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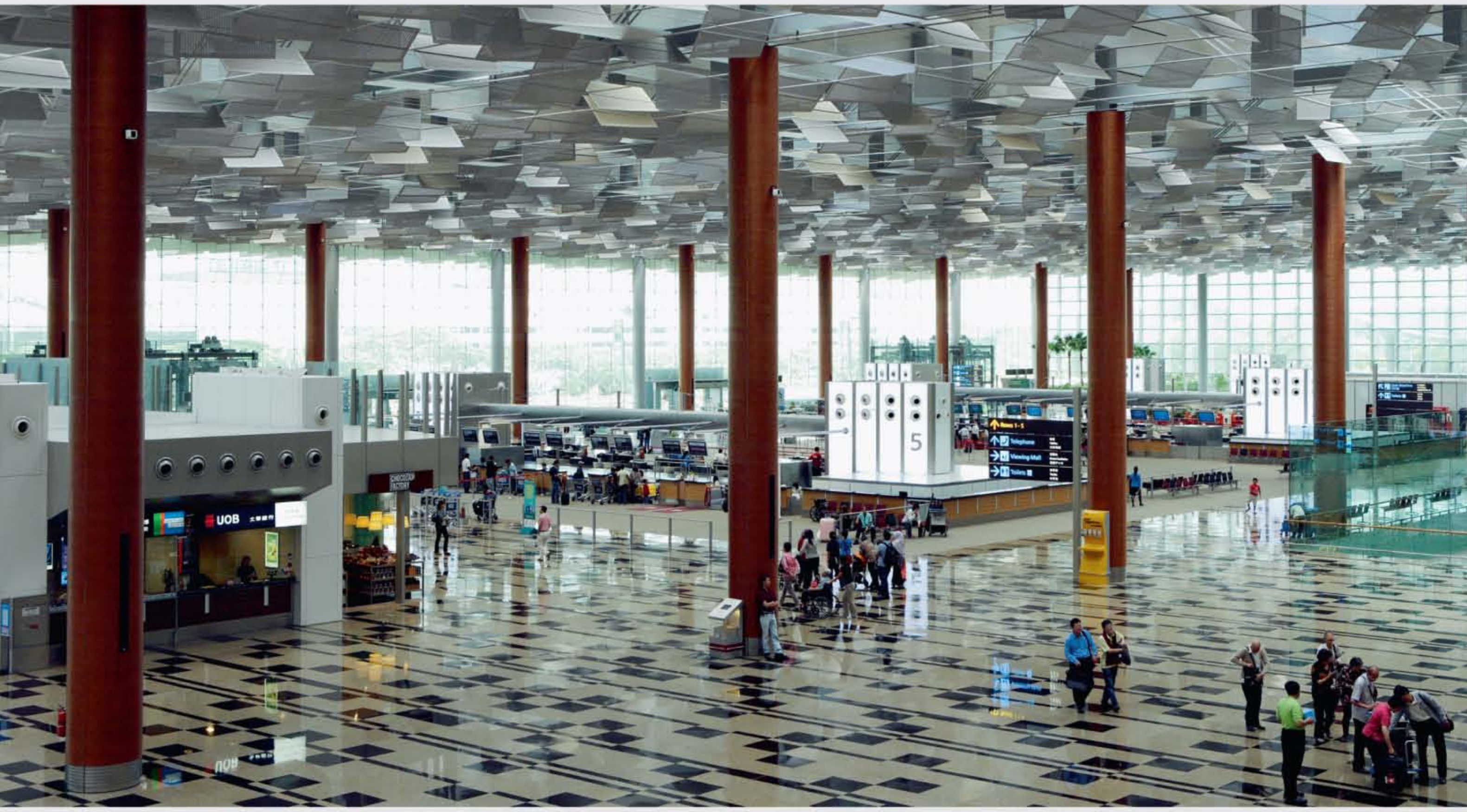

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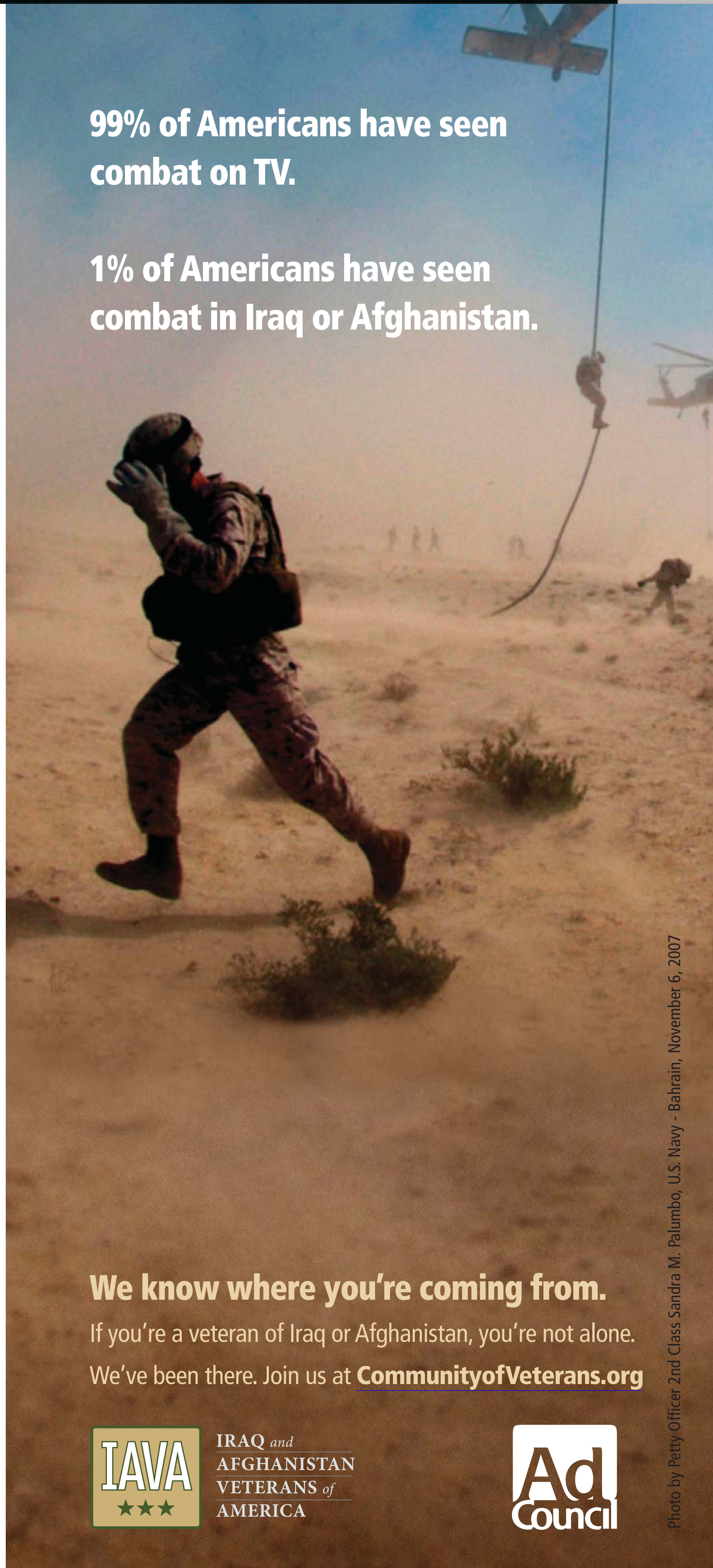

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Cover Design By Amy Price

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NOTEWORTHY

TECHNOLOGY

The latest from the small cell technology vault comes in the form of multi-standard cells. They are the next generation of Wi-Fi/cellular products. This means that the carrier is now developing and deploying small cells with integrated Wi-Fi. On that front:

Alcatel-Lucent has a lightRadio software platform that integrates Wi-Fi solutions from Qualcomm and Motorola into its metrocells. AT&T recently came out with a statement that the small cell component of its VelocityIP initiative will all be Wi-Fi enabled.

Freescale has a small cell solution called QorIQ Qonverge that supports Wi-Fi integration, but the position of the company is not to integrate a Wi-Fi radio, to give OEMs more flexibility in deployments.

And **Qualcomm** recently launched its FSM99xx small cell chipset, which can host Wi-Fi at Layer 3. The important thing about hosting at Layer 3 is that it offers traffic and connection management for technologies such as Wi-Fi.

WI-FI BEAT

The **Hotspot 2.0** standard is expected to become the authentication protocol for small cells. It is being promoted as the platform that will be implemented in carrier Wi-Fi. HotSpot 2.0 can make use of the EAP-SIM protocol making authentication possible without having the need to re-enter passwords as the user passes in and out of cells, enabling small cell roaming.

A working group has been created to promote a new breed of Wi-Fi. The charter of this new group is to define what a multimedia-grade Wi-Fi network is by providing some clarity and direction with specific metrics of the parameters that this platform will be designed around. **Verizon Wireless**, **SAP** and **Aruba** are the primary players partnering with a group of universities including Brandeis, Carnegie Mellon and Northwestern.

DEPLOYMENTS

Enterprise small cells are going to see massive deployments in the next two years. They provide coverage to a floor of an office building or other indoor (and, occasionally outdoor) enterprise and augment the macro network. The emerging model of these cells is a target of opportunity for carriers. Once the Wi-Fi, DAS and cellular platforms are integrated into HetNet, the implications for market share and revenue are staggering. With the bring-your-own-device/anything (BYOD/X) trend, not having cellular and Internet coverage throughout offices and other enterprises is no longer an option. What makes this attractive is that they are almost always connected via Ethernet, as opposed to wireless, offering a wide pipeline for backhaul interconnect to the infrastructure.

CALENDAR

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aglmediagroup.com/aglevents

Wi-Fi North America / Small Cells North America
April 2-3, The Convene Midtown West, New York
northamerica.smallcellsevent.com

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April 7-8, Singapore
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Small Cells World Summit / Small Cells Backhaul Summit / Carrier Wi-Fi World Summit
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COLUMNS

FROM THE EDITOR

Ernest Worthman,
Editor

This Month's Column Topic: ***The Internet of Things***

Welcome to the first issue of *AGL Small Cell Magazine*. I hope you like the look and feel of this second AGL Media Group publication. It has been a labor of love on the part of a great team, from marketing to graphic design to industry contributors. Please let me know your thoughts, and I welcome your feedback.

Now, on to small cell biz...I was waxing small cell philosophy with a business associate and he mentioned the term "the Internet of things." I'd heard that term a few years ago but his mention of it, and how it has progressed in the last five or so years, piqued my interest. As it turns out small cells will be one of the most influential factors in the "Internet of things."

It is common knowledge that the ultimate seamless, global wireless network will be comprised of HetNets — of which small cells will be the most ubiquitous of cells — that will be sewn together to form a global wireless umbrella. That wireless umbrella will enable every type of device to function seamlessly anytime and anywhere, and with anything.

The moniker "the Internet of things" has come about because the physical world is changing. And as it does, it is becoming its own information system. The Internet, as we know it today, is still mostly an information highway. But even as we speak, more and more once autonomous physical objects are becoming intelligent — from the obvious, such as smart communications devices to the not so obvious such as pacemakers and vehicles. And there is more. Microscopic cameras that are swallowed and send wireless data to nearby monitors and databases interconnected by small cells as they pass through the human body. As well, other types of physical equipment, in areas and places such as construction, retail, transportation, complexes and infrastructure, are now controlled by intelligent electronics and are connected, or soon will be, to the Internet's data pipeline — again, much of it though small cells.

Today, sensors are everywhere (remind me to send in that red light ticket I got from a wireless camera that caught my vehicle as I was speeding through). In billboards, entry ways, and credit cards — the list goes on and on. Sensors that interface to your life and exchange data with your own digital profile — what and where you like to eat, your clothes buying preferences, what perfumes and colognes you like, who you hang with, where you go for fun. And all of them rely on the Internet to exchange data — the Internet of things.

It is just beginning. As wireless technologies fall in line with standardized protocols, and ever shrinking, increasingly complex microchips enter the system, virtually every object becomes a candidate for an intelligent interface, no matter how small.

The implications are far reaching. Static business models will be all but gone. Real-time sensing will tailor information presented to you. Ad boards will be electronic and flash a message that addresses you by name and tells you that your refrigerator just reported that you are low on milk, and let you know it is on sale as well.

