes timing to 2019 or 2020. At this point the Chinese government has not provided a detailed timeline.

Exhibit 30: Spectrum allocation in China

		China Mobile	China Unicom	China Telecom
GSM800	Uplink	885-909MHz	909-915MHz	825-840 MHz
	Downlink	930-954MHz	954-960MHz	870-885 MHz
	Sub-total	24/24MHz	6/6MHz	15/15MHz**
GSM1800	Uplink	1710-1725MHz	1745-1755MHz	
	Downlink	1805-1820MHz	1840-1850MHz	
	Sub-total	15/15MHz	10/10MHz	
3G	Uplink	1880-1900MHz* 2010-2025 MHz	1940-1955MHz	1920-1935MHz
	Downlink		2130-2145MHz	2110-2125MHz
	Sub-total	15MHz	15/15MHz	15/15MHz**
TD-LTE	Un-paired	1880-1900MHz, 2320-2370MHz, 2575-2635MHz	2300-2320MHz, 2555-2575MHz	2370-2390MHz, 2635-2655MHz
	Sub-total	130MHz	40MHz	40MHz
FDD-LTE	Paired	N/A	50MHz at 2100MHz	60MHz at 1800MHz
	Sub-total	N/A	50MHz	60MHz
5G***		100MHz at 2600MHz	100MHz at 3500MHz	100MHz at 3500MHz
		200MHz at 4800MHz		
Total		523MHz	252MHz	260MHz

* 1880-1900MHz is refarmed for TD-LTE by CM

** CT uses 825-840/870-885MHz for its CDMA 2G and EVDO service; the 1920-1935/2110-2125MHz has not been used yet.

*** 5G spectrum allocation is based on news report.

Source: Gao Hua Securities Research

Impact on industry dynamics

China's three major telcos have all commented that 5G currently lacks a clear and large-scale business application, at least in the smartphone/cellular sphere for customers. Specifically, they do not believe that many consumers would be willing to pay extra ARPU for 5G's high speed and low latency. We believe that the most obvious 5G applications include autonomous driving, industrial IoT, surveillance, edge computing, and VR/AR. These applications, except for consumer VR/AR, are mainly designed for corporate users and have a limited number of subscribers. Relative to consumers, corporate users tend to be less price sensitive but more quality oriented suggesting that they will concentrate their business on the best service provider in China. For example, a car company is likely to test its autonomous driving system on only the best 5G network and recommend its customers use the same network.

We believe that very few smartphone enthusiasts/high-end users would be willing to pay extra ARPU for 5G service at the onset of the 5G launch as 4G is good enough for normal high-resolution video and gaming. Going forward, we view VR/AR as one of the few potential applications capable of driving widespread adoption of 5G smartphones. We note that expanded adoption of VR/AR would require attractive content and upgraded hardware. A key milestone would be the potential introduction of Apple's own VR/AR gear, which could stimulate the growth of VR/AR content and drive some consumers to pay extra ARPU for 5G service.

5G in the rest of Asia Pacific

Timeline

Significant 5G roll-outs are expected in March 2019 in Korea, and then in 2020 in Japan and Australia. There are no specific announced plans in other Asian countries though we are optimistic on Singapore given a government push to enable 5G technology.

Capex

Japan

- Japanese carriers have been explaining that 5G is not expected to increase capital spending. This explanation implies in our opinion that they are not expecting the total investment for 5G to be greater than that of 4G. On the other hand, carriers in Japan have not commented specifically on annual changes in capex levels either in the positive or negative direction. While we believe annual capex may increase by 5%-10% from the current level, which has been reduced over the past four to five years, we see it is unlikely for the carriers to increase spending to the extent that would lead to material deterioration of FCF levels.
- Japanese carriers do not see a blue sky scenario for 5G to increase their own services revenues similar to most other carrier views on the technology. They also put weight on stable shareholder’s return and therefore they are not likely to expand 5G coverage if it requires a material increase in capex.

Korea

- Most Korean carriers guided flat to down on capex for this year. Because of this it seems unlikely that 5G is ramping materially in Korea where new mobile technology is normally adopted most quickly. Capex looks likely to increase next year, but the tone so far from the companies has been that, as its 3.5GHz spectrum and rollout speed will be moderate, the capex impacts will be minimal.
- KT Corp announced its roadmap to invest W23trn ($20bn) over next 5 years including W9.6trn for 5G network rollout. Out of the W23trn capex, W20trn is from the parent company and W3trn is from the subsidiaries. Current capex is c.W23trn, while W20trn in 5 years (so average of W4trn p.a.) appear large, this actually includes spectrum related costs and other miscellaneous OPEX.

Australia

- Telstra are in the final year of a 3 year, A$3bn capex program (18% capex/sales, excluding spectrum) which has been aimed at preparing its network for 5G.

ASEAN

- The scale of capex depends on whether telcos have already “future proofed” themselves during the 4G rollout. Some countries may have fiberized everything (e.g. Singapore) and rolled out significant number of small cells or even assigned some new spectrum already. So the capex burden was already front loaded, and hence 5G capex (from the incremental standpoint) may be very manageable for those specific telcos/countries. Within the ASEAN countries, Indonesian telcos – in particular – have a low percentage of towers that are served by fiber today but this would need to change if 5G were deployed. Given the size of the country this would represent a large uplift in spending on backhaul assets.

Spectrum spend

- **Japan:** In Japan, spectrum-related costs are minimal. Spectrum bands are allocated to companies by the Ministry of Internal Affairs and Communications (MIC), not by an auction. Spectrum-related costs are limited to a small amount of usage fees on the spectrum.
- **Korea:** Korea government licensed 3.5GHz (for 10-yrs usage) and 28GHz (5-yr usage) for 5G spectrum auction of which three telcos (SKT, KT, and LGU) combined spent W3.6tr for the bidding, 40% less than auction in 4G. For 4G, MSIP (Ministry of Science and ICT) held spectrum auctions in 2011, 2013, and 2016 where telcos participated and aggregate LTE spectrum cost tallied W6.2tr.

Exhibit 31: 5G spectrum and cost in Korea

Spectrum	(W bn)	SK Telecom	KT Corp	LG Uplus
3.5GHz	Bandwidth (MHz)	100	100	80
	Cost	1,219	968	810
28GHz	Bandwidth (MHz)	800	800	800
	Cost	207	208	207
Total	Bandwidth (MHz)	900	900	880
	Cost	1,426	1,176	1,017

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 32: 4G spectrum and cost in Korea

Spectrum	(W bn)	SK Telecom	KT Corp	LG Uplus
2.6GHz	Bandwidth (MHz)	60		40
	Cost	1,278		479
2.1GHz	Bandwidth (MHz)			40
	Cost			827
1.8GHz	Bandwidth (MHz)	55	35	
	Cost	2,045	1,351	
800MHz	Bandwidth (MHz)		10	
	Cost		261	
Total	Bandwidth (MHz)	115	45	80
	Cost	3,323	1,612	1,306

Source: Company data, Goldman Sachs Global Investment Research

- **Australia:** The first 5G spectrum auctions in Australia (3.6 GHz) are scheduled for late November, with pricing likely to be below recent 4G auctions given: (1) competition limits; and (2) low reserve pricing (vs. 4G). The first millimetre spectrum auctions will be the 26GHz band,but this is not expected until FY21.
- **ASEAN:** Spectrum is lacking for certain countries like Thailand, while the cost of spectrum has exponentially risen in the region in the last few years. For Thailand specifically, unused spectrum often sits within certain government/military entities and requires regulators to formulate processes to re-assign the spectrum. However, telcos would likely have to pay large sums for new spectrum, in our opinion.

