Tech2Watch

TOMORROW'S
TECHNOLOGIES
TODAY

Welcome to Tech 2 Watch

Which are the technologies and initiatives that have the greatest potential to change the mobile networks market?

The pace of change in the wireless industry is faster today than it has ever been before. The market is being asked to meet ever-growing demands with increasingly challenging performance expectations, of which growing data traffic is just one aspect. Carriers are looking to enhance performance on existing networks whilst the market goes through the process of evaluating technologies that may form the building blocks of 5G.

In this Tech2Watch article, leading analysts and commentators highlight the technologies that they believe have the potential to meet these demands and change the mobile market. Some are new technologies and concepts that are only just being developed; others have been around for some time but are only now coming to prominence; and others highlight new developments to familiar concepts and solutions. However they all have the capacity to radically change the way that the ecosystem operates and how the market meets the growing demands upon the network.

As technology capabilities and user demands evolve, new technologies will continually increase in prominence, so please do get in touch with the technologies that YOU feel should be included in our next Tech2Watch article, or that should even be the subject of a dedicated Tech2Watch webinar. Get in touch on tech2watch@avrenevents.com to let us know what tech we should be watching out for.

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Millimeter-wave Radio Access

Joe Madden, Mobile Experts

Millimeter-wave radios are coming to market much quicker than expected. In the United States, the 24 GHz, 28 GHz, and 39 GHz bands are available now for wireless communications, and the FCC has just ruled that mobile services can take over in these bands. Verizon Wireless has declared its intention to move quickly to deployment of a fixed broadband wireless network.

To deploy 28 GHz radio access quickly, the industry is taking its best guess at the final configuration of 5G air interface standards, and implementing both network infrastructure and terminals capable of handling the flexible 5G frame structure. This is a challenge, because the standards committees have not finalized the details of the 5G air interface. Until recently, nobody expected these standards to be frozen until 2019.

For the short term, programmable logic will dominate the base stations and terminals. There are no "5G" chipsets for terminals yet, so we can expect FPGAs to appear in customer premise equipment that will be situated on the wall or in the window of a customer's home or office. Eventually, of course the chipsets will be hardened on both ends of the link, but that step will wait for final standards.

One of the biggest challenges will come on the RF side, with tradeoffs between link range and heat in the radio. To make money, the operators need long-range radio links. But at mm-wave frequencies, that means high power, and the current path of technology is not efficient enough to achieve the required radio performance using passive cooling. Nobody wants to return to air conditioners for each base station.

This new direction for the mobile market is a game-changer. This new equipment will allow the mobile operators to compete in the fixed broadband market, with gigabit speed and cost per bit that's comparable to fiber. Early deployments such as the Verizon system will determine the level of investment worldwide, so the next 12 months will be critical to the future of the mobile market.

Macro Base Station Antenna Technology-Migration from Passive Multiport to Massive MIMO Millimeter Wave Solutions

Earl Lum, EJL Wireless Research

One of the areas within the radio access network that has undergone significant transformation over the past five years has been in antenna technology. There are several trends that continue to evolve that play a critical role in the deployment of LTE Advanced, LTE Advanced Pro, and eventually 5G networks. These trends are:

- Higher Port Count Passive Antennas
- Multi-Beam Antennas
- Semi-Active Antennas
- Massive MIMO Millimeter wave Antennas

For massive mobile user density problems that are associated with concerts and festivals, mobile operators have not been successful in deploying a suitable antenna solution to increase capacity. The Coachella Valley 2016 music festival in Indio, CA along with the Super Bowl 50 event in San Francisco/Santa Clara, CA showcased a new type of cell splitting solution, capable of supporting between 10-12 independent beams within a traditional 65 degree half power beamwidth (HPBW) sector. We believe that this type of solution will allow mobile operators to increase sector capacity without the need to deploy small cells.