But without HetNets, this would be difficult if not impossible — the HetNets that are comprised largely of small cells... *—eworthman@aglmediagroup.com*

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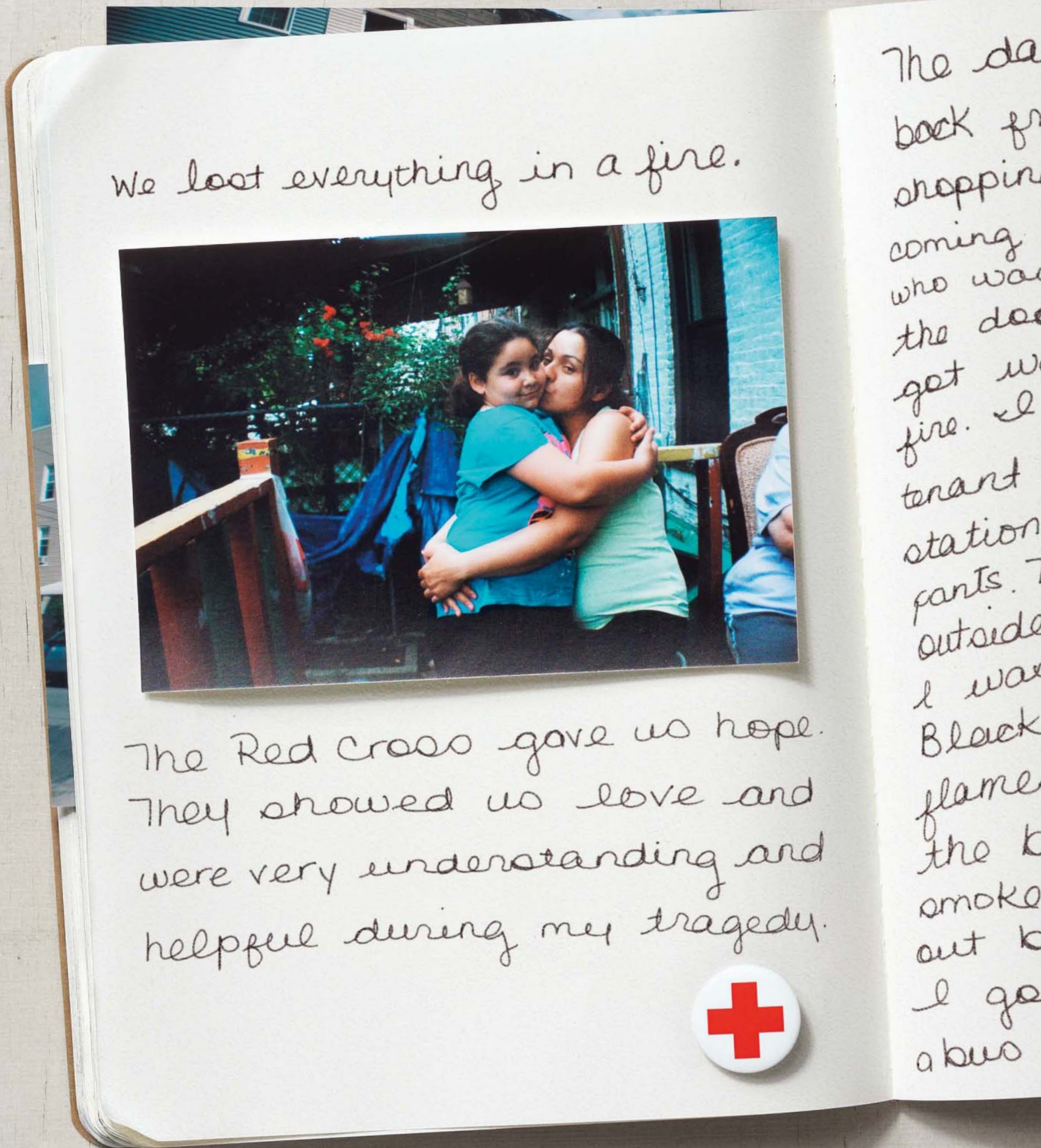

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Richard P. Biby, P.E.,
Publisher

PUBLISHER'S COMMENTARY

This Month's Column Topic: ***AGL Small Cell Magazine***

Welcome to the first issue of *AGL Small Cell Magazine*! DAS and small cells systems have taken over nearly every discussion I've been involved in over the last five years or more. We've covered the topic in *AGL Magazine* extensively over the last couple of years. But as the market continues to expand and mature, the AGL team decided the time was right to break out the small cells segment into a stand-alone publication. Thus, the birth of a new title. We're all very excited and proud of this new magazine. I hope you enjoy it and find it as educational and informative as *AGL Magazine* has been for nearly 10 years.

Technology is finally able to deliver radio frequency signals to virtually all of the nooks and crannies we inhabit. And going forward, upward of 70 percent of these RF signals are going to be data. With this predicted explosion of data consumption looming like a potential black hole gobbling up data, it is understandable why there is so much focus on small cells. They are seen as being the new RF platform that can off-load much of this data from the macro networks.

Small sites are less expensive and deliver capacity right to the customers, and each site operates independently. This leads some to suggest that macrosystems may be passé. However, DAS and small cell systems complement macrosystems, they don't replace them, at least not for the foreseeable future. If all things were equal, DAS and small cell systems would replace macrosystems, and we would take down all the towers. Sure, I see that happening. Not for 50 years or more? OK, seriously, never do I see that happening. It makes no RF engineering sense.

That being said, let's look at things from various perspectives: the macro network owner (tower owner), the small cell network provider, the carrier and the consumer.

From the macro networks owner's perspective, the small site complements the macro network. Small sites alleviate capacity problems, placing many high-capacity network nodes closer to the users. This reduces the immediate need for additional macrosites, which is both good and not so good. Investing in or owning a managed network with a recurring revenue stream is attractive to the typical macrosite owner; it looks a lot like real estate. Ultimately, the need for additional macrosites will continue to grow because new frequency bands will continue to be added, at least for the foreseeable future. Eventually, however, macrosites will load to capacity and the macro network owners will have to deal with that and, the proliferation of small cells.

For the small cell network provider, this looks like a land grab. There's lots of opportunity out there, with no present standardization of deal structure, installations, or designs yet — and, there is no "procedures manual." Yet, it's a great time to be creative and build an organization that can scale, and to turn over as many deals as possible.

To the carrier, this is a nightmare scenario. For years, carriers have been struggling to keep up; deployment schedules, budgets, contractors and sites continue to go only one way. But there was at least some kind of steady growth line. Small cells challenge that and, for the carrier, small site locations will proliferate by an order of magnitude and aggregate the management issues.

To the average customer things only look better and better. There are more ways to check Facebook, contact colleagues, kids and families, and goof around (I could never really watch video unless stationary, but I know plenty of people who do). I can't begin to think of how many kilobytes of data Siri takes every time I say, "call the office." But it works, and we just keep demanding more while wanting to pay less.

This is an exciting time to be in wireless, again.

—rbiby@aglmediagroup.com

COLUMNS

INDUSTRY INSIGHT:
TESTING CHALLENGES OF SMALL CELLS

By Joseph E. Kovacs

Need to expand? Why not get some COWs or COLTs. No, not the four-legged kind, but the kind that help augment the cellular network in times of high demand. I'm referring to the cell on wheels (COW) or the cell on light trucks (COLT) that are brought in for network-taxing events such as the NFL Super Bowl or emergency services during a disaster. While these are temporary solutions that introduce short-term network challenges, deploying multiple fixed small cells in a heterogeneous network (HetNet) subject the network to long-lasting challenges and require testing to ensure network compliance before deployment.

One of the main challenges in a HetNet is dealing with the interference caused by cells and nodes in the network. While small cells need to play well with the macrocell and minimize interference, the big challenge arises when small cells are densely packed. For example, in many areas, picocells are being deployed close to downtown areas where additional network capacity is needed. In addition, these small cells are not being deployed according to traditional methods used with homogeneous networks, but are being located according to traffic patterns where it is convenient to access power via street lamps or traffic lights. Then, add in femtocells, which can be deployed without any network planning and can be relocated at any point making them a wandering cell in the network, and you have the potential for interference issues! Therefore, small cells must be able to handle multiple sources of interference and function properly. To ensure this, sophisticated test equipment is required to ensure that the small cell can deal with this interference, reject out-of-band signals and transmit multiple technologies simultaneously in several bands with various frequency spacings.

CARRIER AGGREGATION AND SMALL CELLS

One of the benefits of carrier aggregation (introduced in Release 10 of the 3GPP spec.) is control channel interference mitigation through the use of cross-carrier scheduling of the component carriers. These carriers must be time aligned for proper operation. This creates new test challenges including the need to accurately measure the alignment of each component carrier and the eNB's ability to simultaneously receive and transmit multiple carriers. In addition, because small cells operate with multiple technologies, this also requires a signal analyzer that has the modulation bandwidth wide enough to analyze and demodulate various technologies. For example, a 1.8 GHz LTE signal and a 2.4 GHz WLAN signal require an analyzer with a modulation bandwidth in excess of 600 MHz. Although these are new challenges, test equipment with the software does exist to make these measurements.

VERIFYING AND TESTING DEPLOYMENTS

With any new design and deployment of wireless solutions, it is important to verify the design in software. Simulation tools can model multiple signals with different radio technologies, channel bandwidths, channel impairments and interference scenarios, which will result in a more robust design and reduce development time and costs associated with multiple board turns, which reduces testing in the end. Simulation software can generate test vectors to verify proper operation of baseband algorithms prior to implementation in hardware. For example, a variety of LTE signals can be generated to determine if the baseband algorithms can successfully demodulate a single carrier or multiple component carriers with cross-carrier scheduling. This is powerful insight — so you get it right the first time!

PHOTO COURTESY OF AT&T

Small cells in a HetNet pose testing challenges, but these can be solved with currently available test equipment and simulation software. And who doesn't want to solve these challenges before they arise?

Joseph E. Kovacs is the Global Business and Partner Manager in the Software and Modular Solutions Division of Agilent Technologies. Agilent.com

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FEATURES

SMALL CELLS:

RECOGNIZING THE OPPORTUNITIES AND MEETING THE CHALLENGES

By Ed Myers

The Wireless Data Revolution and its Impact—Boyle's Law states that a gas will expand to fill the available space. The same can be said for a data network. The more throughput available, the more uses people will find to fill up that pipe. Every month, more than 20,000 apps are released in the Apple iOS store, with the vast majority requiring some sort of broadband connection to run. To date, there have been over 50 billion downloads from the Apple iOS store, with over half of those being downloaded in the last 12 months. The proliferation of smartphones and tablets with even higher resolution cameras and two-way video capabilities has only exacerbated the consumption of data. As such, the wireless networks of today simply cannot handle the onslaught of traffic that is being pushed through the virtual pipes.

The demand for wireless data services, driven by smartphone and tablet use, is in an explosive state of growth — growth that will continue for years to come. A Cisco Systems Inc., study from early 2013 reported global mobile data traffic grew by 70 percent in 2012; wireless data use was almost 12 times greater in 2012 than all Internet traffic — wired and wireless together — in 2000. Cisco predicts worldwide mobile data traffic will continue to expand, increasing 13-fold by 2017, a compounded annual growth rate of 66 percent. Strategy Analytics also predicts a tremendous escalation in wireless data usage, estimating a total rise in data traffic of 300 percent between 2012 and 2017, with wireless video streaming, Internet browsing and apps consuming the terabytes. And UK-based Juniper Research forecasts that mobile data traffic will grow 10-fold by 2017, reaching an "equivalent to almost 42 quadrillion tweets or approximately 7 billion Blu-ray movies." While the predictions may vary slightly, all point to a data-heavy mobile future. Wireless traffic is now measured in zettabytes, or a billion terabytes.