Currently, there are no 5G spectrum auctions being scheduled/held yet in all countries, nor discussed in specific terms. Even the 700MHz spectrum (from the analogue to digital TV transition) for half the ASEAN countries has not yet been assigned nor - in some cases - been utilized after assignment . 5G high band spectrum is only expected to come to market after 700MHz spectrum auctions complete.

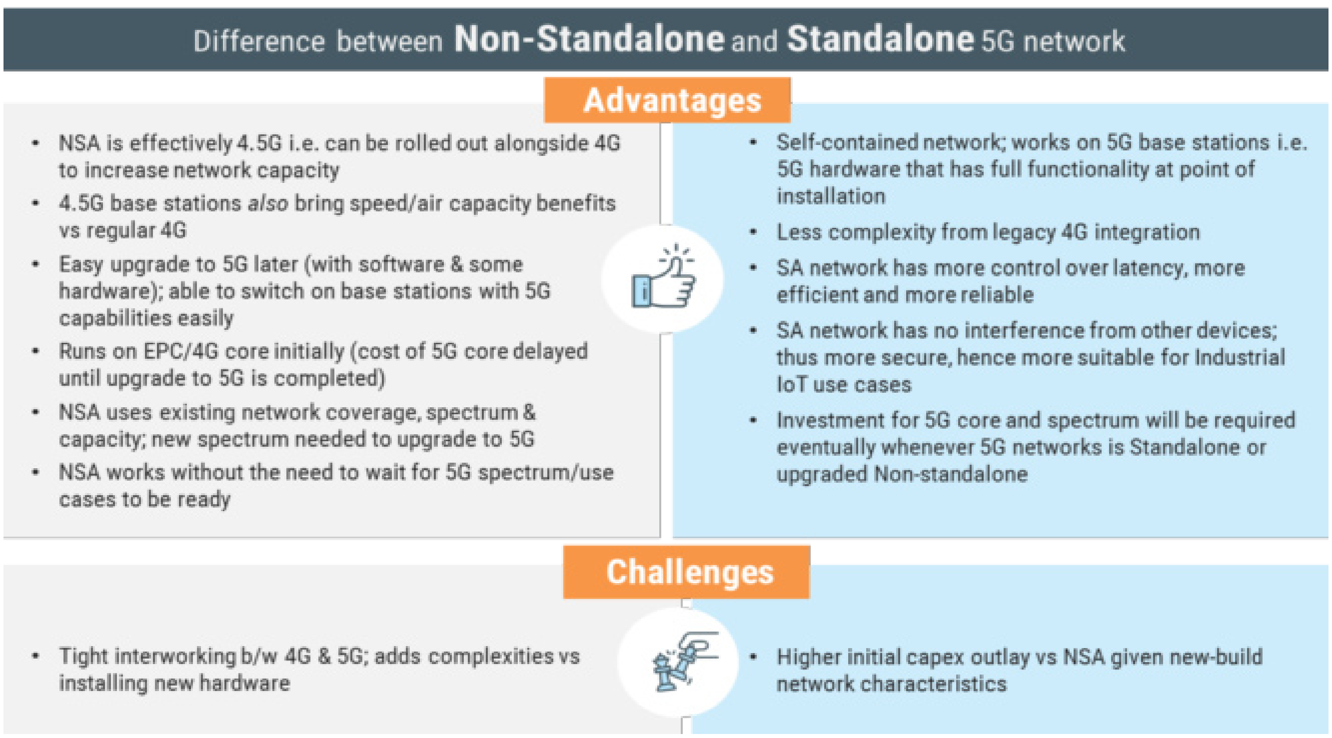
Impact on industry dynamics

- **Japan:** We see 5G is neutral for carriers' revenue, not a catalyst of revenue growth, in the traditional retail smartphone/mobile phone business as rate cuts due to lower bit costs are likely, taking into consideration the high degree of attention for household burden of communication charges. On the other hand, we think carriers are aiming for a rate of several hundred yen (several $) per household with unlimited device connection in the retail IoT market. Also, in the corporate IoT market, special services using 5G, such as localized service with mobile base stations, are likely. However, it is unlikely to be a widespread communication method of IoT devices and to boost carriers' communication service revenue, mainly due to the fact that there are a lot of free communication methods including Wi-Fi and LPWA.
- **Korea:** Fixed wireless is unlikely to be deployed. Korea is relatively small(er) than regions like US and high concentration of population with high density of buildings, which makes 100% wireless 5G deployment possible.
- **Australia:** We believe that 5G/FWA presents an opportunity for the fixed line providers to bypass the government owned, monopoly fiber network that is currently being rolled out (referred to as the National Broadband Network or NBN). This would result in the fixed provider avoiding payment of the significant access costs associated with the NBN, with NBN Co currently forecasting its ARPU (i.e. average access costs) to increase from A$44/sub/month today to A$52 in FY6/22. As a result, should any operators in Australia successfully migrate some of their fixed customers onto their mobile networks, this would result in significant cost savings. We note that although Telstra does not believe that mobile will supersede the NBN, it has estimated there could be an additional 1mn mobile only households in Australia over time (i.e. 15% mobile only households increasing to 25-30%).
- **ASEAN:** We believe FWA technology can present an opportunity for telcos to launch fixed wireless services in areas where fixed broadband penetration is very low because fiber roll out to the home is proven to be challenging and not economical, e.g. Indonesia and Philippines. We see less chance of disruption to industry dynamics in countries like Thailand and Singapore from 5G technology, as all telcos are likely to adopt this along similar time frames. E.g. In Singapore, there is the wide availability of affordable fiber backbone from its nationwide broadband provider (Netlink Trust) for all telcos.

Non-Standalone offers eventual upgrade path to full 5G with capacity benefits now

Non-Standalone technology allows a carrier to add 4.5G capacity now that will seamlessly transition to full 5G capabilities later with an easy upgrade. The rollout of this technology now is helping wireless infrastructure market recovery. NSA base stations are effectively 4.5G ones that have better speed/capacity than 4G ones and can be used to densify an existing 4G network now without the need to invest at that point in a totally new network core (they run on 4G spectrum). They also have the capability to be upgraded relatively easily in future years with software (and some hardware) to full 5G (for Fixed wireless, Enhanced mobile broadband etc) once spectrum is available (and standards for standalone 5G across more use cases eg Industrial have been set). This can be contrasted with Standalone (SA) 5G, which is 5G hardware that has full functionality at the point of installation, and must run on a 5G core/spectrum from the start. There are differences in terms of networks topology, standards, spectrum requirements and likely use cases, for NSA vs. SA.