"For massive mobile user density problems that are associated with concerts and festivals, mobile operators have not been successful in deploying a suitable antenna solution to increase capacity"

The ever increasing number of frequency bands available below 6GHz for current LTE Advanced networks, coupled with the migration from 1T2R/2T2R remote radio units to 2T4R/4T4R remote radio units has significantly impacted the design and implementation of passive multiport antennas within the network. Ten and twelve port solutions are ramping into production with North America driving a significant portion of this demand.

The integration of the active remote radio unit(s) with a passive multi-port antenna is being driven by cell site restrictions globally. The need to reduce the physical number of cables, remote radio units and antenna panels per site is driving some mobile operators to adopt the deployment of semi-active antenna solutions. We note that this product segment, while offering a substantial reduction in the overall site clutter, remains a very small segment of the overall market.

While current base station antennas can support up to an 8T8R MIMO configuration and operational frequencies below 6GHz, the future lies in both increasing the MIMO order to 16, 32, 64 and 128T128R architectures while substantially increasing the operating frequency to the 26-32GHz spectrum and potential up to the 70-86GHz spectrum bands.

The way the industry designs and deploys current mobile broadband networks today will need to undergo a radical shift to support the technology of massive MIMO millimeter wave antenna solutions in the future.

LTE Cat-NB1 and LTE Cat-M1: the future of IoT connectivity?

Aapo Markkanen, Machina Research

Low Power Wide Area (LPWA) networks are arguably the hottest innovation area in telecoms right now. These dedicated networks, promise low bandwidth connectivity for billions of IoT devices worldwide, with the particular benefits of low cost and lower power usage and, as a result, longer battery life. Until now the focus has been on overlay networks from the likes of Sigfox, LoRaWAN and Ingenu, but in the background 3GPP has been working to develop a mobile operator equivalent that can be deployed relatively easily in existing licensed spectrum with (as much as possible) existing infrastructure. This has led to the development of two new standards under the auspices of 3GPP Release 13.

3GPP completed the standardisation of NB-IoT, the first of the two technology evolutions, at a plenary held in South Korea in June, implementing it as a feature into its Release 13. It is likely that the standard will see some modifications later in the year, but an important point is that any further changes need to be backward compatible with what has been ratified. The ratification also saw NB-IoT given (yet again) a new official name: LTE Cat-NB1. Based on our extensive conversations with MNOs, we expect extensive network deployments next year.

The Release 13 feature which for the most part of its standardisation process had been known as LTE-M, and now Cat-M1, was completed earlier in the first half of the year. This development is much closer to existing LTE, but achieves longer battery life and lower cost through reduced functionality, with a significantly slower data rate than standard LTE.

It is notable that there is significant overlap between the two developments in terms of functionality, which may lead MNOs to favour one or the other in the early phases of deployment, but is unlikely to jeopardise either.

Back to Backhaul

Julius Robson, Small Cell Forum

The Small Cell Backhaul has been a bit quiet recently... but now it's back with a vengeance, as operators demand affordable gigabit backhaul to meet next generation capacity requirements everywhere.

The principle market for small cell backhaul is urban densification. Initially we saw relatively small deployments as operators used them tactically as a precision tool to fix isolated problem areas in their network. Operators are now urgently scaling up deployments to become part of their densification strategy. And this is where backhaul is needed. Backhaul connections for urban small cells are set to multiply by 20 times between 2016 and 2020, driving cumulative spending of $6.4bn in the same period [IHS Technology]

At a recent Small Cell Forum webinar, operators didn't mince words when describing the challenges they're facing, and how they'd like things to change. There were calls to unify planning which differs from city to city, let alone country to country. As we see in another article, there is great interest in using higher frequency spectrum for 5G access. However, this places uncertainty around the microwave and millimeter wave backhaul solutions which currently use these bands.

A central theme for the Small Cell Forum's recent Release 7 on HetNet and SON, is the essential role of automation in deploying and operating dense HetNets. SON today is largely RAN centric – automating cell ID and neighbor list allocations. In future, operators need to automate all aspects of end to end service delivery, including backhaul. Operators need small cells and backhaul to be plug, play and forget to avoid high and unexpected O&M costs.