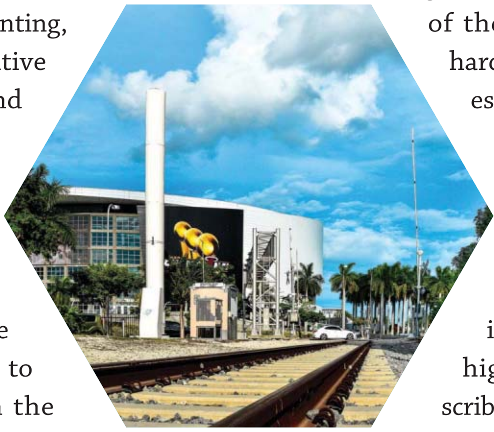
As mobile network operators (MNOs) migrate to 4G/LTE, they are achieving more efficient use of radio channels, while improving uplink and downlink speeds for users, but this is limited by the amount of available spectrum. MNOs are looking to make use of Wi-Fi where possible to help offload the radio network. However, Wi-Fi has inherent limitations with respect to spectrum interference mitigation and mobility. A "managed" Wi-Fi hotspot has the same issues with regard to deployment and backhaul as a licensed small cell.

The MNOs are looking for solutions to accommodate this rapid influx of data. Cell splitting, by adding new macro towers, is time intensive, and the addition of new RF channels is challenging because the MNOs are using their spectrum to full capacity. Small cells, inevitably, are part of the solution.

Small cells are just that — smaller versions of macro tower sites. The antennas are roughly two cubic feet, weigh less than 30 pounds, and are mounted 25 feet above ground level. These small cells are about 1/10 the overall size of a macrosite and are rapidly deployable, economical and provide targeted coverage for those high-density hotspots to offload the congestion from the macro network. In addition, where the investment for new macro infrastructure is cost prohibitive, small cells can be used in areas where coverage is thin or nonexistent today.

"While small cells are viable in a number of situations, they are not a cure-all."

While small cells are viable in a number of situations, they are not a cure-all. Challenges remain to small cell engineering and deployment. These small cells need to be implemented efficiently and in a manner that does not disrupt the existing live network. Small cells can be placed in a wide variety of outdoor and indoor locations, but placement is still subject to rigorous regulatory oversight from state and local authorities. Since every site is different in terms of mounting, loading, and coverage, it is imperative that a simple set of installation and commissioning instructions be replicable across an entire carrier implementation. Backhaul, the movement of traffic from the network edge to the core and back, continues to be the lynchpin in the small cell network. Without a way to efficiently move the traffic from the mobile device quickly, all of the benefits of the small cell are lost. As the MNOs seek to establish these heterogeneous mobile networks (HetNets), they must consider the entire network ecosystem. Meeting these challenges requires a deep understanding of site location planning, broad experience in delivering backhaul solutions and reliable access to capital.



THE CASE FOR SMALL CELLS

In the next 24 months, Tier 1 MNOs are expected to deploy in excess of 100,000 new small cells. Worldwide, nearly 11 million small cells have already been deployed by 47 operators. AT&T Mobility has announced their Project VIP, which alone will deploy more than 40,000 small cells by 2015 in the U.S. Other industry experts predict at least 5 million small cells will ship annually by 2017, translating to an annual growth rate of at least 125 percent beginning in 2014.

The reasons for this industry-wide embrace of small cell technology are many, and begin with the two key fundamental drivers in today's rapidly changing mobile network arena: time and cost. As MNOs race to meet customer demand and improve quality, small cells can provide that much needed relief. Roughly 10 small cells can be deployed in an area that would replace a macrocell in a fraction of the time that it would take to deploy a traditional macrocell. Additionally, the lack of viable real estate coupled with stringent local and state zoning regulations — not-in-my-backyard (NIMBY) — make the siting of a new macro cell challenging within customer demand-driven timeframes. Small cells are the logical option. The deployment cost is significantly reduced by the physical size of the small cell, both in terms of the hardware expense and the required real estate footprint. While small cells alter the scale of a network and add many new sites to monitor and manage, leading to increased operational costs, these expenditures are generally offset by the value inherent in a more efficient and higher capacity network, more subscriber traffic and an improved experience. Small cells can be deployed on the sides of buildings, on utility poles, street furniture, along right-of-way corridors, in airports, schools and indoors. The coverage can be targeted for parks, stadiums, hospitals, office buildings, residences, or anywhere traffic offload is required. Small cells operate on licensed frequencies, and improve an MNO's quality of service capabilities, while offering additional coverage flexibility. For example, a series of small cells can be deployed near stadiums to add additional capacity during big games or events. Those same cells can then be moved the following week to cover the championship parade route. Or, they may stay permanently fixed in those locations as a capacity "underlay" network complementary to the existing macro network.

The cost, deployment time and signal quality benefits that make small cells invaluable for increasing capacity in dense urban areas also make them vital in outlying rural regions. While the expense of constructing macro cell towers in unpopulated regions may not be justified, small cells are cost-effective, and are helping MNOs reach new subscribers and improve the data services across regions for existing users.

By offloading data from the macrocell, improving coverage at the cell edge and between cells, and by connecting difficult-to-reach rural areas, small cells are becoming an increasingly attractive solution for handling mobile network growth.

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MAKING SMALL CELLS WORK

While small cells bring great promise, their deployment presents certain challenges, particularly in the areas of infrastructure demand and regulatory requirements. There are high-profile instances where cities are attempting to regulate against the proliferation of small cells in an area by imposing regulatory hurdles. Small cells still require zoning approvals and a mountable, co-locatable structure (such as a utility pole or low rooftop) for the antennas, with access to utilities and backhaul services.

Although the small cells themselves weigh approximately 30 pounds, there is ancillary equipment that is required to support this mini base station. For example, there may be a need to house the backhaul equipment, a router to properly control and direct the information, or even a battery backup system with generator access in the event of loss of power. This entire package can weigh upward of 400 pounds and can put a tremendous strain on utility poles that were installed dozens of years ago, and which were initially designed to support only transmission lines. Additionally, rooftop and building owners will have to weigh the prospects of incremental revenue with the need for consistent third-party access, potential leakage or damage to their property.

In the U.S., the utility grid for the most part is clean and reliable but these small cell systems are designed for low power consumption (100 – 200 watts @ 110VAC), which may not be economical for the utility company to provide this type of service along high-tension lines.

Small cells use a mix of backhaul solutions to connect with the core network; these solutions are often guided by the constraints of a small cell location. Just as often, the location choice itself is influenced by existing infrastructure and real estate considerations.

Available backhaul options today range from fiber to high-capacity, fixed broadband wireless. While fiber is the preferred backhaul option, connecting fiber to multiple small cell sites in dense urban areas, for instance, may not be cost effective. The conundrum is that it may not be cost effective to dig up and repave the streets of a city center or a suburban shopping area to connect hundreds of small cells with fiber, but those areas are where the capacity is needed. So, MNOs may look to high-capacity microwave solutions to provide this vital connectivity. However, high-capacity microwave is traditionally limited to line-of-sight and licensed spectrum availability, which puts further limitations on the small cell placement.

CONCLUSION

MNOs today are pursuing a comprehensive strategy for small cell deployment that considers network capacity and coverage needs and backhaul requirements together, balancing issues of backhaul deployment costs, real estate opportunities, network capacity and coverage needs and service-level requirements.

These heterogeneous networks are a multi-layered series of interlocking high-capacity networks tied together with network intelligence. Together, they are driving transformation within the carriers at a rate never experienced. These next-generation small cells will likely evolve using the same platform that drove the traditional macrosite builds: co-locatable structures, available power and efficient backhaul. The nature of small cells and their varied and multiple site potential require the pursuit of a new approach. Speed to market is more critical than ever before to be able to enhance and shape the overall customer experience. Companies can deliver these key attributes in a single, comprehensive platform. Combining backhaul and construction capability with access to thousands of miles of rights of way through urban, suburban and rural population areas, offers attractive opportunities for small cell deployments throughout the U.S.

Small cell technology is no longer a hypothetical future for mobile network environments. Nor is it a distant solution to coverage and capacity concerns: it has already arrived. Deploying the technology in a way that is cost-effective and cognizant of future network evolution requires an understanding of multiple backhaul solutions and emerging technology, and a commitment to incorporating new real estate into the equation of site considerations.

Ed Myers is the vice president at Parallel Infrastructure. He's responsible for tower and fiber infrastructure sales, emerging technology ecosystems and new right of way development. Parallel Infrastructure is the first universal right of way (ROW) management and development company focused on monetizing and maximizing the value of underutilized land along railroad and highway corridors. For more info, visit parallelinfrastructure.com.

COVER STORY

THE WI-FI AND SMALL CELL UMBILICAL CORD

Integrating an unlicensed, de facto wireless data standard into a largely licensed spectrum is challenging. Yet it will happen, and all levels of small cells will integrate it as the principle data carrier of tomorrow's heterogeneous networks (HetNets).

BY ERNEST WORTHMAN, EDITOR

When Wi-Fi was in the visionary stages, few, if any, of those championing it could have seen that it would become the wireless platform for the data tsunami of the 21st century. And it would have seemed just as improbable that the licensed segment would have to integrate unlicensed technology into its systems.

But that was then, and this is now, and the integration of Wi-Fi into both licensed and unlicensed cellular spectrum is a reality. And it's not just a spur technology; it's the main integration platform. Carriers and other wireless network providers are faced with the fact that Wi-Fi is here to stay and so the issue becomes how to capitalize on the integration.

THE RECKONING

The vision that was Wi-Fi gained traction because it's a solution for interconnecting local area Ethernet networks, thus transforming the enterprise intranet into a highly capable local network.Wi-Fi uses the free-for-all industrial, scientific, medical (ISM) bands, with no reliance on expensive licensed spectrum and fewer

PHOTO COURTESY OF ALCATEL•LUCENT

concerns regarding quality of service (QoS). For that reason, it gradually took over first the consumer, and then the enterprise as the de facto data platform.

The cellular community didn't see Wi-Fi as a threat. And rather than seeing it as a complementary technology, the 3rd Generation Partnership Project (3GPP) decided to do a fundamental re-architecture of its system. That produced an all IP-based, packet-focused, evolved packet core (EPC) which, when integrated with orthogonal frequency-division multiplexing (OFDM)-based Long Term Evolution (LTE) access technology, was supposed to fire a shot across the bow of the Wi-Fi ship and disarm the Wi-Fi threat.

The rest is history. Wi-Fi didn't go away, carrier alternative technologies didn't happen on a large scale and small cells are about to make strange bedfellows out of licensed and unlicensed technologies.

THE REALITY

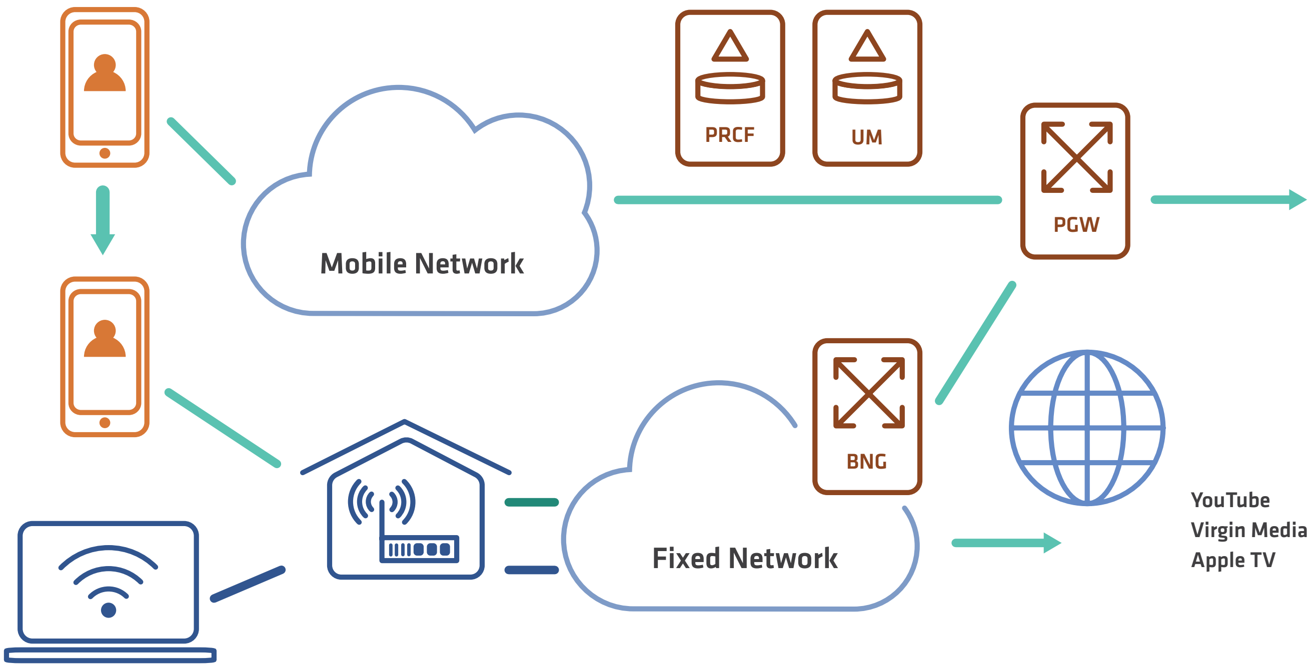
Over the past few years, carriers especially have made a 180-degree turn when it comes to Wi-Fi integration. After years of resistance and trying to deploy proprietary and profitable data subsystems, they are now in lockstep and ready to integrate.

