IN-BUILDING WIRELESS DEPLOYMENTS

EVALUATING INDUSTRY OPTIONS FOR COVERAGE AND CAPACITY IN THE SHIFT TO ULTRA-BROADBAND

STRATEGIC WHITE PAPER

Subscriber demand for uninterrupted, ubiquitous connections for bandwidth-hungry applications has created a need to extend the reach of cellular networks indoors. However, in-building environments are uniquely challenging due to "clutter" in the form of cement walls, elevator shafts, metal and, more recently, low-E glass, which negatively affect the propagation of a wireless signal. Clever architectural derivatives of the basic components of a cellular base station are available that, at first glance, appear to address the need to increase coverage and capacity. But, there is no one-size-fits-all solution to the indoor deployment challenge. The available Distributed Antenna System (DAS), Distributed Radio System (DRS) and small cell architectures each have strengths and weaknesses, which must be assessed and balanced against network objectives, the limitations of the indoor environment, future capacity requirements, and cost. This paper presents an analysis of the available options.

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1 EXECUTIVE SUMMARY

One of the most urgent and challenging questions facing the wireless industry today is how to provide acceptable cellular coverage indoors for subscribers while anticipating that today's deployments must scale to support the growing demand for data. Wireless operators must provide indoor coverage today and ultra-broadband networks for tomorrow. Providing the required coverage can be difficult. Indoor environments can be hard to reach with outdoor macro cells because of site availability, frequency, and building clutter. In addition, the actual deployments that operators must support are varied and complex, ranging from small to large enterprises, sporting venues, public service spaces, convention centers, casinos, and outdoor environments. Many proposals by macro vendors, enterprise vendors, small cell vendors, and Distributed Antenna System (DAS) vendors are being offered to wireless operators, neutral host providers, enterprises, and building owners. More than ever, the industry needs guidance on how to address this market, which was recently estimated to be worth $4.3 billion in 2014 growing to $8.5 billion by 2019.[1]

The objective of this paper is to provide an explanation of the basic in-building architectures that are available to wireless operators, and assess the strengths and weaknesses of each option.

2 IN-BUILDING WIRELESS ARCHITECTURES

Architectures that provide indoor wireless service are composed of three fundamental building blocks, which mimic the architecture used in outdoor base stations: a baseband unit, a radio, and an antenna. These building blocks can be centralized, distributed, or integrated together into modules, which are then distributed throughout a building and connected with cabling between each element and back to the operator core.

Table 1 describes three basic architectures that can be used indoors:

- Distributed Antenna Systems (DAS)
- Distributed Radio Systems (DRS), a name used by Alcatel-Lucent to describe an in-building architecture similar to a macro Cloud Radio Access Network (RAN), which consists of distributed, all-in-one radio head (RH) and antenna modules that communicate back to a centralized baseband unit
- Distributed Baseband Systems (small cells)

It also explains how the building blocks are centralized or distributed throughout a building.

Table 1. In-building cellular architectures

	BASEBAND UNIT	RADIO HEAD	ANTENNA	IN-BUILDING CABLING
DAS	Centralized	Centralized	Distributed	Analog or digital RF connecting radio head and antennas over dedicated cable
DRS	Centralized	Distributed as integrated modules		Common Public Radio Interface (CPRI) connecting the baseband and the radio head over dedicated cable
Small Cells	Distributed as integrated modules			Ethernet to the core using shared cable

1 "*In-building Wireless*", ABI Research, February 2014.

These architectures have fundamental strengths and weaknesses when deployed indoors, especially with respect to how cabling, or backhaul, inside the building are utilized. Table 2 compares the basic architectures as they would be applied by a wireless operator deploying a network to provide capacity for ultra-broadband experiences in indoor environments.