Virtualization of small cells is also changing the game for backhaul. The forum has now published its nFAPI interface which enables C-RAN benefits over packet Ethernet type connections, unlike CPRI based C-RAN which generally needs fiber. Other so-called 'functional splits' of the small cell are possible, each providing a different tradeoff between the benefits of centralization and the required backhaul performance. In the longer term, virtualized functions can be moved around according to transport performance, allowing operators to squeeze the most from their deployed assets. Guidelines on transport performance requirements for different splits are currently being developed for our next release 8 on virtualization in November.

"The Small Cell Backhaul has been a bit quiet recently...but now it's back with a vengeance"

So after the hype and the disillusionment, small cell backhaul is re-asserting its place as an essential ingredient in the future HetNet. And together with simplified site acquisition and automated deployment, is back on the Forum's agenda.

LTE in Unlicensed and Wi-Fi

Kyung Mun, Mobile Experts

The competition for unlicensed spectrum use is rising. Mobile operators who have long viewed the use of unlicensed bands with Wi-Fi as sub-optimal are working towards deploying well understood and operationalized LTE in the unlicensed bands. A basic premise of "LTE unlicensed" (LTE-U) technologies is to opportunistically harness unlicensed bands for supplemental capacity augmentation while managing service quality through control signalling in the licensed bands. Various "LTE unlicensed" (LTE-U) technologies, including pre-standard LTE-U, LAA, LWIP, LWA and MulteFire, are vying to satisfy the needs of service providers and enterprises. The underlying motivation for the LTE-U technologies is to lower the unit cost of delivering mobile data. By effectively leveraging free spectrum, the overall cost per bit economics becomes much more favorable.

The increasing interest in unlicensed spectrum use is to some degree a response to the rising competitive dynamic between mobile and fixed operators who have largely stayed within their dominant positions in fixed (i.e., high-speed broadband and video services) and mobile (i.e., mobile telephony and broadband) services. As consumers increasingly opt for mobile-centric offerings, both fixed and mobile service providers are looking to extend their wireless networks to meet the growing need for capacity and seamless mobility handling, in and outside premises.

This competition for unlicensed bands through LTE-U is a game-changer for the mobile industry and the larger telecom industry context. While the mobile industry works to harness the abundant spectrum bands in the higher-spectrum millimeter wave bands through "5G" technology, an immediate "tapping" of the unlicensed and shared bands through the LTE unlicensed technologies provides a near-term pathway for additional capacity. Moreover, "strategic" placements of the LTE unlicensed radio nodes provide longer-term physical anchor points for 5G radios as operators and enterprises look to continuously densify and extend their networks inside and outside of premises where consumers and workers generate and consume mobile data.

The competition for strategic locations and spectrum with LTE and Wi-Fi technologies will intensify as operators and enterprises seek to meet the growing demand for mobile preference in communication and entertainment services. The battle for unlicensed spectrum among Wi-Fi, LTE and possibly "5G" is a reflection of the rising competitive dynamics between fixed and mobile operators and convergence behavior of consumers and enterprise workers.

"The competition for strategic locations and spectrum with LTE and Wi-Fi technologies will intensify..."

CBRS and MulteFire: Single Spectrum Technologies Could Be a Game Changer for In-Building

Randall Schwartz, Wireless 20/20

One of the most important network development areas for 4G and 5G networks is the enhancement of in-building networks to augment coverage and capacity from the mobile operator's outdoor networks. Considering that most multi-tenant buildings demand there be coverage for all major mobile operators in that market, the added technical need to support all subscribers adds some critical design criteria to successfully deploy these networks. Fortunately, some spectrum-based technology solutions are now coming to market which can help support the critical demands.

In order to build in-building systems that can support multiple operators, there are several solution paths that can be employed. First, each operator can deploy their own system in the venue, but this is not possible because it is unsightly, uneconomical and, in some cases even physically impossible to support 3 or 4 individual infrastructures. Multi-operator DAS systems provide support for all of the operators with one infrastructure, but this has the challenge of needing to support all of the frequencies for all of the operators.