For example, AT&T is committed to deploying 40,000 small cells, and Verizon intends to purchase hundreds of remote radio units (RRUs) and radio base stations (RBSs) from Ericsson. Although the actual deployment schedules are a moving target, these two, and other operators around the world are in the process of making decisions about how to set out this new order for network architecture and rollout. Most industry experts agree that 2014 will be seen as the year of small cells, with 2015 being the year when large-scale rollouts begin.

THE DRIVING FORCES

Over the past few years, large volumes of streaming content of various types started to clog the traditional wireless infrastructure. Multimedia applications on mobile devices (music and video, two-way video conferencing and social networking, for example) grew to become more than 70 percent of the traffic on wireless

WI-FI INTEGRATION IN 4G NETWORKS



networks by the end of 2013. Carriers and other network operators have implemented a variety of solutions, but they generally consist of better compression schemes, more efficient access scheme algorithms and better hardware. But these are patches, not real solutions. Current cellular bandwidth can't handle all the data coming its way.

Much of today's traffic consists of low-mobility, high-bit-rate applications such as video. Figure 1 (Page 22) graphically illustrates the many different possible applications vying for bandwidth. These applications consume significant air-interface resources in the process. It's become increasingly apparent that some sort of offload subsystem will be needed to handle these types of applications. Given the constraints on spectrum licensed for cellular use, Wi-Fi has emerged as an attractive option to offload this type of traffic and free up cellular resources as more high-mobility devices come on line (wearable devices, smart communications devices and connected cars are some examples). As these data-intensive applications become the norm, cellular spectrum will be gridlocked, regardless of what technology the carriers have devised to better utilize spectrum, and Wi-Fi has become the apparent solution.

There is also the business case for Wi-Fi. Other than charging cellular customers for bucket voice and data services, there has been little other revenue for carriers. Apps have opened up some opportunities, but also two issues. First, they use bandwidth. And second, users have gotten used to falling wireless service prices and are balking at paying for apps. So Wi-Fi is also seen as an opportunity to provide apps and services that can generate revenue. One problem is that users are accustomed to free Wi-Fi, so exactly what models will work, and how, is still unclear. Some schemes have been tried and there is a lot of experimentation, but no solutions are obvious yet.

Users have come to expect ubiquitous access to applications and content 24/7, whether they are at home, at work or mobile. Increasingly, they expect the experience to be unhindered by access network inter-working constraints or incompatible technologies.

THE STANDARDS DANCE

Eventually, all high technology leads to standards, and cellular/Wi-Fi integration is no exception. Recently, there have been significant developments with standards organizations paving the way for greater Wi-Fi use by service providers. The Institute of Electrical and Electronics Engineers (IEEE), the Wi-Fi Alliance (WFA) and the Wireless Broadband Alliance (WBA) have plans to standardize carrier-grade Wi-Fi features such as HotSpot 2.0 and Next Generation HotSpot (NGH). And the 3GPP is moving to further standardize Wi-Fi-to-3GPP internetworking capabilities.

Hotspot 2.0 is being defined by the WFA for an industrywide initiative, and NGH is being defined by the WBA. Both will provide a number of standardized features that will improve the user experience on Wi-Fi networks and further simplify integration with mobile networks. HotSpot 2.0 primary platform will offer a secure Wi-Fi connection with the ability to use a variety of user- or device-based credentials. It also promises to improve Wi-Fi network discovery and selection by providing new mechanisms for access points to broadcast information and for devices to query information from access points without the need to associate first.

> "Eventually, all high technology leads to standards, and cellular/ Wi-Fi integration is no exception."

For its part, the cellular industry is developing a single, mobile, broadband standard that will accelerate the integration of the Wi-Fi/cellular model. LTE has emerged as the 4G technology of choice for all major operators. The gravitation to 3GPP-based standards for 4G facilitates integration with Wi-Fi as there is a greater economy of scale for mobile devices supporting access, more roaming partner opportunities, and hence, increased incentives for operators to invest in Wi-Fi/3GPP interworking infrastructure. The result of this collaboration, both within and across the licensed and unlicensed platforms, is designed to improve Wi-Fi/cellular interworking by refining how cellular devices select Wi-Fi networks, and by developing options for integrating Wi-Fi networks into the cellular core.

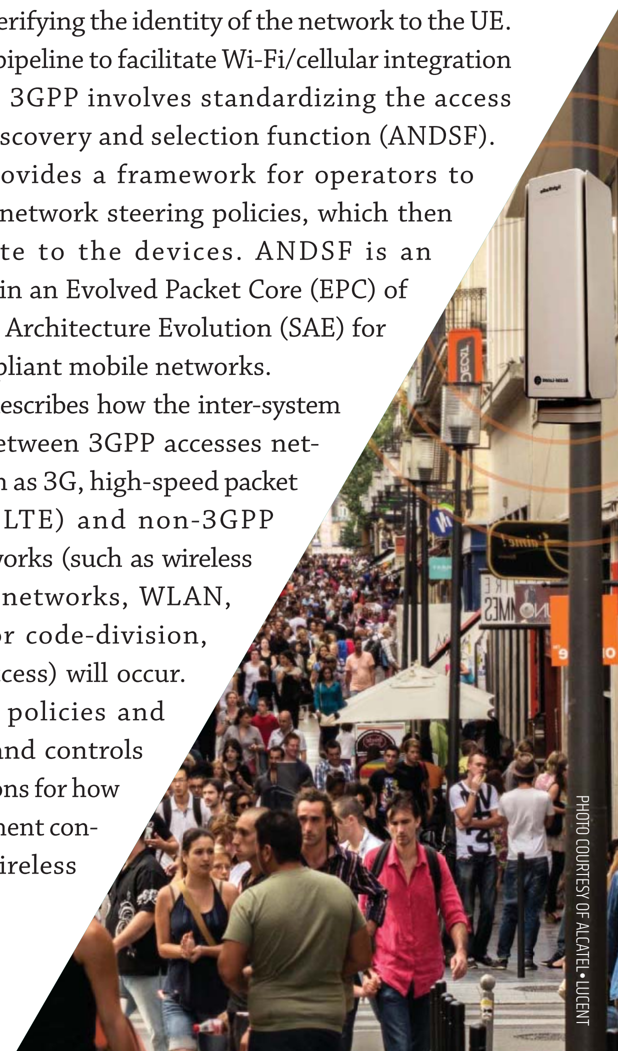
Most visible in the standards discussion is the extensible authentication protocol method for third-generation authentication and key agreement/subscriber identity module (EAP-AKA/SIM) based authentication. Within this are a number of protocols that essentially define configurations, handshake protocols, authentication protocols, and certificate and trust levels, among others. Wi-Fi interconnect is being combined with S2a-based mobility over GTP (SaMOG) trusted access to the 3GPP core. This integration will allow end users to seamlessly roam between cellular and Wi-Fi access networks.

EAP is a simple authentication protocol designed to provide a generic framework for user authentication in a network within IP-Networks. EAP itself does not define how authentication is done, rather it outlines a framework that can be used to define a specific authentication protocol. EAP methods generally are the interface that is used for authentication with a remote server.

EAP-SIM and EAP-AKA are subsets of EAP that are used for authenticating cellular subscribers over Wi-Fi networks using the SIM or USIM credentials of cellular subscribers as the authentication key. They also facilitate mutual authentication, authenticating the user equipment (UE) within the mobile network while verifying the identity of the network to the UE.

Another pipeline to facilitate Wi-Fi/cellular integration within the 3GPP involves standardizing the access network discovery and selection function (ANDSF). ANDSF provides a framework for operators to customize network steering policies, which then promulgate to the devices. ANDSF is an entity within an Evolved Packet Core (EPC) of the System Architecture Evolution (SAE) for 3GPP-compliant mobile networks.

ANDSF describes how the inter-system mobility between 3GPP accesses networks (such as 3G, high-speed packet access or LTE) and non-3GPP access networks (such as wireless local area networks, WLAN, WiMAX, or code-division, multiple access) will occur. It defines policies and priorities and controls the conditions for how user equipment connects to wireless



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networks. ANDSF is used to provide policy-driven intelligent network selection and traffic steering. This approach implements the ANDSF client in devices that communicate with ANDSF servers. By distributing tailored policies to the ANDSF client, operators are able to steer traffic between Wi-Fi and cellular for better user experience and to allow better usage of network and radio resources.

A final area of development is defining a solution to allow trusted WLAN to access the 3GPP core. In Release 11, 3GPP work involved creating protocols that allow non-3GPP devices to access the EPC directly. This assumes trusted WLAN access to the EPC and is based on SaMOG. This approach provides the ability to directly offload Internet traffic from the trusted WLAN gateway or access to operator packet data networks (PDN) via the packet core. In Release 12 enhancements are being made to the SaMOG protocols to provide mobility with IP address preservation and support for multiple-PDN connectivity over Wi-Fi. This will also offer tighter radio access network (RAN) integration, which enhances traffic steering and mobility between 3GPP and Wi-Fi. The outcome will be a better user quality of experience (QoE) and better utilization of network resources.

FIGURE 1 — APPLICATIONS VYING FOR BANDWIDTH

In the end, all of these solutions will enable roaming, seamless handovers and more intelligent network steering, with the end result that users will have uninterrupted, data services as they rotate in and out of the various cells —macro, small and Wi-Fi hotspots. Authentication will remain valid and follow the user with automatic transfer among networks. That is, these standards seek to provide a transparent and secure user experience regardless of the radio access technology used to serve a given subscriber.

THE HARDWARE

Virtually all wireless devices support Wi-Fi in many variants (IEEE 802.a/b/g/n/ac). Many of these devices support dual radio interfaces (licensed cellular and unlicensed Wi-Fi) and are capable of using both radios simultaneously. The pressure to make these devices mimic the untethered landscape of the cellular world is rapidly gaining traction.

Widespread proliferation of Wi-Fi-enabled devices has led to dramatic increases in data traffic across Wi-Fi hotspots. This has carriers and other network providers seeing opportunities across the globe, and there's a drive to make hardware that will support heterogeneous networks. As mobile devices have become more intelligent, they've become the intelligence that is the most aware of actual network connectivity conditions, and have also become the decision maker when it comes to network conditions in real time. This evolution in intelligence with both networks and devices represents a significant opportunity for carriers around the world. And, as more and more devices become frequency agile (capable of operating on multiple technology types), the push to have integrated and intelligent networks will become paramount.

With the combination of operator policy and network/device intelligence, it's now the device that is in a unique position to make the best determination of which traffic should be transported over what access type.

TOMORROW'S NETWORK MODEL

The single most significant challenge to overcome in integrating cellular and Wi-Fi is that Wi-Fi is unlicensed. This parameter challenges virtually every approach to the integration process and HetNet development. For example, most of the services that travel over Wi-Fi network infrastructures don't belong to licensed wireless

PHOTO COURTESY OF ALCATEL•LUCENT

operators. Therefore, the traditional metrics that carriers use to collect user usage habits, patterns and locations do not apply to Wi-Fi communications. This means that Wi-Fi users have an autonomous presence in stand-alone unlicensed networks. However, with evolving standards that support Wi-Fi and 3GPP interworking, the networks of tomorrow are starting to take shape.