Exhibit 33: We see advantages and challenges for both Standalone and Non Standalone 5G



Source: Company data, Goldman Sachs Global Investment Research

We note NSA offers the ability (1) to make investments to improve the *current* 4G network (i.e deliver more *capacity* now) via densification using 4.5G base stations *and* (2) these NSA (4.5G base stations) bring some improvements regarding speed/air capacity vs. 4G. Meanwhile (3) these NSA base stations have the capability to be upgraded to full 5G later via software (or other) upgrades even though (4) NSA can be built initially on top of a 4G core (i.e. evolved packet core) rather than involving extra cost *at the time of rollout* on a *new* 5G core (the latter is required from the *start* for SA 5G). Moreover, this NSA/4.5G hardware can be put in place even though (5) 5G spectrum may not be available yet as the 4.5G base stations start out running on 4G spectrum, and work even though (6) use case/standards finalisation required for certain aspects of Standalone 5G may not have been completed yet. Thus telcos can improve their 4G networks now without having to invest in a totally new 5G core (which only has to be done later once the upgrade to 5G is done) and (7) can upgrade relatively quickly/easily to 5G *later* once spectrum/use cases etc have been finalised. Of course we note (8) some Standalone base stations will be rolled out in future years which are SA enabled from the start, but by putting in place NSA now that is upgradable later this will allow some 5G capabilities to be unlocked relatively easily in future (without having to start from scratch with pure SA hardware). We note the availability of Non-standalone technology has been accompanied by a stabilization of revenue trends in wireless infrastructure market demand, as seen in recent vendor results. That said, we argue that while to some degree this is due to the easy upgrade path it offers to 5G, it is also to a significant degree due to the improvements in speed/capacity that densification of the network with NSA/4.5G offers now. We also explain elsewhere that this could be another factor that could impact the shape of the cycle (potentially making it shallower) due to demand pull-ins.

Exhibit 34: Key differences include upgradability, standards, and spectrum requirements.

	Difference between Non-Standalone and Standalone 5G network	
	Non-standalone (NSA)	Standalone (SA)
Network topology	• **4.5G base station** (which is **upgradable to 5G** later) • Built on top of **existing infrastructure** i.e. 4G/LTE; more of an upgrade	• Base station **enabled for 5G** as soon as it is installed • **New-build infrastructure**, including new base stations, backhaul links & core network
Software/ hardware upgrade	• Requires **software upgrade** of existing 4.5G base stations • **Leverages current installed base** and 4.5G infrastructure	• **No intial** hardware or software **upgrades** required • New installations of base stations **already 5G enabled**
Standards	• The **3GPP standards** (Release 15 Phase 1) for NSA were finalized in **December, 2017**	• **Initial standards** launched in **Jun, 2018** for regular SA (Release 15 Phase 2) • Release 16 which focusses on **Industrial** (new features like massive IoT) expected **in 2019**
Spectrum requirements	• Can use **same spectrum as existing 4G bands**	• Telcos need **separate dedicated** slice of fresh spectrum
Applications/ Use cases	• Suitability greater for **more localised deployments** vs nation-wide rollouts • **Enhanced mobile broadband** for smartphones i.e. AR-VR, HD video, etc. • **Fixed Wireless Access roll out** in semi-dense areas (and massive sensor IoT)	• More **suitable for new and self-contained network** • Key use cases inlcude mission-critical industrial IoT e.g. Robotics/Factory Automation • Also applicable to P**ublic Safety** use cases

Source: Company data, Goldman Sachs Global Investment Research

Non Standalone technology is based on LTE and can be installed alongside existing 4G base stations, with a simple upgrade path to full 5G later

- Non-standalone technology is effectively 4.5G hardware that is sold now that will be upgradable to 5G later via a software upgrade (and or hardware modifications).
- This can be contrasted with Standalone (SA) 5G, which describes 5G base station hardware that has full functionality from the point of installation (i.e. with no upgrade required). This is new build infrastructure (i.e. a new base station, plus a totally new 5G core). NSA does *not* need a new network core i.e. leverages the evolved packet core (4G core) at the point it is installed.
- Thus at the point when NSA hardware (effectively 4.5G) is first installed the telco is improving its 4G network (and the new base station adds to the existing 4G based network infrastructure of base stations) helping to expand data capacity. On top of

this the 4.5G technology brings with it benefits in terms of performance related to speed.

- However, when a NSA base station is installed, there is not an accompanying cost of building a new 5G core, as the 4G core can be used at that point. However, the telco will be able *later to seamlessly upgrade* to full 5G via a software upgrade to the baseband (and potentially some modifications to the radio/antenna), without having to roll out totally new SA equipment from scratch.
- Thus it gets to improve its network performance now, in the knowledge it can relatively easily upgrade to 5G later i.e. with a software upgrade (and some minor hardware adjustments potentially, depending on the vendor), without having to do a totally separate SA rollout down the line once SA spectrum, standards etc are finalised.
- Meanwhile the investment in the 5G core can be deferred until the point at which the upgrade to full 5G is made.
- Currently upgrade path varies vendor by vendor. For example, some vendors allow for base band upgrades purely with a software upgrade, whereas some require more base band hardware swaps. Meanwhile the early NSA solutions have required new radios to be installed later to leverage new spectrum bands once the full 5G capability is turned on, regardless of whether the base band is fully software upgradable (although we note some vendor solutions will in due course proliferate more broadly that have radios that can run on both 4G and 5G bands).

Exhibit 35: Initial rollouts in US based on Non-Standalone, followed by China drive towards Industrial IoT

		Timeline	Use Cases
US	NSA: 2018 SA: 2019	• Nokia/Ericsson expect **initial NSA 5G rollouts by end of 2018**; Verizon announced the launch of commercial 5G in Oct, 2018 • Large scale **commercial 5G** deployments only expected to happen in **2020-21** when device ecosystem will also be available • US is focussing on Non-Standalone 5G architecture currently; **Standalone** is expected to **scale up in mid to late 2019**	• Near to mid-term focus is on **Fixed Wireless Access (2019-20 at scale)** • **Enhanced mobile broadband** in mid-term (2020-21 at scale) • Relatively **lower emphasis on Industrial IoT**
China	NSA: 2019 SA: 2020	• Hundreds of thousands of **5G base stations** expected in China (the largest region for field trials) **by 2020-21 at large scale** • China focussed on Standalone 5G deployment; **Standalone expected to launch in 2020** with focus on industrial use case • Slower than US potentially due to government **allocation of spectrum to even out competition** dynamics between top telcos	• China's **Industry 2025** plan driving govt.'s push towards industrial IoT • Focus is on **automated manufacturing** & **enhanced mobile broadband** • **Fixed Wireless less** in focus (given extensive fiber footprint)
Korea & Japan	NSA: 2019 SA: 2021	• Korea to see **small scale NSA** deployments in **early 2019** with **large scale Standalone** rollouts **expected in 2021** • Mid band roll outs expected in Japan in 1Q19 (for Tokyo Olympics); **major deployments** are not expected until **2H 2020/21** • Japan is **focussed on Non-Standalone** currently; deployment of **Standalone** at scale is expected **in 2021**	• **Korea** placing special emphasis on **FWA; Japan** focussed on **eMBB** and **IoT** • **Japan** is expected to provide limited 5G services **Rugby World Cup 2019** • **Docomo D+** (partners on board) & **Industry 4.0** to drive 5G adoption in Japan
Europe	NSA: 2020 SA: 2021	• Europe slower than other regions; **Nordic countries** expected to deploy 5G relatively earlier in Europe (i.e. **in 2020)** • High bid value in **Italy** spectrum auctions is a **positive** sign; Ericsson to rollout NSA 5G in **Switzerland** by **YE18** • Europe **currently focussed on Non-Standalone**; **Standalone** 5G is not expected to be deployed before **2021**	• Europe is more focussed on **enhanced mobile broadband** • EU operators expected to get access to 700MHz band (for eMBB) by **2022** • There is also a drive towards **industrial IoT in Germany**