New spectrum options can allow one neutral spectrum option a reality for future systems. The CBRS spectrum (light-licensed spectrum in the 3.5 MHz band) and MulteFire (unlicensed spectrum in the 5 GHz band) are two examples of new technology options which have the potential to change the technical and economic formulas for in-building networks. Both these technologies are neutral spectrum, which can support LTE protocols for all operators. As such, a venue owner or a neutral host operator could deploy such a system in a venue, and provide connectivity and capacity to all operators. By supporting only one frequency, these networks should be deployed at a cost basis far lower than systems which support up to a dozen different frequencies.

As products become available for CBRS and MulteFire, single spectrum in-building systems could provide a game changing solution for the deployment multi-operator in-building solutions. Both operators and venue owners need to watch developments for these key new technologies carefully.

The Sharing Revolution

Simon Fletcher, Real Wireless

Over the last five years the growth in the understanding of the value creation of the Sharing Economy in consumer markets has led to increased investment in businesses that monetise the sharing economy, for example the Mobility-as-a-Service of the automotive sector. The wireless industry has been realising increasing value from sharing of infrastructure as 3G deployments have matured, and 4G offers more features to enable sharing. A GSMA survey of Mobile Operators in 2012 found the top three reasons for sharing were:

- The need for new entrants to quickly establish national coverage driven by commercial or regulatory imperative.
- Downward pressure on ARPU, leading to cost saving pressures.
- Data traffic congestion in urban areas alongside a lack of new sites.

Mature passive sharing approaches on macro sites have led to Standards and commercial arrangements that establish active RAN sharing, maintaining logical networks for each Operator through to the Core. The advent of MOCN and in the small cell market, Neutral Host, continues the sharing evolution. Both the FCC and Ofcom are establishing frameworks around releasing spectrum (especially in the 3GHz range) that will encourage spectrum sharing.

Looking further forward, the 5G research[1] and standardisation communities are working on establishing a viable technical realisation of architectures that will enable sharing of spectrum, RAN functional entities, and the flexible utilisation of compute and storage at the edge and deeper into the network. These advances are typically inspired by the architectural approaches and business models of the IT Industry; Saas, PaaS, IaaS etc. New horizontal platforms upon which new business models can emerge are being defined, using concepts like Virtualisation, Software defining, and slicing of resource. These initiatives promise to deliver a much more dynamic and open architecture enabling Tenants to take control of the QoE of their Services.

These developments all point to significant changes in the approaches to sharing. Whilst

MNOs will continue to mature their active sharing, new players may well emerge from the vertical industries, leveraging sharing of software and hardware assets to underpin strategic alliances with key players in the wireless industry.

"The wireless industry has been realising increasing value from sharing of infrastructure"

MEC: The importance of location

Monica Paolini, Senza Fili

Virtualization releases us from many of the constraints of implementation. Network functionality can be instantiated on hardware that is not specifically tied to the function and that can be assigned dynamically in real time. This gives us flexibility and freedom in optimizing the allocation of network resources – and also in where these functions reside in space.

Does this mean that location is no longer relevant? That all can be moved to a cloud that can be anywhere? Not so fast. Location becomes more prominent with virtualization, because it gives us a choice on where we want functionality to reside, and that has an impact on performance, QoE, cost, complexity, security, and resource utilization.

***Virtualization releases us from many of the constraints of implementation"**

Mobile Edge Computing (MEC) is one of the most salient examples of how location of network and service functions matters when we optimize network performance and QoE – specifically by pushing functions and content that are typically part of the core closer to the edge -- to the RAN and to the subscriber.

An ETSI-driven standardization effort, MEC provides a distributed network architecture designed to benefit latency-critical functions and content. MEC allows operators to squeeze out more value from the existing network infrastructure by improving latency -- and hence QoE. With MEC, operators may need less capacity to meet their traffic requirements (read: postpone the need for network expansion) or leverage available capacity to give a better experience to subscribers (read: lower churn, reduce congestion).