There are two basic models of Wi-Fi/cellular interworking for 3/4G and Wi-Fi networks. Each has a variety of implementation methods within the global model, which allows for tweaking systems for specific and differing requirements.

Loosely coupled network models place the Wi-Fi performance outside licensed operator control and there is not a common converged wireless solution (no partnerships exist between the mobile operator and its partners, the wireless Internet service provider (WISP) or mobile system operator (MSO) and the entity that has deployed the Wi-Fi network. In a tightly coupled network model, the opposite is the case, and the Wi-Fi performance is within the 3GPP operator control.

With loosely coupled networks, the end user experience is more volatile. Issues that a user within this network may experience include IP session discontinuity, which results in interruption of data connectivity when reselection occurs between networks. Typically, this type of solution is used where either no workable network option exists between the multiple network operators (MNOs) and Wi-Fi deployment, or cost is a primary factor. It simply provides offload of best-effort traffic to Wi-Fi while freeing up resources on constrained cellular networks. To make this model more appealing and reliable, ANDSF technology can be implemented to guide traffic-steering decisions, which can minimize the disconnect and better optimize the user experience.

Tightly coupled networks are much more complex and are the model of choice for HetNets. Such networks implement integration between the 3GPP and Wi-Fi RANs, with common core infrastructure. This integration provides IP session continuity, resulting in a seamless end user experience.

> "The most significant challenge to overcome in integrating cellular and Wi-Fi is that Wi-Fi is unlicensed."

The benefits of these networks are attractive to carriers and MNOs. They can now make decisions based on which RAT will provide the greatest QoE for a given subscriber/service at a given time and location. In some cases, trusted carrier Wi-Fi may provide that best experience, at other times the cellular radio access technologies (RATs) might do so. This data can now be used to implement intelligent operator-controlled network selection. This ensures that the decisions to off-load Wi-Fi traffic are made in a way that optimizes QoE. Adding ANDSF gives operators an even tighter means of guiding Wi-Fi network selection within a tightly coupled network.

As well, ongoing discussions are being held within the 3GPP RAN standardization group on network centric solutions supporting Wi-Fi and 3GPP interoperability. This next step will optimize offloading and traffic

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steering decisions relative not only to the concerned user's experience but also the other active users in both the 3GPP network and Wi-Fi, optimizing system resources and QoE for all immediate users.

THE CHALLENGES

Although the appeal of Wi-Fi seems to have only an upside, the challenges faced by both Wi-Fi and MNOs are complex. There are many problems the industry needs to address before Wi-Fi/cellular integration can be fully realized.

Paramount to Wi-Fi/Cellular integration is the realization of a complete intelligent network selection solution that allows operators to steer traffic in a way that maximizes user experience and addresses some of the challenges at the boundaries between RATs (2G, 3G, LTE and Wi-Fi).

As Wi-Fi devices move in and out of Wi-Fi networks and cellular networks, the selection and reselection methodologies must be able to compare pattern usage and reliably predict the next connection based upon that usage. Intelligent prediction or preselection must be available and reliable because in some worst-case scenarios a user may be in a specific Wi-Fi cell for only a few seconds. Therefore, predictive behavior must have a high level of reliability and accuracy to keep the user experience intact and be able to have the next connection ready to go. Figure 2 shows the potential variation in data rates in relationship to the distance from the 3G cell and the Wi-Fi node. Note the sharp drop in data rates in the area where the device and network are trying to determine which network to use. This is the area of concern for accurate preselection.

A second area of concern is having the device and system make intelligent choices in a mixed wireless network of LTE, high-speed packet access (HSPA) and Wi-Fi. If a system selects or reselects the strongest Wi-Fi network, it has to ensure that the network isn't under a heavy load. If it is under a heavy load, it is a poor choice and results

FIGURE 2 — PREMATURE WI-FI SELECTION

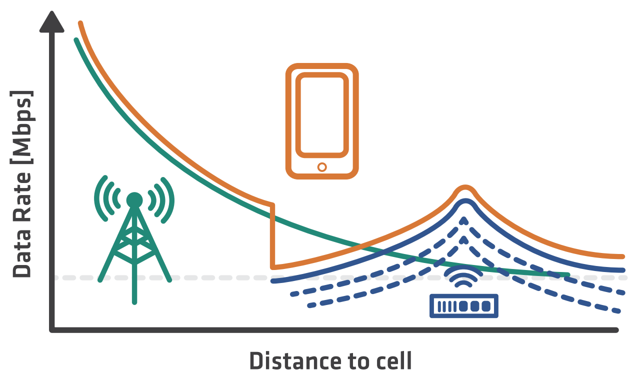


FIGURE 3 — UNHEALTHY CHOICES

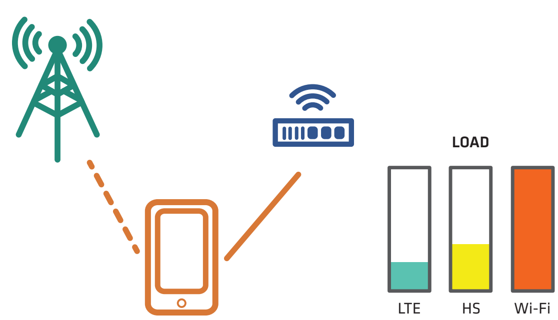


FIGURE 4 — LOWER CAPABILITES

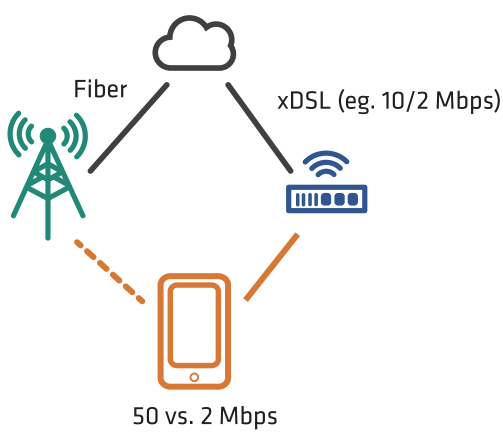
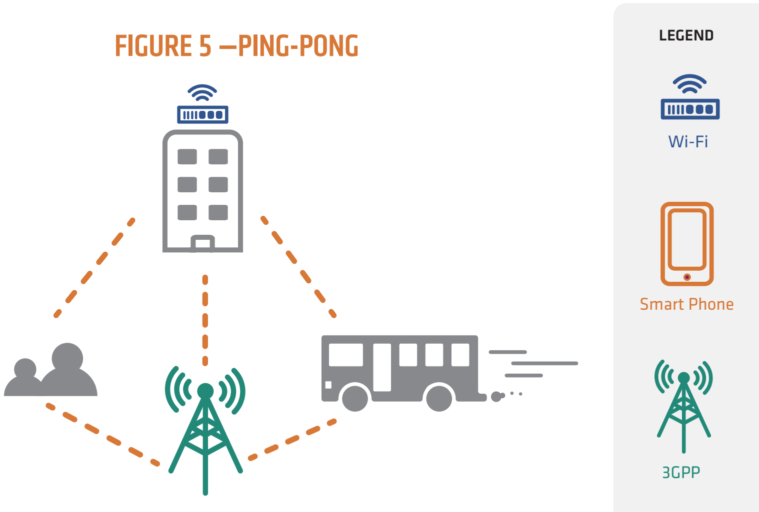


FIGURE 5 —PING-PONG



in degrading the end user experience. A lightly loaded cell on the edge with lower signal strength may be a much better choice than a heavily loaded cell with a stronger signal strength and slower throughput (see Figure 3).

A third challenge to integration is choosing a network with the best dynamics. For example, in some cases, reselecting a strong Wi-Fi access point may result in reduced performance — the Wi-Fi cell is served by lower bandwidth in the backhaul than the cellular base station currently serving the device (see Figure 4).

A final challenge is ping-pong. This occurs when the network has difficulty deciding which connection, Wi-Fi or cellular, should be locked onto. This can occur for a number of reasons, such as poor preselection algorithms, environment, weather and cell edge location, that cause changing signal strengths that confuse the device. It reduces the user experience by bouncing the user between the two systems, causing, at a minimum, reduced throughput and at a maximum inability to connect reliably or at all (see Figure 5).

CONCLUSION

Despite the challenges, technology will bring Wi-Fi and cellular together. The number of potential market opportunities in both the deployment and content of HetNets is staggering. Today's users expect to access anything, anywhere, anytime and to do so with any wireless device. That sets the baseline for the networks of the future.

The largest hurdle, bringing the players on both sides of the table together, has finally been cleared. In the last couple of years, both the licensed and unlicensed sides have come to the table with the realization that segregation is no longer an option. Carriers need the capacity and Wi-Fi needs the mobility.

The hardware, interconnect logic, software algorithms, and integration layers are well on the way to successful assimilation and to a global, ubiquitous, seamless, platform-independent network — one that will connect all things wireless to all other things wireless. The Internet of things has arrived.

The All-In-One High Density Solution

Finally an integrated option for wireless coverage and capacity, Wi-Fi and other IP applications

As data traffic continues to grow in urban environments, traditional macro base stations are not sufficient to meet the increasing demand of mobile data users and small cell base stations are not a sustainable solution due to their complex architecture and limited reach. Dali Wireless, a leader in Digital Distributed Antenna Systems, introduced the High Density Solution (HDS) to allow seamless coverage in highly populated areas. With its integrated Wi-Fi access point that supports IP-based sensors, this is your all-in-one solution for optimal coverage.

FEATURES

UNDERSTANDING SMALL CELL BACKHAUL:
CHALLENGES AND SOLUTIONS

By Asad Zoberi

Small cell backhaul has the potential to make or break the success of widespread small cell adoption. Effective and reliable backhaul technologies are necessary to ensure consistent, five nines small cell performance. However, because small cell is still evolving, some issues are not yet well understood, and it will be challenging to find the sweet spot, especially at an acceptable price point.

The momentum for deploying a small cell infrastructure is an unstoppable juggernaut, so solutions will be found. It's just a matter of how and when. Despite the challenges facing the small cell backhaul industry, antenna technologies are emerging as viable solutions to ensure a seamless experience for the mobile user.

SMALL CELL'S CRITICAL IMPORTANCE

Mobile data consumption has been increasing at an explosive rate and is likely to continue to do so for the foreseeable future. According to Cisco's 2013 Visual Networking Index Global Mobile Data Traffic Forecast, mobile data traffic is expected to grow 13-fold between 2012 and 2017, to a staggering 10+ exabytes per month.

With the rollout of LTE and other next-gen wireless services coupled with the growing number of wireless users, carriers are approaching the limits of available spectrum, particularly in urban areas where data traffic is often most concentrated. As a result, these carriers are increasingly moving toward small cells to increase network capacity, expand the edges of the network to include areas where service was previously unavailable or unreliable, provide superior indoor and outdoor wireless coverage, and make better use of the spectrum.

The Small Cell Forum considers small cells "an umbrella term for operator-controlled, low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi that typically have a range from 10 meters to several hundred meters."

By adding these small cells, which may be femtocells, picocells, microcells or metrocells, mobile operators are able to offload a significant amount of traffic from the macro network in order to increase network capacity without having to add new macrosites, which are much more cost-prohibitive and complex to install. This creates a heterogeneous network or HetNet, by creating a mix of a macro layer and a small cell layer. Vendors and mobile operators alike consider small cells increasingly essential to allowing additional capacity and improving spectrum utilization by providing a complement to the macro layer.

Because small cells are reasonably priced and make for easy installation almost anywhere (See Figure 2 on page 28 for a small cell disguised on a marquee), they are an ideal choice for providing coverage to small populations such as a single building, a city block or even a rural village. Most mobile network operators (MNOs) anticipate a ratio of three to six small cells per macro (even more for some).

> "The momentum for deploying a small cell infrastructure is an unstoppable juggernaut..."

UNDERSTANDING SMALL CELL BACKHAUL

The main purpose of small cells is to have cells in heavy traffic areas and isolate them from the mobile network operator's main network to allow offloading of traffic from the core network for greater spectral efficiency. However, the data from the small cells has to then be taken back to the mobile operator's core network. Small cell backhaul provides the necessary transmission link between the small cell and the core network.