Source: Company data, Goldman Sachs Global Investment Research

The network standards and spectrum requirements and applications associated with Non-standalone 5G are different vs. Standalone

- Standards relevant to Non-standalone technology are different vs. Standalone. NSA is based on Release 15 Phase 1 of the 3GPP standards, which were finalized in December 2017; by contrast, the first group of standards for SA were launched in June 2018 and are known as Release 15, Phase 2 (see Exhibit 21).
- That said, Release 16 which focuses on the Industrial use case (which has new features such as massive IOT) is not expected until the end of 2019).
- We also note that NSA (effectively 4.5G) can use the *same* spectrum as existing 4G bands, whereas telcos need separate dedicated slices of fresh spectrum for SA 5G

(note NSA can operate on 4G spectrum using one radio, but another radio will be needed to use 5G spectrum when an upgrade to 5G is made, albeit over time more and more BTS from some vendors will have dual radios).

- While we note that according to the 3GSM roadmap, Enhanced Mobile Broadband for smartphones (potentially for use cases such as AR-VR, HD video etc, albeit this is yet to be seen) and Fixed Wireless Access (in semi dense areas) can be delivered with both NSA and SA, we expect full performance capabilities of these e.g. speed to be realised only on SA. Further, use cases such as Industrial IoT (e.g. factory automation) and public safety, typically require a new/self contained network, for which a Standalone 5G network configuration is needed.
- Thus, given that relevant standards, spectrum allocation and the telco business model for use cases such as Industrial IoT will not be finalised by the end of 2019 at the earliest, this will place limitations on the scale of *Standalone* 5G rollouts near term, in our view, albeit we see small rollouts in the US in 2H18, per Nokia/Ericsson, for Enhanced Mobile Broadband and Fixed Wireless (with a further ramp in 2019).

Capacity needs, economics and seamless technology upgrade path of Non-standalone 5G; **telcos already rolling out this technology**

- Telcos, mainly in the US for now, have started buying Non-standalone base stations currently (effectively 4.5G), as per commentary from Nokia and Ericsson, rather than Standalone 5G hardware (we expect a very small amount of the latter in 4Q18). Theoretically, in coming quarters telcos could buy Standalone 5G hardware which works "out of the box" without further upgrades (the standard was set in June).
- Installing Standalone hardware which works straight away on 5G would potentially bring convenience in terms of installation (ie no upgrade needed) and theoretically have potential to yield the advantages of 5G i.e. faster speed, better latency, higher reliability etc. However, such a base station would not necessarily be able to deliver such performance advantages unless the telco had secured 5G dedicated spectrum (for Standalone 5G), which is unlikely to be the case in most geographies, pending auctions etc. Furthermore, business models related to certain theoretical use cases may not have been settled yet.
- Moreover, some of the potential advantages of Standalone 5G, e.g. the fact it is suitable in theory for the Industrial IoT use case, are not deliverable today pending *standards* for such specific use cases being finalised (as well as resolution of certain other bottlenecks we discuss below). Notably, as explained above, standalone requires a totally new 5G core, which costs extra money. Thus even if the cost of a SA base station will be similar to that of an NSA base station (e.g. including software upgrade cost) the 5G core represents a significant chunk of extra investment, which would not make sense unless the 5G network can deliver a meaningful uplift in performance (which again is not possible if e.g. spectrum is not yet auctioned/secured).
- Therefore carriers benefit by installing Non-standalone hardware *today*. This is effectively 4.5G and can coexist with the existing 4G network. Thus it helps densify the network i.e. add capacity, but 4.5G also brings speed and other advantages vs. 4G. Importantly however it can be upgraded *later* (i.e. in the

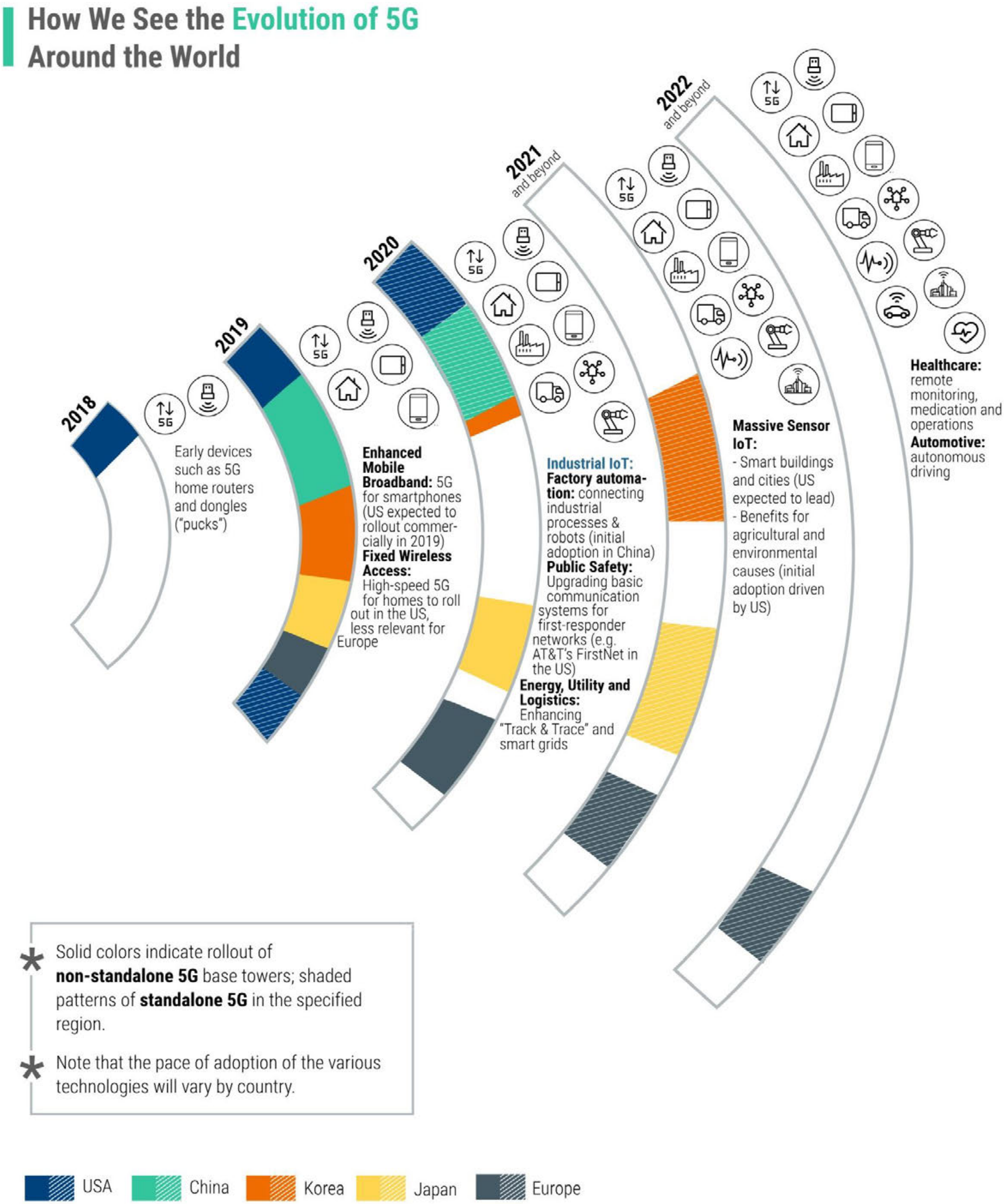
next 1-2 years) using a relatively easy/inexpensive software upgrade (and/or relatively small hardware modifications), once spectrum becomes available (and the business models and/or use cases become crystallised). Whereas we estimate the prices of SA and NSA base stations are roughly the same, NSA does not involve investment in a new 5G core from the point at which the base station is rollout. In other words this is deferred until the upgrade to 5G is made. Thus telcos can future proof themselves to ensure that they not only improve the density/quality of their network today but also can take advantage of full 5G capabilities later, once use cases, standards and spectrum status have been crystallised.