This is of paramount importance in an environment in which latency-sensitive traffic is the fastest growing type of traffic (video streaming, gaming, conversational video, and IMS-based voice) and the one to which subscribers ascribe the highest value. In this

context, latency is as crucial as capacity. A network with plenty of capacity that is slow feels congested to the end user. Expanding capacity is still necessary but no longer sufficient for good QoE, and we cannot afford to wait for 5G to minimize latency.

[1] For example see the 5G-PPP project 5G-NORMA (https://5g-ppp.eu/5g-norma/)

C-RAN in 5G

Stefan Pongratz, Dell'Oro Group

C-RAN (centralized and coordinated RAN) is a RAN architecture that moves the baseband unit (BBU) to a central location, connecting the BBU to the radios via fiber or microwave (Figure 1). The objective of centralizing the baseband is to improve the performance and use resources more efficiently and dynamically by pooling resources together. Cloud-RAN intends to propel the C-RAN architecture further by using NFV and data center resources to virtualize various aspects of the baseband with the ultimate goal to improve performance, flexibility, scalability, and efficiency. The number of functions that will be implemented via VNFs will vary depending on the state of the infrastructure and the associated benefits of the particular use case. There could be VNFs to implement various L1, L2, and L3 functions on separate VMs, while there can be separate VNFs to implement sub functions for L1-L3.

Figure 1: RAN Baseband Architectures

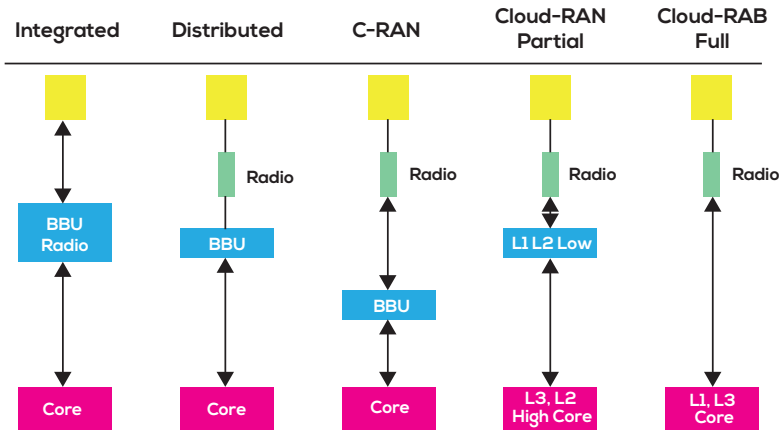
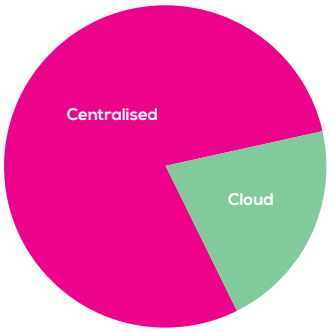


Figure 2: 5G C-RAN & Cloud-RAN Baseband Revenue Splits by 2020



*Centralised architecture assumes L1-L3 or higher layers of L2 and L3 are centralized. Cloud architecture assumes L1-L3 or higher layers of L2 and L3 are implemented using general purpose processors.

"We expect that with more efficient fronthaul technologies, the benefits of centralized and cloud architectures will be more compelling with 5G"

From a market revenue perspective, it is fair to conclude that the C-RAN architecture has not lived up to its hype and it will likely remain a niche technology with 4G confined to fiber rich markets.

With 5G, however, the base-station architecture will need to evolve to accommodate the wide range of potential use cases and the extreme cost-per-bit requirements for making 5G a reality. Distributed architecture dominated the 4G era–and while we expect this architecture to play a crucial role initially for 5G for both outdoor and indoor deployments, we expect that with more efficient fronthaul technologies, the benefits of centralized and cloud architectures will be more compelling with 5G (Figure 2).

The shift from 4G to 5G will not by itself eliminate all the inherent technical and business case challenges with the C-RAN and Cloud-RAN architectures. But the combination of the diverse use cases, the need for a more agile and cost effective architecture, and the expected progress with NFV will increase the likelihood the business case can be justified – provided the incremental improvements outweigh the increased cost of transport, which will likely remain the primary C-RAN/Cloud-RAN adoption barrier, even with 5G.