Backhaul can take many forms. For example, backhaul for small cells used in residential and enterprise installations typically varies from that of metrocells

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commonly used for deployments in public, high-trafficked areas, which vary still from that of rural small cells. It has become undeniable to operators that small cell deployments will require greater investments of time, cost and effort than initially anticipated.

According to a report by Heavy Reading, "Leading backhaul equipment vendors are investing in new generations of products and features that are cost- and performance-optimized for the requirements of this new street-level edge of the mobile network." There are many factors to consider in order for operators to succeed in their target markets.

SMALL CELL BACKHAUL CHALLENGES

Naturally, when new small cell sites are added, seamless user experience and high performance are critical, and electrical radiation patterns must be closely analyzed. Cost-efficiency is also a natural concern. Small cell deployments present many unique challenges to make sure cells perform consistently as needed under dynamic, often unstable conditions and in crowded environments over which the operator has little control. Backhauling becomes a key consideration, particularly given the high range of wireless frequencies in the typical scenarios.

One of the primary backhaul challenges is that while integrating the antenna and electronics (see Figure 1) outdoor unit (ODU) is imperative, small cells have to maintain a low visual impact and integrate well into their surroundings (such as on a utility pole), as traditional large antennas with apparent parabolic shapes are not typically welcomed by the public in highly visible areas. Thus, it can be difficult to identify an ideal location for the backhaul provider to provide access, which often requires that the mobile operator and backhaul provider consolidate technology and work together to find a solution that remains aesthetically pleasing while ensuring that the small cell's reliability is on par with that of the macro network — and that the mobile user will have the same seamless experience whether on the macro network or the small cell.

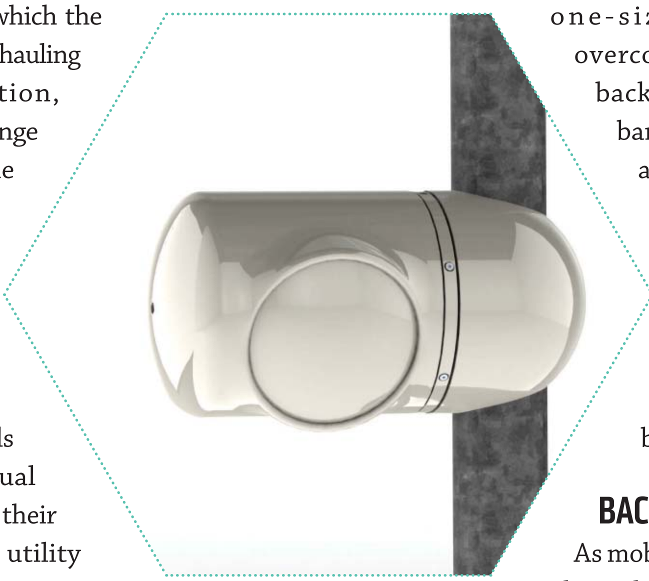

FIGURE 1. NEXT-GENERATION INTEGRATION OF THE ODU WITH THE ANTENNA.

This will give mobile operators the opportunity to get a better understanding of how they have to evolve the network architecture and traffic management to integrate small cells, and it will give vendors time to introduce the solutions that meet performance, functionality and cost requirements. Ultimately, many of the lessons will come only once small cells are commercially deployed in fully loaded networks. In the meantime, it has become clear that small cells are not going to be as cheap or easy to install as initially expected. To get good performance and reliability, to manage interference and to achieve the desired capacity density, operators have to invest in best-of-breed hardware, and plan their network and choose locations carefully. It is a process that can be complex and the addition of a sub-layer is bound to increase overall network complexity.

Although there is no universal, one-size-fits-all approach to overcoming backhaul challenges, backhaul does not have to be a barrier to widespread small cell adoption. The key to backhaul success lies in being cognizant of the environment and purpose for which the small cell is being deployed and understanding the range of backhaul solutions.

BACKHAUL OPTIONS

As mobile operators continue to learn through trials and first deployments what the primary backhaul challenges are, backhaul remains one of the most critical issues in the small cell community. Operators are looking for better ways to overcome these challenges in order to provide a better mobile experience, while vendors are devoting considerable effort to develop new solutions or add new functionality to existing solutions without driving equipment and operating costs up and pricing themselves out of a market that aims to be cost-effective.

There is a range of backhaul solutions that can address the variety of small cell uses. For high-performance microwave backhaul, traditional line of sight (LOS) and non-line of sight (NLOS) propagation offer two approaches that provide a viable alternative to fiber or copper backhaul, which can be costly and impractical given the location of small cells and the necessity of maintaining a low visual impact. However, a direct line of sight does not always exist between nodes, and LOS typically requires parabolic dishes, which could prove aesthetically unsuitable at many small cell locations. NLOS microwave point-to-point and point-to-multi-point wireless may be necessary in this respect — and require less-intrusive equipment — there has been some concern that it is prone to 5-10 ms latency, which is problematic for common real-time applications. However, findings by Ericsson reported in the February 2013 Ericsson Review support that NLOS can in fact be a viable solution for small cell backhaul. Because small cells are only intended as short-distance solutions, the high-system gain that supports targeted link distance and mitigates fading with traditional LOS backhaul can instead be used to compensate for NLOS propagation losses.

FIGURE 2: A SMALL CELL INSTALLATION FEATURING AN ULTRA-SMALL PARABOLIC SFA FOR MINIMAL VISUAL IMPACT IN THE ENVIRONMENT.

While NLOS may sometimes be suitable for the <6 GHz spectrum, this part of the spectrum is too limited and cost prohibitive for the needs of many operators. Thus, backhaul solutions also need to be considered for small cells operating on higher frequencies of the spectrum, which are less constraining to data usage. More and more operators are looking at these higher frequencies as part of their long-term strategy. This includes:

Traditional LOS 6-42 GHz bands: Generally, LOS links give predictable performance outcomes. This high-performance microwave spectrum is typically reliable and scalable. However, several issues may limit the use of these frequencies for small cell backhauling, including difficulty in reaching acceptable gain while reducing product size, complex licensing requirements, limited throughput and spectrum congestion.

60 GHz V-band: This high-frequency spectrum is particularly advantageous because it has low or no spectrum cost thanks to its license-exempt status, and there is a good amount of spectrum available in the 60 GHz range. Interference is limited and high-frequency reuse is possible in this portion of the spectrum because high signal loss in this frequency band attenuates interfering signals and the maximum range is constrained to around one mile or less, which is a sufficient distance for small cell backhaul links. Point-to-point links can achieve data throughput rates up to 1 Gb/s, which meet or exceed the needs of most multi-mode small cells.

70/90 GHz E-band: E-band backhaul equipment benefits from higher data capacities than 60 GHz but under the current FCC standards requires a larger dish (one-foot diameter) antenna. The European Telecommunications Standards Institute (ETSI) Class 3 standard is also compatible with E-Band for small cells. Several radio manufacturers are working on developing higher-capacity and more economical radio platforms that would most likely increase usage of this band for small cell applications.

A POTENTIAL SOLUTION: SMALL FORM ANTENNAS

Backhaul can seem like a daunting process that can potentially deter operators from deploying small cells, but this does not have to be the case. Small form antenna (SFA) technologies (see Figure 3) in the high-frequency bands can address the common challenges of small cell backhaul in order to successfully integrate antennas and electronics that have a low visual impact and enable small cell microwave radio components to look like a single part.

Viable backhaul technologies include:

Microstrip/PCB: These antennas can be flat — like a circuit board — and visually pleasing. However, performance issues have been reported with PCBs. In addition, these antennas can be cost prohibitive.

Horn array: These antennas, although not as flat as PCBs, are optimized for higher frequencies (60 and 80 GHz). One of the major disadvantages with these antennas is that a horn array for each frequency band has to be a separate design, making it likely not as cost competitive.

FIGURE 3. A SMALL FORM ANTENNA WITH A SHAPE CLOSE TO A PARABOLA (OPTIMIZED FOR PATTERNS AND EFFICIENCY).

Ultra-small parabolic: These antennas target a wide frequency range from 38 GHz to 80 GHz with one reflector for 60/80 GHz and one reflector for 23/42 GHz. In terms of performance, cost and appearance, ultra-small antennas are the superior option for small cell backhaul. Another consideration for small cell antennas is integration with the electronics, which can be easily achieved with ultra-small parabolic antennas.

Radio integration: There is further room for innovation in the area of the packaging structure for small cell backhaul with a focus on camouflaging the two components to look more natural in the landscape, including options such as different shapes, hidden mounting structures and different colors that help ensure as much transparency as possible.

CONCLUSION

As mobile operators continue deploying more small cells in a variety of environments over which they have little control, the complexities of backhaul are becoming increasingly apparent. Though small cell backhaul can seem like a challenge, especially while maintaining a site that is aesthetically pleasing without sacrificing performance or becoming cost-prohibitive, there are, in fact, viable options.

Companies are exploring and designing antenna technologies that enable backhaul for small cells operating in diverse ranges of the high-frequency spectrum. The ultimate result will be a seamless experience for mobile users as they are transitioned from the macro network to the small cell, while freeing up additional spectrum for the mobile operator to support increasing data traffic.

Asad Zoberi is key account manager at RFS. Zoberi is a member of IEEE and has over 20 years of experience in product management, sales and marketing and business development in microwave, in-building wireless and RF markets. For more info, visit rfsworld.com.

FEATURES

THE TECHNOLOGICAL FUTURE OF SMALL CELLS

By Vladan Jevremovic, PhD

Small cell technology has been a hot topic for the past few years. There is virtually unanimous agreement among industry experts that this is the wave of the future for the wireless industry. AT&T's forecast, for example, predicts that in 2014, small cell deployments will outnumber distributed antenna system (DAS) deployments by a 40-to-1 ratio. Figure 1 presents a relative comparison of small cell growth over other options for managing the predicted data onslaught.

All this points to a bright future for small cells, but there are technical challenges that must be faced in order to implement large-scale, small cell integration into 4G mobile networks. Fortunately, technological advancements, such as heterogeneous networks (HetNets) and self-organizing networks (SONs), will enable universal small cell deployments.

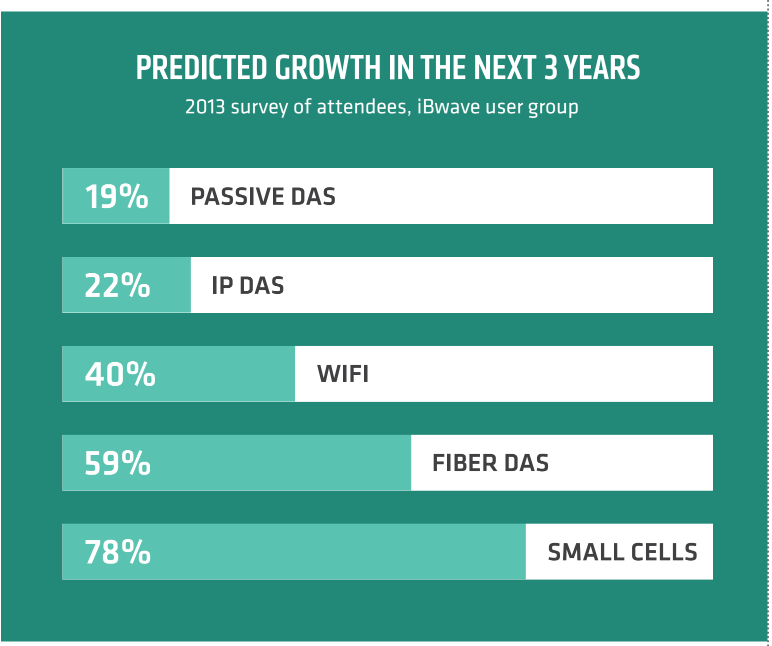

FIGURE 1. SMALL CELLS VS. OTHER COMMUNICATIONS TECHNOLOGY OPTIONS.

WHERE SMALL CELLS BEGAN: WIRELESS "GOLD RUSH"

It began with the FCC's personal communications system (PCS) spectrum band auction in 1995, which is generally considered the beginning of the digital mobile wireless era in the U.S. The auctioned spectrum was made available specifically for new digital wireless protocols, such as IS-95 code-division multiple access (CDMA), Groupe Speciale Mobile Assoc (GSMA) and IS-136. Because the new protocols were cheaper to deploy and had greater user capacity than the older analog protocol, the mobile wireless industry suddenly became more lucrative.