Table 2. In-building architecture comparison

	BENEFITS	KEY CHALLENGES
DAS	Coverage • Most mature and well known solution for deploying 2G, 3G, and LTE in-building coverage • Host neutral (one antenna system can support multiple wireless operators) • Radio Access Network (RAN) vendor agnostic • In-building KPIs are easy to manage because the distributed antennas are considered as one logical sector or cell (so no actual handoffs occur as a user moves through a building) • Multiple logical sectors can also be deployed and KPIs can be maintained by minimizing handoffs • When deployed as a mono-operator network (not neutral host) the baseband can be used for RF interference management and to simplify placement of antennas, or can be tied to a nearby macro baseband for improved DAS to macro mobility	Expensive • Dedicated cabling within the building or to the building for the DAS network is very expensive • Backhauls RF in the building, which is an inefficient use of backhaul and can limit the ability to add future capacity • Requires significant auxiliary equipment to amplify/process RF signals and to enable neutral host (DAS head end and RF repeaters) • The system's scalability can be limited by the fact that it must support many simultaneous resources (multiple operators, multiple standards, multiple bands) • Uses high-power (e.g., 40W) radio heads and attenuators to generate RF signals, which create high real estate, power and cooling costs for operators and building owners (high-power radio heads are appropriate for driving a passive antenna DAS system, but only ~10 mW is required to drive a digital DAS system (which transmits digitized RF over fiber) • RF design and optimization is expensive and challenging, especially in response to any changes from the outdoor macro penetrating indoors. Some vendors offer a 'mono-operator' DAS variant to help mitigate these issues, but must trade-off neutral host capability in the process.
DRS (new solution, for stadiums or as part of a future Centralized BBU/ Cloud RAN architecture)	High Capacity in dense venues • Centralized baseband can be used for RF interference management and to simplify placement of antennas • Transmitting CPRI is more efficient than transmitting RF	Not neutral host, expensive cabling • Dedicated cabling can be very expensive but is easier to install • CPRI requires more bandwidth from in-building cables than small cells (using Ethernet) and typically operates on "dedicated" fiber with an offered load of 2.4 Gb/s • Not neutral host today, but theoretically can be
Small Cells	High Capacity • Uses shared cabling in the building • Low CAPEX cost/capacity/sq. meter with reduced OPEX in the form of no lease or cooling costs for a cabinet in the building to host centralized equipment – relevant for a single operator deployment • Addresses hot spot requirements as end user demand grows • Can be deployed and optimized at a per-node/per-sector level	Not Neutral Host • Slightly more expensive than DAS (CAPEX) when providing equivalent coverage, but this is offset by the fact small cells will deliver more capacity • KPIs from access points are expected by operators to be similar to what has been achieved on macro nodes. To accomplish this, deployments must use high quality design guidelines combined with RF optimization or emerging Self-Organizing/Self-Optimizing Network (SON) algorithms. • Distributed baseband, unlike centralized baseband in DAS, requires the access points to interact with each other via X2 for LTE RF interference management and coordination. For certain advanced features, like CoMP, this is less efficient than managing in a centralized baseband.

In the past year, a number of innovations have been introduced to improve upon the basic in-building architectures described above. These variations are discussed in Table 3 (DAS), Table 4 (DRS), and Table 5 and 6 (3G, 4G small cells respectively).

Table 3. DAS innovations

DAS	BENEFITS	KEY CHALLENGES
Basic DAS	• Mature solution to deliver 2G, 3G, and 4G • Neutral host • Solutions offered with dynamic allocation of capacity, meaning that an operator can remotely shift capacity from one building (part) to another depending on demand	• Requires dedicated cabling in the building to transport RF (analog or digital) signal to distributed antennas (leveraging digital DAS over fiber partially relieves this constraint) • Dedicated backhaul likely supporting 2G, and 3G already from multiple operators, leaving little budget for adding LTE and Wi-Fi® • High CAPEX for equipment and fiber, and high OPEX for in-building real estate and cooling
Low Power RH – DAS: Use low power radio heads (for example, 1W small cells) instead of 40W radio heads and attenuators to drive a digital/active DAS	• Reduce footprint, power consumption, and cost for radio equipment feeding DAS networks in the basement of buildings • Improved RF performance	
Direct BBU - DAS: Eliminates the need for conventional radio heads; the digital I/Q samples from the BBU are directly injected into the DAS to eliminate the need for re-conversion	• Further reduce footprint, power consumption, and cost for equipment feeding DAS networks • >80 percent OPEX savings over five years for a large stadium • Improved RF performance	
Mono-operator DAS	Analog RF over Cable: • A mono-vendor deployment uses a single centralized baseband, which can be used to improve RF interference management between the distributed antennas and simplify design and deployment • Can use existing CAT 5/6/7 cables in the building, although they must be dedicated over to the network like any DAS (a challenge) Digital RF over cable: • Flexible deployment of distributed antennas due to improved RF interference management leverages vendor's baseband • Can use existing cables in the building, although they must be dedicated to the network like any DAS	• As per above • No longer neutral host and not upgradable to host neutrality • Not multi-vendor: must be same vendor throughout the building • Consumes more bandwidth from in-building cables than does a small cell solution • A 20 MHz LTE carrier is likely the most that can be transmitted over a CAT 5/6/7 point-to-point or multi-point dedicated cable (across 2G/3G/4G), and increasing capacity of the in-building network requires more dedicated point-to-point cables • Requires fiber between centralized radio units and a baseband cabinet at eNodeB sites, which limits the market application to fiber-rich countries • Proprietary technology, which can be difficult to use with other vendor's solutions, limiting it to footprints where the mono-operator DAS vendor is incumbent