Impact of Virtualisation on Radio Access Network (RAN)

Sue Rudd, Strategy Analytics

Virtualising the RAN

Virtualisation in its broadest sense means the *'pooling of resources of a similar type'* both logically and physically. Virtualisation enables resources to be reused dynamically both to ***improve capacity utilisation and simplify operations*** - both of which directly reduce the Mobile Network Operator (MNO) Total Cost of Operations (TCO) per Gigabyte (GB) and help MNOs meet the rapid growth in traffic.

Much of the early focus in Network Functions Virtualisation (NFV) was on the Data Centre and virtualisation of the Core Network. In 2015 many said that virtualisation of the RAN (vRAN) - whether through Centralised RAN, Cloud RAN (C-RAN), or dynamic power control and frequency assignment with Self Organising Networks (SON) was years away. See the survey and workshop we did at RAN World 2015.

Trials have led to Deployment, Diverse RAN configurations and lower Costs

Demonstrations that we described after MWC 2015 by Telefonica with Alcatel Lucent (now Nokia) and trials by China Mobile and SKT have turned into deployments. Many of these are now positioned as pre-cursors to 5G RAN architecture.

On the vendor side earlier this year Nokia both announced its commercial Airscale™ solution on the path to virtualised 4G/5G; and deployed 4G C-RAN for TD-LTE at large events with China Mobile. Ericsson is now offering pre-SG 'Plug-Ins' for Massive MIMO, Multi-User MIMO and RAN Virtualization. Huawei offers multiple commercial configurations of LampSite™ that blur the boundary between small cells and C-RAN.

New Operators are now committing to C-RAN deployment including Verizon and Sprint in the US.

Multiple Configurations

Parallel discussions of alternate RAN functional splits by EU FP7 Project iJOIN and Small Cell Forum etc. are creating the range of flexible configuration options needed to deliver vRAN cost effectively for multiple Use Cases in Dense Urban, Remote Rural and Shared Operator locations.

Innovative new vendors are adding very flexible or cost effective solutions to these RAN configuration options from vendors like Blue Danube, Cisco, Fujitsu, Hitachi-CTA, Intel, NEC and Parallel Wireless as well as Cavium and Radisys.

vRAN Cost Savings

Some of the biggest breakthroughs for improved TCO/GB come from sharing Baseband radio Units (BBUs) at an adjacent or remote aggregation site for:

- Dynamic use of Spectrum
- Remote Radio Heads (RRHs)
- MIMO
- Steerable Antennas etc.

Or from new 'fronthaul' options that leverage both CPRI and emerging alternatives:

- Shared Ethernet over Fibre
- GB Microwave

as well as the original

- Dedicated 'Dark Fibber'

These have all dramatically accelerated the cost effectiveness of vRAN options.

vRANs for Service Flexibility

And now vRANs are beginning to be viewed as a facilitator for value added services - a concept already being pioneered by SK Telecom - and soon Mobile Edge Computing (MEC) and Gi-LAN services.

Conclusion

Commercial virtualisation of the RAN is starting and will deliver both significant cost savings and create new revenue opportunities that will be of paramount important to MNOs in 2017.

Independent Small Cells

Charles Murray, Analysys Mason

Much of the hype around small cells makes the assumption that mobile operators will pay for their deployment, just like they do with macro networks. However, the finances of mobile operators are pretty challenging at present and their appetite for significant investment in small cells which also increases operating costs is lukewarm at best.

This economic picture creates the need for independent small cells, where the costs of both the hardware and backhaul (typically consumer-grade DSL) will be met by the building owner in the same way they provide WiFi.

Small-cell technology has come on a long way in the last few years and costs have fallen; however up-take is still very limited. In order for small cells to be used in an independent fashion a few remaining technical challenges need to be overcome.