The next few years were "gold rush" years, with carriers competing to be the first to launch their own nationwide networks. At the time the primary network design goal was to provide ubiquitous signal coverage, namely, five bars all the time. This meant that a typical cell site had big directional antennas 150 to 200 feet above the ground, and had a range of up to a mile in urban areas and a few miles in suburban areas. These macrocells, which cover roads and outdoor public areas, are known as the macro network.

THE BIRTH OF SMALL CELLS

As the calling plans became cheaper, user penetration skyrocketed, and by the late '90s operators started to look for ways to increase the capacity of their networks. Increasing cell site sectorization (cell splitting) and reducing the height of cell sites were early solutions for capacity shortages. Next came picocells, which had significantly smaller output power, less capacity and a smaller form factor than macrocells, and were also less expensive.

As smartphones proliferated in the second half of the '00s, the subscriber usage pattern shifted from voice calls, made outdoors or in a vehicle, to data download/upload made indoors while being stationary or semi-stationary. Thus, a need for a third type of cell was born, a cell that would be capable of transmitting indoors at a power level comparable to that of a mobile device, and would have a form factor comparable to that of a Wi-Fi modem. Those were first known as femtocells, but have since been consolidated with picocells under the "small cells" moniker.

SMALL CELLS TODAY

Today's 4G mobile network macrocells are up to 100 feet high, and are typically located on rooftops, providing umbrella coverage to a large area. Conversely, outdoor small cells are typically found mounted on lampposts or

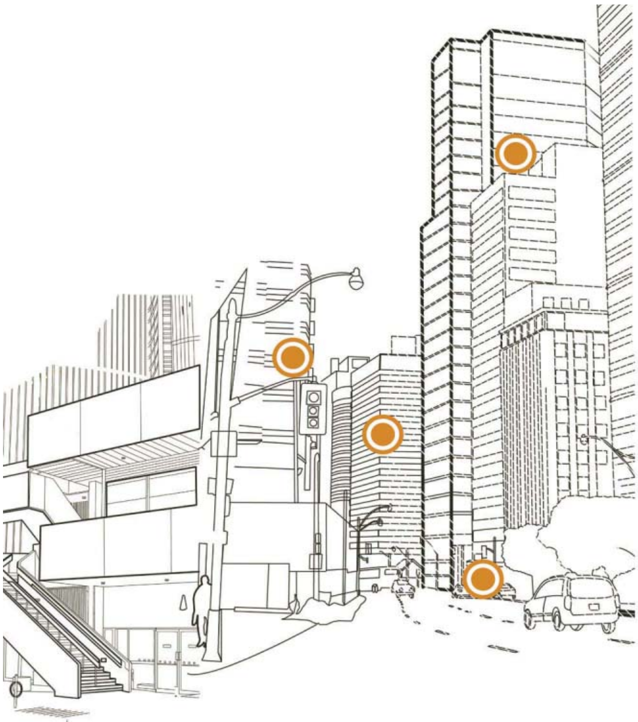

FIGURE 2. TYPICAL LOCATIONS FOR SMALL CELLS WITHIN THE HETNET.

sides of buildings, 10 to 15 feet above the ground and provide capacity to customers nearby using a much smaller footprint. Small cells are also found inside structures, providing coverage and capacity in reception areas, lobbies and store fronts, as well as in enterprise offices on higher floors (see Figure 2).

The integration of small cells and macrocells is generally defined as a HetNet. Thanks to the inclusion of small cells within HetNets, this new paradigm will offer an unprecedented set of challenges related to how they are planned, deployed, optimized and operated.

CHALLENGES OF HETEROGENEOUS NETWORKS

Deployment Dynamics

Macro networks are designed by engineers and optimized by RF technicians in a process that is predominantly manual and can take weeks. This is a costly process that requires skilled RF labor. The sheer number of small cells in a HetNet dictates a design and deployment process that is primarily field driven, where a cluster of small cells is designed and optimized by IT personnel in a matter of hours. This is an inherently low-cost process done by personnel not skilled in RF; because of that, the design and planning tool used for small cells has to be simple to use and inexpensive. It also has to be tablet friendly, because most small cell designs will be completed on the spot, during a site visit.

RF optimization tools have to be self-optimizing and have to have self-healing capabilities. That means having the ability to self-diagnose and fix most common network problems without human intervention. Because of the projected scale of small cell deployments, streamlining the approval process is going to be crucial in order to properly manage the deployments.

Real Estate

Space is at a premium on lampposts, traffic lights and other types of street furniture on which small cells may be mounted outdoors. While lampposts and traffic lights are typically owned by utility companies, it is the local government that sets the rules for their secondary use, such as cell site location. Generally, municipalities tend to be restrictive and rarely allow more than one set of antennas/transmitters on street furniture. Likewise, for aesthetic reasons, building managers are reluctant to allow each carrier to mount their own cluster of in-building small cells. This is a much different situation than what operators faced with macro networks, where there was always enough space to collocate antennas on a tower or on top of a multistory building. Operators now need to increasingly work together in order to deploy neutral host networks and maximize the limited amount of small cell real estate available to wireless network equipment.

Backhaul

With long term evolution (LTE) advanced data rates reaching 1 Gb/s, there is only one technology capable of providing backhaul for those data rates at 99.999% (the so called "five nines") reliability, and that is optical fiber. While macro cells may get fiber backhaul, the sheer number of small cells needed to get deployed is a near guarantee that only a fraction of them may be eligible for fiber. Extending fiber to all outdoor small cells is cost prohibitive, as it costs a few thousand dollars per meter in most metro areas.

An alternative solution at slower data rates is fixed wireless backhaul. Fixed wireless backhaul can be microwave backhaul, point-to-multipoint local multipoint distribution service (LMDS), wireless mesh or free space

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optics. Each has its own limitations: microwave backhaul and LMDS require line of sight; LMDS is sensitive to rain; wireless mesh data rates are comparatively much lower than the other two; and free space optics, while capable of delivering data rates comparable to fiber, is limited by line of sight requirements and is also sensitive to fog and snow. However, as pressure mounts to provide small cell networks, backhaul solutions will continue to evolve and there is little doubt that backhaul issues will be resolved. They have to be because without cost-effective, reliable and sufficient backhaul, nothing will work.

Truck Rollout

Mass deployment of small cells is only commercially viable if the installation and commissioning process is much simpler and faster than deploying macrocells. Most low-power in-building small cells need to have plug-and-play installation, so that IT managers or building managers can complete the process themselves. Rolling out a truck with technicians for installation and commissioning should be done only if outdoor small cells or a large cluster of indoor small cells are being deployed.

Interference

Interference is a challenge that has large-scale ramifications. While there are different types of interference issues within HetNets, most important is to maintain throughput and data rates. When there are a large number of small cells in a HetNet, it means that cell site density is a couple of orders of magnitude higher than in macro networks. High cell density means that many sites will have their signal above the threshold at a mobile's receiver. While being close to a cell site means that the serving signal is good (five bars), if a cell phone "hears" many non-serving cell sites, then it experiences a high level of interference. This is significant because signal to interference and noise ratio (SINR) determines data rates, and high interference implies low SINR and slow data rates. Thus, without some kind of intelligent interference control or cancellation, the benefit of being close to a cell site quickly disappears even at a short distance away. This may leave customers frustrated, because when they see five bars they automatically assume that their data connection should also be fast, when in reality it is not.

Handoff

Because of the significant increase in cell site density, the handoff between small cells occurs much more often than the handoff between macrocells, so handoff algorithm has to be tight, fast and accurate. More handoffs mean that handoff signaling traffic significantly increases as well. Signaling traffic is already much heavier in 4G networks than in any previous networks because smartphone applications need to periodically communicate with websites to provide application updates. Therefore, adding more traffic for handoff signaling makes the possibility of reaching a signaling capacity limit in a cell a challenging reality. Once that happens, the network refuses data connections even though there may not be very many users running active data sessions. This effectively reduces network capacity and slows the average data rate per cell.

CRITICAL FACTORS FOR SMALL CELL ADOPTION

These challenges are the consequence of economies of scale. For small cells to live up to their true potential, HetNets have to be designed, deployed and operated in a far more efficient manner than macrocell networks. It is the author's opinion that the efficiency in these networks can be achieved if the following methods are part of the network deployment:

Neutral Host Cell Sites/Neutral Host Network Operators

Because of the lack of real estate for outdoor small cells, collocating multiple small cells may not always be possible, and operators may be forced to house multiple wireless operators under one small cell enclosure. Such a cell site is called a neutral host cell site, and a strategy wherein wireless operators share a cell site is called a neutral host deployment. Large-scale neutral host deployment may give rise to a new class of wireless operators: neutral host network operators. They will be known as network operators despite the fact that they don't hold spectrum, because they will plan, design, deploy and operate a cluster (or even a small network) of neutral host cell sites, and charge wireless spectrum holders, namely, macro mobile network operators, an operational monthly fee. Having a third party install and operate a portion of the network for a fraction of the cost would help reduce capex for macro mobile network operators.

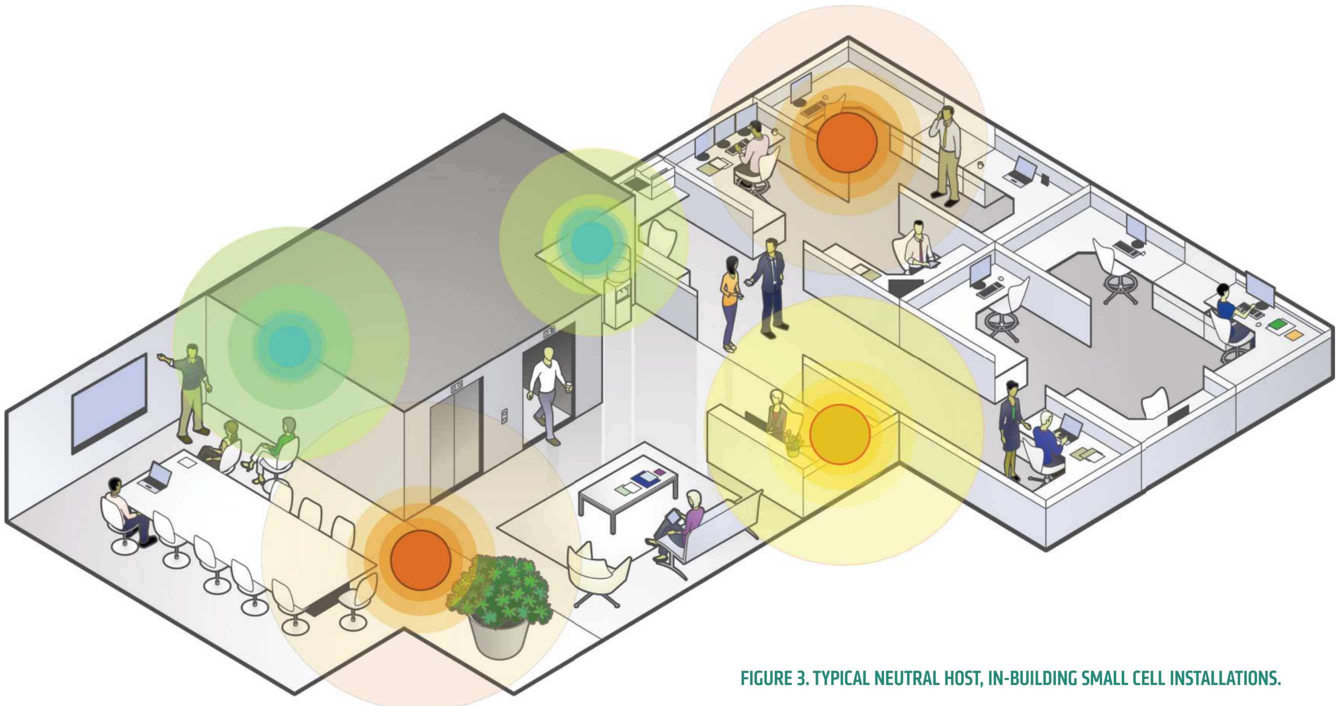

FIGURE 3. TYPICAL NEUTRAL HOST, IN-BUILDING SMALL CELL INSTALLATIONS.