- Indeed, the upgrade to 5G is easy (a quick software upgrade and/or small hardware modifications). Of course in the future telcos will no doubt roll out SA base stations from scratch (obviating the need for an upgrade of hardware). However, by putting in place a certain tranche of NSA/4.5G hardware today, the telco will know it can easily upgrade to 5G once spectrum/use cases etc are finalised, without having to roll every single base station out from scratch (using SA).

The wireless infrastructure market is stabilising vs. a low base as 4.5G/4.9G (NSA) hardware helps serve current capacity demands, but this could impact the shape of the 5G cycle

- We believe that the fact that telcos are able to roll out Non-standalone technology under the broader 5G umbrella so as to benefit from capacity upgrades now (as with all advances in hardware vs. prior generations) but also with a view to gaining an easy upgrade to full 5G capabilities and use cases *later* can help the wireless equipment market in 2018/19. Indeed this is already benefiting vendor financials.
- However, it could also lead to demand for SA 5G hardware effectively being pulled in, and therefore the shape of the broader 5G wireless cycle being shallower i.e. after the initial uptick in 2018/19 from NSA, the introduction of SA 5G in 2020 (and to some extent 2H19) may not lead necessarily lead to further growth. Our scenario analysis from Exhibit 26-35 aims to illustrate a range of potential outcomes.

Different geographies are focusing on Non-Standalone currently with longer term emphasis on Standalone



Source: Company data, Goldman Sachs Global Investment Research

Perspectives on 5G from **Eric Hutchinson**, CEO of Spirent Communications, a leading UK based equipment test player

What role is Spirent's playing in 5G?

5G has the potential to change our world and empower a new industrial and social revolution. As the industry accelerate to make 5G possible, everything will change – new devices, antennas, chipsets, frequencies, architectures, KPIs & vendors –leading to unprecedented complexity. When complexity collides with urgency, test and assurance becomes critical. Spirent's 5G Test and Assurance leadership assures the communications industry fulfills its promise of quickly and safely launching 5G to deliver new revenues, savings and experiences to its customers including OEMs, NEMs, CSPs and Enterprises.

Spirent helps its customers a) **Simplify** 5G by reducing the complexity and economics of testing; b) **Accelerate** 5G innovation and time-to-market of new services; and c) **Assure** 5G operationally delivers the new revenues, savings and experiences promised through a new automated approach to service assurance.

Testing and Rollouts

Three trends are driving rollouts and placing a heightened focus and attention on the role of Test and Assurance:

1. Market acceleration

- Just how quickly has the 5G timeline accelerated? Consider that the industry originally predicted commercial launches of 5G for 2020 or even later. And that the first industry standards (5G Phase 1) were released end of 2017 (3GPP R15 New Radio Non-Stand Alone). During 2017 alone, 47 lab and field trials were announced. Now we are talking about launches this year with CSPs such as Verizon announcing 5G Fixed Wireless Access in 3-5 US markets during 2018 and AT&T announcing it will launch 5G in 12 US Cities by end of 2018. China Mobile announced the world's largest 5G trial network across five Chinese cities during 2018 along with plans to offer a full commercial 5G service by the end of 2019.
- This acceleration creates risks. It dramatically compacts the R&D period increasing the risks of failure to deliver the new experiences and services that will delight our customers. There is also financial risk. As long as the industry is still in the spending cycle for 4G, the cost of accelerating 5G requires either new capital investment, cost efficiencies or a faster return on investment. A new breed of Test and Assurance can help offset these risks by reducing the economics of testing and validating 5G while accelerating time-to-market.

2. Technology challenges

- **New architecture, new complexity.** 5G introduces a major paradigm shift evolving to a completely new architecture including a new core, new radio, new spectrum, and new devices and chipsets.
- **New Radio, New frequencies.** New frequencies such as millimeter wave and new technologies such as Massive MIMO / Beamforming mean the complexity of the radio has grown. These offer huge potential in regard to capacity, but the use of these frequencies is challenging due to propagation and penetration characteristics.
- **Being all things to all users.** A significant challenge with 5G is the need to simultaneously service consumers and industry verticals. The huge increase of IoT devices, for example, will put a huge emphasis on data integrity and performance.
- **Lofty goals and huge expectations.** The ambition of 5G cannot be understated. The promised improvements in data rates, device density, traffic capacity, throughput, latency, and spectrum efficiency must be realized in order for consumers and industries to embrace the change.
- **Network virtualization**. 5G is dependent on the network's ability to simultaneously service different industry verticals, enable service agility, and realize cost efficiencies. But virtualization comes with a steep learning curve and complexity. Currently there is no unified, rigorously-defined standard to guarantee interoperability, nor a methodology to assure continuous and consistent performance.
- **Security.** The massive increase in connected devices and pervasive use of virtualization with edge distributions will exacerbate security threats and broaden the attack surface.

Test and Assurance plays a pivotal role in simplifying the complexity of testing 5G through the use of emulation and new test methodologies. For example, network and traffic emulation can play a pivotal role in simplifying the complex 5G testing.

3. Potential

- The potential of 5G is large with industry players such as IHS and Qualcomm estimating 5G will enable $12.3 trillion of global economic output by 2035. Establishing new revenues will be critical and not just form current consumer and enterprise customers but from new markets such as Automotive, Industrial Manufacturing, Healthcare etc.
- But 5G needs to deliver. Consumers will base their willingness to pay more money on how they experience 5G. New markets and industries will judge adopting 5G based on the knowledge CSPs understand their world and the proof that 5G will not only consistently deliver but open up new opportunities. Test and Assurance can play an important role in helping assure 5G operationally delivers the promised experiences, savings and revenues.
- In addition, it can be a value-add enabler for new opportunities in mission critical markets such as automotive, healthcare and Industry 4.0 where SLA management, automation and performance requirements are critical.

Regional Timeline for 5G?

Establishing global leadership in 5G has moved into the arena of National importance and is a strategic cornerstone of many countries' future digital economies.