Small cells need to be self-starting and able to register with all of the gateways of all operators as they will need to serve multiple operators. A cell needs to know its location, for emergency response purposes. Between the cell and the networks, a number of decisions need to be made: power level, what neighbouring cells to use, etc.

Active management of independent small cells through the OSS will also be needed. Because the cells sit on contended DSL backhaul and the radio environment, typically deep in building, is not known, any number of radio interference problems may materialise. As a result, the impact that a small cell has on customer experience needs constant monitoring, so that parameters can be adjusted as problems appear. In addition, the operators' OSS will need the ability to take a cell off air if the customer experience is seriously affected.

All of this management needs to be fully automated and enabled through deep analytics and intelligent decision making. If the industry analysts' forecasts of small cells prove correct then there will be far too many of them for a mere human to control.

Analysts

Aapo Markkanen

Aapo Markkanen is a Principal Analyst at Machina Research, where he focuses on access technologies and the role they will play in the evolution of M2M and IoT connectivity. He has a particular research interest in Low Power Wide Area (LPWA) networks and competing short-range alternatives. In addition, Aapo contributes to Machina Research's coverage on other emergent IoT topics, advising vendors, service providers, and end users on a variety of market and technology issues that will shape tomorrow's connected enterprise.

Before joining Machina Research, Aapo worked as a Principal Analyst at ABI Research, where he led various research activities related to M2M, the Internet of Things, and big data.

Aapo holds BSc and MSc degrees in management studies from the University of Tampere, Finland.

Charles Murray

Charles is a Principal at Analysys Mason. He specialises in mobile network sharing, operator M&A, and infrastructure projects - including tower deals, procurement and network outsourcing. He brings together deep technical and commercial knowledge with robust financial analysis to guide operators and investors through complex issues. Charles has a degree in Engineering from the University of Cambridge.

Earl Lum

Prior to starting EJL Wireless Research, Earl Lum was the Managing Director of the Wireless Technology Equity Research sector for Montgomery & Co. Before this, Earl spent 7 years as the Executive Director for the Wireless Technology Equity Research group at CIBC World Markets. His team pioneered the methodology of supply chain analysis for equity research within the wireless sector. Earl also established core research areas focusing on compound semiconductor technologies including: GaAs, SiGe, InP, SiC and GaN. Prior to joining Wall Street, Mr Lum also served as senior research analyst at Gartner Group/Dataquest. He established the wireless semiconductor research platform and pioneered research in the emerging GaAs compound semiconductor market. Mr Lum also worked as Senior RF Design Engineer for Tyco Electronics M/A-Com, RF Transistor R&D Engineering Manager for Spectrian Corporation and Product Engineer at National Semiconductor Corporation. Earl holds a B.S. in electrical engineering from the University of California, Santa Barbara.

Joe Madden

Joe Madden is Principal Analyst at Mobile Experts LLC. Mr. Madden is widely viewed as the leading analyst in Small Cells and Mobile Infrastructure. He leads a team of analysts in highly accurate base station and mobile device forecasts, including primary research in semiconductor areas.

Mr. Madden graduated, cum laude, from UCLA in 1989 and is a Silicon Valley veteran. He has survived IPOs, LBOs, divestitures, acquisitions, and mergers during his 26 years in mobile communications.

Julius Robson

Julius Robson is an independent wireless expert for clients with requirements ranging from the deeply technical IPR analysis through to the commercial development of business value propositions. Julius also leads the Small Cell Forum's Steering Committee, coordinating across work groups to deliver cohesive outputs on its objectives of Enabling Digitized Enterprise and Deploying HyperDense Networks. Julius has chaired a number of groups within industry forums including the NGMN alliance and the LTE/SAE Trial Initiative (LSTI). His background is in wireless technology research and standardisation, and he was Nortel's delegate to 3GPP RAN during the development of LTE. He holds a BEng in Electronic Engineering and an MSc in Microwave and Optoelectronics.