Dedicated Spectrum Allocation for Small Cell Networks

To control and reduce handoff traffic to and from macrocells and to mitigate interference from macrocells, a separate spectrum band needs to be dedicated for small cell deployments. Having two separate spectrum bands would then separate a HetNet into two networks: a macro network and a small cell network. This would help control the traffic flow between the two, reduce overall interference in each network and also limit the handoff between the two. The FCC has recognized a need for a small cell spectrum band and has recently created an initiative to allow small cells to share 3.5 GHz spectrum band with satellite service, which may encourage carriers to adopt this strategy.

Self-optimizing Network Algorithms

Self-optimizing network (SON) algorithms are a diverse group of algorithms that help automate installation, self-configuration, diagnosis and optimization of HetNets. Here are some of the more important SON algorithms.

Network Planning and Deployment

These are self-configuring algorithms that enable plug-and-play self-installation with minimal network operations involvement. An example of these algorithms is automatic neighbor relations (ANR), which identifies surrounding sites and populates the neighbor list with them. Another example is PCI (cell ID) selection based on the pre-populated list and based on detected PCIs at surrounding cells. Yet another example is self-configuration of RF power and initial antenna downtilt, which reduces the amount of interference that a newly installed cell site brings into the network.

Network Optimization

These are algorithms that mitigate interference in real time. Examples of such algorithms include the antenna downtilt adjustment, which, along with the power transmission adjustment, is used to reduce the interference and/or limit the coverage of the cell. Both techniques are essential to balance traffic load between groups of neighboring cells, which helps to even out network performance. Another example is the enhanced inter cell interference cancellation (eICIC), which coordinates transmission between macro and small cells by blanking macrocell transmission over specific subframes in a frame. This technique reduces data through-put in a macro network but dramatically improves data rates of user equipment (UE) located near the cell edge of small cells within the macrocell's coverage. Another example is the coordinated multipoint transmission and reception (CoMP) algorithm, which allows neighboring small cells to coordinate scheduling and transmission of the signal to a UE that is near the boundary of the two cells.

Network Operations
These are algorithms that minimize monitoring and adjustment, providing analysis and recovery of faults, automated upgrades, reconfiguration of surrounding cells after a cell site has failed and auto inventory reporting of components from all network elements.

SON algorithms are critical for the success of complex networks such as HetNets. For SON to be widely adopted by network operators, its algorithms need to be standardized and interoperable. Another important standardization aspect is multivendor interoperability, which would guarantee seamless operation of network infrastructure equipment from different original equipment manufacturers (OEMs). Without standardization and interoperability, the economies of scale are not achievable and the full potential of HetNets may not be released.

SMALL CELLS — THE IN-BUILDING ANGLE

In-building coverage has long been the bane of macro networks. Who hasn't had to find a sweet spot in a building to use their smartphone or other wireless device? For that reason, small cells are the ideal solution to in- building coverage and Internet issues. Owing to their form factor and their transmit power level, small cells are a natural fit for in-building deployments. In the past, small (less than 10,000 square feet) and many medium-size (10,000 to 100,000 square feet) in-building venues would use RF repeaters to feed a passive distributed antenna system (DAS) that would extend signal coverage throughout the venue. The choice of RF repeaters as an RF source was done for cost saving because macrocells were too expensive, too big and had too high an output power for in-building networks. Passive DAS was routinely chosen over active DAS because it was less expensive, even though it provided unequal transmit power distribution on the downlink and low signal-to-noise ratio (SNR) on the uplink. The net result was that in-building traffic was supported by the macrocell (via a repeater). For a long time, this was the Achilles heel of in-building networks.

This is about to change as small cells are not only less expensive than DAS, but also provide dedicated in-building capacity, thus keeping in-building traffic off of the macro network. They also provide equal transmit power from each location, which makes planning in- building networks easier. Limited passive loss on the uplink guarantees higher uplink SNR, which is critical for achieving high uplink data rate. However, for some large venues (100,000+ square feet), such as stadiums, small cells may not be the ideal choice.

THE FUTURE

Small cells are the key components in network evolution from macro voice-centric networks to HetNet data-centric networks. Owing to their small form factor, low cost and low transmit power, small cells can be deployed directly at traffic hotspots, often within a customer's meter. Hotspot identification, real-time traffic management and interference mitigation are going to be largely automated via a set of network planning, optimization and operation algorithms called self-optimization network algorithms (SON). SON will eliminate most of the need for manual-labor-intensive engineering, which is a good thing because the number of cell sites in 4G HetNets will increase by a factor of 100 or more over the number of cell sites in 3G macro networks. As this occurs, challenges, considerations, best practices and potential roadblocks all need to be considered before the mass deployments begin.

Vladan Jevremovic is currently the Director of Engineering Solutions at iBwave and responsible for developing custom solutions as well as developing propagation algorithms within iBwave's research and development team. Mr. Jevremovic has been in the telecommunications industry for 20 years. For more info, visit ibwave.com

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BUSINESS AND FINANCE

By AGL Small Cell Magazine Staff

Small cells are big business and the financial and business markers and forecasts show that. One report from ReportsnReports, published in January of this year, indicates that LTE has gained considerable momentum in global deployments, and LTE Advanced (LTE-A), which offers carrier aggregation, is gaining traction as well.

The report estimates that the LTE infrastructure, which integrates macrocell base stations (eNBs), small cells and EPC/mobile core equipment, will be a $15 billion segment by the end of 2015.

5G is on the horizon and South Korea is first out of the gate. The service is 1,000 times faster than 4G services and comes with a 1.6 trillion (US $1.5 billion) implementation price. Insiders say the South Korean government believes there will be fierce competition in this market in a few years. A report from The Economic Times predicts that their 5G service will roll out in 2017 with commercial service available around 2020. The government hopes to implement the plan with investment and cooperation from operators such as **SK Telecom** and **Korea Telecom** as well as handset makers like **Samsung** and **LG**.

Samsung and **Apple** lead LTE-enabled smartphone shipments with a combined market share of 73%. This includes spending on LTE macrocells, small cells and EPC/mobile core equipment **Huawei** and **Ericsson** lead the LTE infrastructure market with a combined market share of 44%. Samsung is expected to significantly increase its stake in LTE infrastructure contracts, and eventually become a Tier-1 vendor by 2017. Wireless carriers and vendors will spend at least $1 billion per year in R&D to drive standardization and commercialization of 5G technology, according to RnR.

The outdoor small cell backhaul market has new financial data out from Infonetics. According to the report, deployments of outdoor small cells will be driven largely by mobile operators' need to enhance saturated macrocellular networks in urban, high-traffic areas and improve the mobile broadband. Of the wireless microwave technologies, licensed millimeter wave accounts for the largest portion of outdoor small cell backhaul revenue. Outdoor small cell backhaul connections are expected to reach 656,000 in 2017, with the revenue growth shifting from North America to Asia Pacific and EMEA by 2017. Infonetics expects $3.6 billion to be spent on outdoor small cell backhaul over the five years from 2013 to 2017, with the market kicking into high gear in 2015. This figure is in addition to the over $43 billion being spent on macrocell backhaul during the same five year period.

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COLUMNS

LEGAL NOTES: 3.5 GHZ SPECTRUM ACCESS SYSTEM

By J. Gregory Higgins

If you missed the FCC workshop January 14th and the discussion of 3.5 GHz, you missed the most crowded meeting I can recall in many years. Even Chairman Tom Wheeler — in his opening comments — made note of the unusual length of the security line entering the building. But when an opportunity arises to discuss spectrum and what the FCC might do with it, people from every area of the industry turn out to push their respective agendas. Spectrum is like real estate, they aren't making any more of it, yet everyone still wants to own more.

Chairman Wheeler pulled no punches as to the FCC's views for 3.5 GHz: "My message to you all today is really simple. Small cells and sharing spectrum are a priority for this Commission." Of course, how that sharing actually happens technologically and systemically and how the sharing percentage is devised are the big questions. Based on the level and degree of comments filed by the likes of Google, ALU, Qualcomm, Microsoft, WISPS, and other industry sector representatives affected by the advent of the Spectrum Access System (SAS), there will be some work to do over the next few months.

Central to the proper operation of the SAS in the 3.5-GHz band is the category into which a user is placed, and the resulting interference possibility that each category must accept. There are three categories: Incumbent Access, Priority Access and General Authorized Access. The Incumbent Access category is fairly straightforward encompassing mostly government uses of radar and fixed satellite positions. These users would have preeminent protection from harmful interference from all other SAS users. Priority Access (PA) would include users with critical quality-of-service requirements such as hospitals, utilities and public safety. These users would enjoy "some" interference protection at designated and specific geographic locations and times. General Authorized Access (GAA) users would be the least protected interference users, and would have "opportunistic" access to the SAS within "designated geographic areas." GAA users would be required to accept interference from Incumbent Access and Priority Access tier users. The lowest of the low GAA would be unlicensed frequency users taking part in the SAS.

You don't have to be a lawyer to see the gaps in some of that language. There are serious concerns about how conflicts between SAS category users will be resolved both technologically and operationally. This drives uncertainty, which doesn't fit well with network build planning nine months out or more and is not encouraging for carriers and businesses with goals for faster networks and customer network satisfaction, especially when the care centers will be the ones hearing the initial customer complaints, not the FCC.

Most of the OEM and tech-centric commentators portrayed a complex but ultimately solvable technological puzzle for SAS implementation, especially possible due to small cell applications. Although others did not dispute these positions substantially, the time it would take to devise the perfect system seemed incongruent with the desired network planning and product development of some depending on their respective products and place in the industry. A few common threads emerged as likely strategies for solving SAS/small cell implementation issues: require a geo- location database common to the TV White Space system, develop a method for marking a PA user device and use a listen-before-talk approach (allowing many users to use the same radio channel).

Key to the next stage of discussions is developing policy regarding where the control will be placed for power levels and other aspects to control access and interference, where the boundary between the SAS and operator networks will be placed, and how fraud and security concerns will be addressed. The panelists and commentators provided a vast amount of information, and this process has only just begun.

To view the FCC workshop presentations go to *fcc.gov/events/35-ghz-spectrum-access-system-workshop*.

J. Gregory Higgins is a respected telecom lawyer and a speaker at AGL conferences. He can be emailed at Greg.Higgins@TheWirelessLawyer.com. For more info visit TheWirelessLawyer.com.

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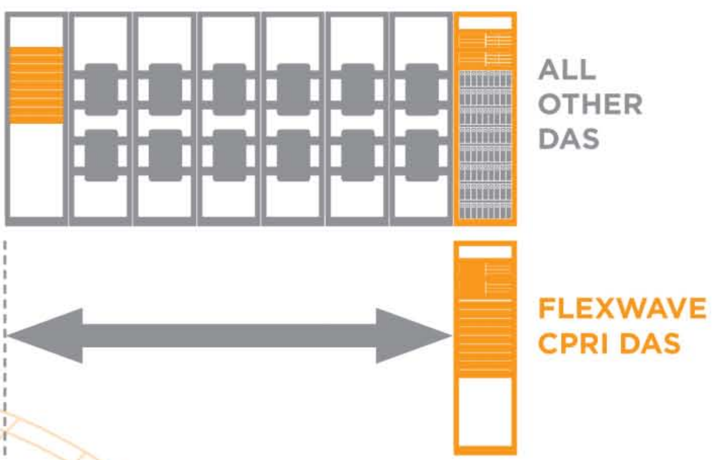
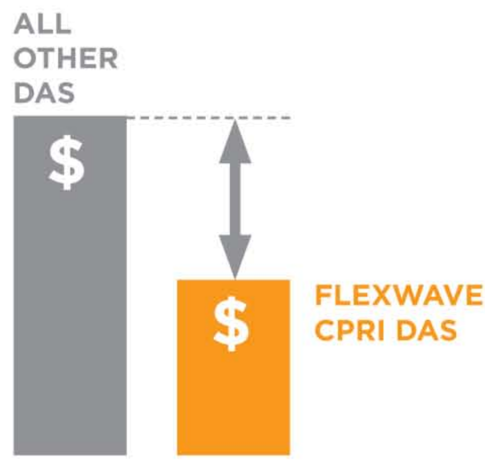


SAVE

Cost savings estimates from a Bell Labs use case of a high capacity, multi-operator venue



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