- For example, leadership in 5G is highly important for China's economic growth with the China Academy of Information and Communications Technology (CAICT) estimating that the 5G market could account for RMB1.1 trillion (US$166 billion) or 3.2% of mainland China's entire GDP in 2025, generating 8 million jobs and adding RMB2.9 trillion in economic value by 2030. One of the key differentiators with China's focus on 5G is the early development of the ecosystem, including device manufacturers, thus creating an environment geared towards rapid adoption. Focus in China has also shifted towards Stand Alone 5G, and combined with the push for handsets to be developed quickly for 2019, there is a desire to support enhanced 5G enabled services such as AR/VR.
- In the US the focus has been on 5G NSA and the utilization of 4G resources. AT&T's strategy of an underlay LTE Assisted Access network with gigabit speeds is a prudent plan to avoid poor service quality during 5G back to 4G handovers. On the other hand, Verizon's focus on Fixed Wireless Access (FWA) demonstrates that the potential of mmWave can be achieved with live trials demonstrating speeds up to 1Gpbs from 1/3rd of a mile away in both line-of-sight and non-line-of-sight (trees) environments.
- In Europe acceleration towards 5G has been gaining quiet momentum. For example, in the UK auctions have already happened for the 2.3 and 3.4 GHz frequency ranges, Government investment is ripe, over 200 trials and research initiatives are underway and carriers like EE and BT are targeting 2019 for commercial launches. It is clear 5G is of national importance for the UK Government's long term economic strategy and focus is towards social and commercial enterprises which will bolster the UK economy and address an ageing population. This is directing 5G technology investment towards Ultra-low latency use cases such as Transportation, Connected Autonomous Vehicles, Health, Industry 4.0 and Smart Tourism.

From a Test and Assurance industry perspective initial focus was on the 5G Radio with lots of prototyping in the mmWave ranges (initially 24 & 28) while commercial launch testing was focused on the sub 6GHz ranges. This relates to a mixture of the use case focus, cost of deployment (i.e. reuse of current RAN real-estate) but also the regulators timeline (initial auctions are in the sub-6GHz range). New focus towards 39GHz ranges has begun as CSPs explore larger coverage area potential from their base-stations and street furniture antennas for data, voice and video services. This could become critical to reduce the number and cost of 5G small cells which are currently estimated to be required.

Priorities are now also moving to 5G devices and their availability. Especially smartphones, with a number of vendors announcing 2019 release i.e. Sony Xperia XZ3, OnePlus 7, Huawei P30 Pro.

Non-Standalone vs. Standalone?

Most CSP's are starting with an NSA implementation as it provides them the fastest way to deploy 5G New Radio and provide Enhanced Mobile Broadband Services to their customers. It also allows them a flexible and cost-controlled migration path in regard to how their networks should evolve towards 5G based on use cases and coverage requirements. In addition, NSA allows CSPs to better utilize and depreciate the investments in 4G.

The other key tenants of 5G, Ultra Reliable Low Latency and Massive Machine Type Communications which will be enablers for a new generation of services in Automotive, Smart Industries, Healthcare etc. are slated for the 3GPP Release 16 standards which are set to be finalized during 2019. At this point the SA mode will be a prerequisite, but until then NSA can start to deliver value and help CSPs master the intricate challenges which 5G New Radio brings.

To ensure a successful adoption of this new technology, carriers and equipment manufacturers alike must work on new network testing and validation procedures such as Scale testing, 4G Extension testing, New Radio testing, Shared network testing, and Integration and interoperability testing.

Industrial end applications deepdive

The European Industrials and Capital Goods perspective

As highlighted in our **Factory of the Future** series, new technologies and innovations are disrupting the manufacturing landscape. Within the connectivity segment, we see fast ranging implications from Silicon Carbide. Faster, more secure and reliable internet connections will enable growth of the industrial internet of things (IoT), which supports applications such as predictive maintenance, LiFi or digital simulation and control of manufacturing processes.

Predictive maintenance

By installing sensors on equipment that monitor the performance and condition indicators, such as temperature, noise or pollution, manufactures can offer customers predictive maintenance using big-data analytics. In the elevator industry, for example, **Kone** and **Schindler** monitor the performance of their customer's lifts and offer predictive maintenance in advance of actual breakdowns of the equipment. This creates value for customers as downtime is minimised and benefits the elevator companies as they can more effectively deploy their fleet of service technicians.

Digital twin

Equipped with more secure and faster internet connections, manufactures increasingly digitalise the planning and monitoring of manufacturing processes using a digital twin. A digital twin is a computer simulated replication of a machine or entire manufacturing process. It encompasses a 3D model, an electronic design, bill of material and digital simulation software to replicate the real-world equipment into a fully digital reflection. By designing a manufacturing process fully digitally and simulating the interaction between different machines ahead of the physical installation of the factory, the layout of machines and design can be optimised in order to reduce cost and improve efficiency of the manufacturing process. Truly secure communication connections are an essential enabler of the digital twin as manufactures cannot allow digital vulnerabilities in a factory or plant that is a critical link in their customer's supply chain.

LiFi

LiFi (Light Fidelity) is a technology providing high speed internet connection using lighting sensors. Similar to Wifi, Lifi is used in indoor and in close proximity to the end-application, however offers the advantage that only receivers with access to the same digital lighting source can access the network. As a result, Lifi offers a physically secured internet connection as the blocking of light for example by a wall or physical barrier, will block the emission of the internet signal. This makes Lifi an attractive technology in manufacturing settings or more generally in applications where a high level of technology is essential. In order to fully utilise the potential of Lifi, ultra-fast internet connections are required and so the deployment of 5G via Silicon Carbide will accelerate the adoption of the technology.

The China Industrials Perspective: scope for 5G to enable specific automation opportunities

An Interview with **Jacqueline Du**, Goldman Sachs Asia Machinery and Diversified Industrials Analyst

Q. What is the outlook for the Robot and Factory of the Future themes in China?

A. We believe China's manufacturing's upgrade needs to see a further step from individual robots and machines towards connected systems in the next 3-5 yrs, for both factory automation and process automation, where the 5G wireless network could potentially play a key role in industrial connectivity. We expect to see the automation industry move beyond individual machine/robots to the underlying controller, drive and software systems (or information automation). AI and robotics integration can also make a potent combination in manufacturing given various application scenarios, such as more effectively facilitating image processing and analysis, assembly, quality control etc., or Cognitive Factory across a broad spectrum of end-markets. Research and application studies on machine learning, for example cross-modal learning based on availability of big data, are already undergoing, and being supported by the government and receiving large private funding. Meanwhile, cyber security has also emerged as an issue that needs to be addressed.

Q. What is China´s plan for the next generation Robotics+AI technology?

A. China became the world's largest robot market after 2013. In 2017, China sold 37,825 units of robots by domestic brands, an annual increase of 29.8% yoy. In 2017, the total financing of global AI startups reached a record high of US$15.2 billion. Chinese companies were 48%, and US companies were 38%. With regard to the number of patent publications, China has grown from 328 in 2016 to 641 in 2017; the United States has increased from 108 to 130. However, in terms of creativeness, Europe and the US still leads China. The most important thing about AI is to combine technology and application scenarios.