Kyung Mun

Kyung Mun is a seasoned technology strategy and product development professional with over 20 years of experience in mobile, wireless, and cable industries. Kyung has contributed to advancement of mobile communications and telecom at Motorola, Texas Instruments, Alcatel-Lucent, CableLabs, and a few start-ups in between.

Kyung received his BSEE from the University of Texas at Austin and MSEE from Georgia Tech. He later acquired an MBA from Southern Methodist University.

Monica Paolini

Monica Paolini, PhD, is the founder and president of Senza Fili. She is an expert in wireless technologies and has helped clients worldwide to understand new technologies and customer requirements, create and assess financial TCO and ROI models, evaluate business plan opportunities, market their services and products, and estimate the market size and revenue opportunity of new and established wireless technologies. She frequently gives presentations at conferences, and writes reports, blog entries and articles on wireless technologies and services, covering end-to-end mobile networks, the operator, enterprise and IoT markets. She has a PhD in cognitive science from the University of California, San Diego (US), an MBA from the University of Oxford (UK), and a BA/MA in philosophy from the University of Bologna (Italy). You can reach her at monica.paolini@senzafiliconsulting.com.

Analysts

Randall Schwartz

Randall Schwartz has been a key participant in the broadband wireless market for the last 20 years. He is the founder of Wireless 20/20, a leading broadband wireless consulting group and the developer of the WiROI Business Case tool. He brings 30 years of experience in wireless industries, as well as semiconductor. The Wireless group has extensive experience in deploying broadband wireless systems in a wide variety of markets. Schwartz has led development projects with over 60 operators around the world, helping clients by developing business cases, supporting technology selection, and building network deployment plans. Wireless 20/20 has successfully helped operators build plans for deploying networks with HSPA, HSPA+, WiMAX, LTE, WiFi and other broadband wireless technologies.

Simon Fletcher

Simon takes responsibility for the overall technology offering and strategy of Real Wireless. Through its expert Advisors Real Wireless works with clients in the creation of wireless technologies, their deployment and optimal use. Prior to Real Wireless Simon worked at NEC Corporation leading developments of emerging global market product strategies, portfolio alignment, and innovation programmes including early 5G, Cities and IoT business. With a primary focus on infrastructure and network edge technologies he represented NEC in joint ventures developing 3G and 4G global market products; working in various Systems, Consulting and development project management roles including Steering roles in LSTI and NGMN for early LTE Proof of Concept and Trials. He is the Innovation Manager for the 5G-PPP project 5G-NORMA which develops enabling technologies, architectures, and economic insights for 5G.

Stefan Pongratz

Stefan Pongratz joined Dell'Oro Group in 2010 and is responsible for the firm's Carrier Economics and Mobile RAN coverage. While at the firm, Mr. Pongratz has expanded the Mobile RAN research adding significant detail on LTE and small cells. He has authored several Advanced Research Reports on the mobile market covering topics such as the evolution of small cells and C-RAN. He also built the firms Carrier Economics coverage, including revenue and investment trends of the 50 largest carriers worldwide.

Prior to joining Dell'Oro Group, Mr. Pongratz was with Anritsu Company for 10 years, where he was most recently a Senior Product Manager responsible for portable spectrum analyzers and cable & antenna analyzers used to verify base station quality. During his tenure at Anritsu, Mr. Pongratz also held positions in engineering and manufacturing management.

Mr. Pongratz holds a B.S. and M.S. in Electrical Engineering and an M.B.A. from UC Davis.

Sue Rudd

Sue Rudd, Director Service Provider Analysis, Wireless Networks and Platforms, Strategy Analytics Inc.

Sue has over 20 years' experience developing business cases for Mobile Broadband, Voice and Value Added IP services. Her current work focuses on matching new technology to business opportunities including Revenue and TCO per GB with specific analyses of: LTE/Next Gen. Services, video delivery, cloud services, content delivery networks (CDNs), NFV/SDN, traffic monitoring for CEM, diameter signaling, small cells, carrier Wi-Fi roaming, SON. Previously she worked for Comverse Motorola & BBN. She has degrees in Economics from Cambridge University and MBA in Operations Management from Wharton.

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