Q. Why would 5G be needed?

A. The 5G wireless network, unlike previous generations which focused on data communications for consumers, is more focussed on machine-type communications and B2B connectivity. The shift is due to the fact that competitiveness of 5G extends far beyond ever-increasing data transmission speed towards supporting connectivity with unprecedented reliability and low latencies. According to 5GACIA (5G Alliance for Connected Industries and Automation), "5G may cause a disruptive impact on the manufacturing sector since the related building blocks, such as wireless connectivity, edge computing or network slicing, find their way into smart factories." The Chinese government has started to actively promote IoT adoption in manufacturing. In 2018, The State Council/MIIT released a 3-Year Action Plan for Industrial Internet with the target of reaching 300k enterprises operated in industrial internet platforms in 10 cross-industry platforms by 2020E and over 5 platforms established and entering the testing period by 2018E.

An Interview with Rockwell China General Manager of Power Control Business Unit, **Mr. Jianping Zhang**

Q. What is the industrial internet? What is the current progress and future challenges related to IoT development in China?

A. The Industrial internet is about smart manufacture, with the interaction among Machine/ Computer/ People based on big data technology. Mainly IT/OT integration at current stage, i.e. the combination of CRM/ERP+MES systems, the connection from equipment level to enterprise level. A total solution provider in the industrial internet should have capabilities covering both IT/OT for enterprise/plant & machine. At the moment, most of the demand in the Chinese market on connectivity stays at machine level and the holistic factory connectivity solution is still in its infancy. However, total solution providers like Rockwell have already started breaking into industries such as life sciences and pharmacy, where productivity/safety requirements make total solutions more appealing. The key problem is that, if equipment is not digitalized, it is not possible to build up the connectivity.

Q. What is the communication/data storage standard adopted in the industrial internet in China now?

A. For data storage, currently many corporates prefer private cloud for security. But public cloud should be the future direction due to compatibility & the benefits of sharing. For date transition, Ethernet became no.1 as of last year due to the advantage of being able to connect with the internet directly but the important part is data security, the key is to build a firewall. Rockwell Automation is the key member of Smart Manufacturing Leadership Coalition, they adopted Ethernet/TCPIP at the very beginning on hardware. Besides, there are other standards promoted by different companies, for example, Profibus by Siemens and CC-Llink by Mitsubishi.

Q. Who are the players in this market?

A. There are many players covering different industries. Rockwell and Siemens are the main players in the high-end market. Mitsubishi plays well in the mid-end market. We also have some local competition but with technology gap.

Q. Will internet giants be a threat in this arena in the future?

A. Unlike B2C market, B2B is a much more complex ecosystem to disrupt. IT/OT integration is naturally difficult and demands experienced-based knowledge in industrial operations. Internet companies need to find their OT alliances if they intend to compete there in the future. From my perspective, IT Company would be more a partner than threat for traditional OT company.

Viewpoint from Japan's FA sector: Focus on whether 5G ultimately saves costs

We think only few Japanese FA (factory automation) equipment manufacturers would see a major business model change from employing 5G. Most Japanese FA equipment manufacturers, who assert strengths in "edge" of the production process, meaning either components or equipment itself on the factory floor in particular, are suppliers of machinery and parts used globally and are positioned differently from US/European manufacturers who excel in high-end infrastructure networks and integrated electrical/infrastructure system manufacturers". In this page, we outline our views on three points: (1) barriers to introducing 5G, (2) machinery and parts fields that could be impacted by 5G, and (3) manufacturers/industries that could benefit directly and indirectly from 5G.

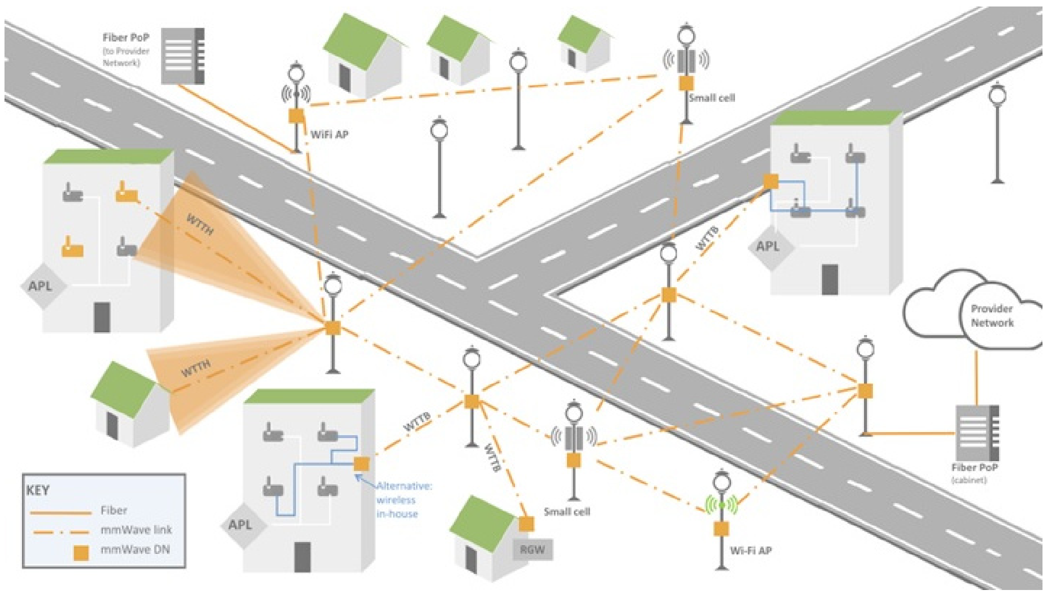
1. **Barriers to introducing 5G: Focus above all on costs versus benefits**: The biggest incentive for introducing automated equipment and processes is likely that it saves costs (i.e. reducing labor costs, improving productivity, and offering other benefits). Our Japan team thinks this is also likely the key theme in introducing 5G. In other words, the benefits versus costs of an IoT network inside a plant that introduces 5G network technologies must be larger than older network technologies that are simpler and cheaper such as existing LAN cables, Ethernet, and Wifi. For instance, visualization in the product manufacturing process can be adequately achieved with relatively unsophisticated methods such as the so-called kanban method (just-in-time inventory management) and simple I/O equipment switching. Since utilization of existing infrastructure technologies (Wifi and industrial PCs) suffices, we think 5G must offer benefits versus costs exceeding this in fields where large volumes of data must be processed speedily (inspection processes, discussed later, are a clear example). In our view, it will take a considerable amount of time to completely switch existing infrastructure, not to mention cost, barring no newer applications and processes.
2. **Machinery and parts fields that could be impacted by 5G:** The feature of the processing of data between machinery/parts in which Japanese FA equipment makers excel is their high speed/massive frequency. Transfer speeds for the large volumes of data between equipment used in "edge" fields, such as servo motors and controllers, are very fast. On this point, the advent of 5G would appear to offer advantages, but a major question also arises: What really are the advantages of using 5G to enable wireless communications with equipment connected by existing network cables? We expect the answer will probably depend on the aforementioned cost savings. The advantages of 5G are likely to be captured in mobile autonomous robots (mobots; the combination of collaborative robots (cobots) and automated guided vehicles), portable inspection equipment, and entirely new processes where automation has yet to truly make a mark. At this point, we think these fields are unlikely to lead to major business opportunities for existing Japanese FA equipment makers in terms of the TAM.
3. **Stocks that could benefit from the advent of 5G:** We have heard of some machine tool manufacturers fielding inquiries for parts processing for antennae for 5G-compatible base stations, but the scale of orders is still quite small. As it is still unclear what machinery/parts might be suited to wireless communications that have not been automated, we think business opportunities associated with IoT within factories is limited at present. In terms of major changes and benefits for Japanese FA equipment manufacturers as a whole, we think capex is likely to increase if large-scale design changes are made when customers strengthen their response to 5G for smartphone makers. While 5G is a nascent technological field offering opportunities, we find it a little difficult at this juncture to recommend Japanese FA machinery makers that are positioned to leverage it.

Key competitive technologies

Telecom Infra Project

The Facebook-led Telecom Infra Project is currently studying feasibility of the 60GHz spectrum for usage through the mmWave Networks Project Group. The Group is being led by Facebook and Deutsche Telekom (and supported by Intel and Vodafone) and was kicked off in September 2017. The Project Group is currently focused on cost economics modeling, validation of 60GHz networking for metro applications, network planning and best practices. The use cases to be supported are fixed wireless access to homes and offices, mobile backhaul, and smart city applications.

Exhibit 36: Overview of TIP



Source: Telecom Infra Project

802.11 WLAN standards

Several advancements in 802.11 WLAN standards are offering multi-gig performance and/or support IoT deployments. 802.11ax (or Wi-Fi 6) is the next generation of Wi-Fi technology to succeed 802.11ac and is expected to be available in 2019. The standard will incorporate additional bands in the 1GHz – 7GHz range in addition to the 2.4GHz and 5GHz spectrum in use today. 802.11ah (or Wi-Fi HaLow) is designed to use unlicensed sub-1GHz spectrum and is primarily focused on IoT deployments (Industrial IoT, Connected Cars, Smart Home and Smart City). 802.11ad (or WiGig) is designed to operate at 60GHz as a complement to the 2.4GHz and 5GHz Wi-Fi to offer multi-gigabit low latency connectivity. Importantly, while they offer lowered latency characteristics, they are not yet matching the specifications of 5G fixed wireless access.

Exhibit 37: 802.11 vs. 5G

Standard	Latency	Other important characteristics
802.11ah (HaLow)	Not comparable (greater than 10 milliseconds)	- Designed to be used for low power, high range IoT deployments - Deployment scenarios could include street lights, parking meters etc.
802.11ax	Sub-10 milliseconds	- Next gen Wi-Fi standard - Broad range of use cases including home, enterprise and commercial deployments
802.11ad (WiGig)	~7 milliseconds	- Multi-gigabit speeds with low latency offset by low range (owing to the use of 60GHz spectrum - Finding use in virtual reality headsets already
5G NR	~1 milliseconds	- Next gen cellular standard - Offers the lowest latency and expected to find broadest range of use cases

Source: IEEE, Goldman Sachs Global Investment Research

Glossary

Enhanced Mobile Broadband (eMBB)	Usage of 5G for smartphones; requires high data rate across wide coverage of area
Fixed Wireless Access (FWA)	Usage of 5G to deliver high speed data network to the home; typically targeted for video
Industrial IoT (Factory automation)	Usage of network to connect industrial processes and robots
Industrial IoT (Logistics)	To deliver more efficient "Track and Trace" logistics
Industrial IoT (Public Safety)	Upgrading basic communication systems for First Responder networks
Latency	Total time it takes a data packet to travel from one node to another
Massive MiMo	Massive multiple-input, multiple-output (MIMO) groups multiple antennas at the transmitter and receiver to provide better throughput and better spectrum efficiency
Millimeter Wave (mmWave)	Milimeter wave (mmWave) has frequency between 30–300 GHz and wavelength in the range of 1-10 mm and is used for high-speed wireless communications
Non-standalone (NSA)	4.5G hardware that can be upgraded to 5G (through software and hardware upgrades)
Radio Access Network (RAN)	Part of a mobile telecommunication system residing between a device such as a mobile phone, and provides connection with its core network
Standalone (SA)	Base station equipment which is 5G-native and can run on a 5G network as soon as it is installed

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Accelink Technologies (N/N, Rmb26.46), ADTRAN Inc. (N/A, $12.45), Analog Devices Inc. (S/N, $91.92), AT&T Inc. (N/N, $31.24), Belden Inc. (B/N, $55.78), Bharti Airtel (B/N, Rs313.55), Bharti Infratel Ltd. (NR, Rs256.50), BT Group (N/N, 262.00p), China Mobile (HK) (B/N, HK$77.65), China Tower Corp. (B/N, HK$1.16), Ciena Corp. (B/A, $32.62), CommScope Holding (N/N, $18.10), Corning Inc. (N/N, $32.22), Delta Electronics (B/N, NT$130.00), Disco (N/N, ¥16,550), Dish TV India (N/N, Rs38.15), Drillisch AG (N/N, €44.40), Elisa OYJ (B/N, €35.42), Ericsson (B/N, $8.39), Ericsson (B/N, Skr75.92), Fiberhome Telecom Tech (S/N, Rmb28.22), Fujitsu (B/N, ¥6,987), Fujitsu General Ltd (NC, ¥1,603), Hon Hai Precision (N/N, NT$71.90), Iliad (N/N, €119.15), Juniper Networks Inc. (S/A, $28.71), Keysight Technologies Inc. (B/N, $61.82), KONE Corp. (B/N, €43.76), Lumentum Holdings (B/A, $44.47), Murata Mfg. (B/A, ¥17,315), NEC (N/N, ¥3,520), Netlink NBN Trust (N/N, S$0.78), Nokia (N/N, $5.47), Nos SGPS (B/N, €5.49), Orange (B/N, €15.16), Orange Belgium SA (S/N, €16.50), Proximus Plc (N/N, €24.44), PT Sarana Menara Nusantara (B/N, Rp525), Royal KPN NV (N/N, €2.61), Samsung Electronics (B/N, W41,850), Samsung SDI Co. (B/N, W206,500), Signify NV (B/N, €23.49), Singapore Telecommunications (B/N, S$3.08), SK Hynix Inc. (N/N, W69,600), Spirent Communications Plc (N/N, 129.60p), Sunrise Communications Group (B/N, SFr87.45), Swisscom (S/N, SFr479.30), TalkTalk (S/N, 126.90p), Tech Mahindra Ltd. (B/N, Rs705.50), Tele Columbus (N/N, €3.84), Telecom Italia (N/N, €0.57), Telefonica (N/N, €7.93), Telefonica Deutschland (N/N, €3.58), Telenet (B/N, €43.82), Telenor (N/N, Nkr166.45), Telia Co. (B/N, Skr41.99), Telstra Corp. (B/N, A$2.93), Ulvac (B/N, ¥4,170), United Internet (N/N, €39.75), Verizon Communications (B/N, $60.30), Xilinx Corp. (B/N, $92.48), Zhongji Innolight Co. (N/N, Rmb43.97), ZTE Corp. (A) (N/N, Rmb19.87) and ZTE Corp. (H) (N/N, HK$15.38)

Disclosure Appendix

Reg AC

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