Table 4. DRS innovations

DRS	BENEFITS	KEY CHALLENGES
Basic solution: Proposed as a solution for stadiums where fiber is available. This is a relatively new architecture and, as such, its basic solution is considered here as an innovation.	• Transports CPRI via fiber to a radio/ antenna module vs transporting RF (as with DAS), allowing for a more efficient use of backhaul than DAS • RF interference between antennas managed at a centralized baseband closet in a venue, as with a virtual RAN or Cloud RAN architecture • Architecture allows for the highest capacity/network in very dense applications and large venues (like stadiums) where the availability of fiber is unconstrained and readily accessible • Architecture can be used for coordinated transmission across multiple antennas with interference management handled by the centralized baseband	• Requires dedicated cabling in the building to transport CPRI • Assumes that backhaul is unlimited • Assumes that placement and number of antennas is unconstrained and unlimited • Not neutral host

Table 5. 3G small cell variations

DISTRIBUTED BASEBAND SYSTEMS (3GPP WCDMA/ IUH SMALL CELLS)	BENEFITS	KEY CHALLENGES
Single Vendor IuH: IuH access points deployed in-building with a small cell gateway deployed in the wireless operator's core. Alcatel-Lucent approach.	• Shared use of a building's cabling • Collapses an in-building many-node small cell network into the equivalent of one logical NodeB when connected back to the operator's core • Follows a femto-architecture with auto-provisioning and configuration for simplified integration into the wireless operator's network • Gateway enables capacity to scale by supporting an unlimited number of access points • Application Programming Interfaces (APIs) available to support local breakout and enterprise IT functions as a value add service for in-building tenants	• Scaling to very large campuses may be a challenge because the backhaul from the building to the operator's core may not sustain the signaling resulting from mobility between many access points • Achieving macro-like KPIs when handing traffic off between the small cell and macro network • Continuing to prove that KPIs between access points deployed in-building can reach macro levels allowing for tolerance for deployments which may stress or violate RF design guidelines • Not neutral host • Each unit typically only supports 16-32 users, limited by modem
Two Vendor IuH: IuH access points, requiring interoperability with a second vendor's small cell gateway	As per above	As per above, but also: • Must interoperate with a second vendor's gateway, but some vendors use a proprietary protocol, while some gateway providers also compete with their own access points and are, therefore, less motivated to interoperate in multi-vendor environments

DISTRIBUTED BASEBAND SYSTEMS (3GPP WCDMA/ IUH SMALL CELLS)	BENEFITS	KEY CHALLENGES
• **Two Gateway IuB**: IuB access point with local controller, connecting to a second vendor's IuH small cell gateway, which is deployed in the operator's core network	• Provides a local gateway at the building, which enables intelligent management and soft handoffs between access points for improved access point to access point call drop KPIs • Local gateway enables local breakout for integration with enterprise IT and for limiting signaling back into an operator's network • Shared cabling, assuming it can support IuB specs (e.g., delay tolerance)	As per above, but also: • Cost of additional gateway in an enterprise environment limits solution to large-node deployments so the gateway cost can be ammortized over many nodes (i.e., solution does not scale down) • Ensuring secure separation of IT functions from an operator's network functions in a common gateway • Requires connection to a second vendor's small cell gateway, meaning a two-gateway architecture • Handoff KPIs between the macro and the in-building network are not better than traditional IuH architecture with hard-handoffs between the small cell network and the macro
NodeB Architecture: Small cell access points connect directly to Radio Network Controler (RNC)	• Provides in-building versions of outdoor NodeB solution with software and features that are harmonized with the macro • Common controller for macro and indoor, but no small cell gateway • Possible to achieve excellent KPIs between access points, as with a macro, assuming an excellent RF design	• IuB specifications require tight timing synchronization and tight tolerances for delay, which likely requires dedicated cabling in-building • Not neutral host • Size of network (number of nodes) limited by availability of RNC resources (specifically the allowable nearest neighbors) as there is no gateway with which to "hide" the small cells as one logical NodeB • Access points and RNC must be provided by the same vendor.

Table 6. 4G small cell variations

DISTRIBUTED BASE-BANDSYSTEMS (4G AND MULTI-STAN-DARD SMALL CELLS)	BENEFITS	KEY CHALLENGES
eNodeB Emulation: Basic configuration with access point connecting directly to a high capacity Mobility Management Entity (MME) and Packet Core or through an optional small cell gateway.	• Shared use of a building's cabling • Capacity scales with the number of nodes deployed • Operator able to select best-in-class supplier independent of macro providers (multi-vendor enabled by standards) • Each unit will typically scale to 128 users or more depending on configurations • Able to support integration of Wi-Fi and 3G technologies • Designed using the same pricinples as a macro network, with node to node communications working in the same way as eNodeB to eNodeB communications.	• The RF from the macro can radiate indoors and interfere with the access points deployed in the building, leading to degraded KPIs. SON features are being studied to address this problem, but operator requirements for SON are still being defined. This inhibits operator acceptance for multi-vendor networks indoors. • KPIs are perceived to be degraded in multi-vendor macro and small cell network, although that hasn't proven to be empirically true. • No inherent simplification of RF design guidelines or deployment over what would be used to build a macro network.

DISTRIBUTED BASE-BANDSYSTEMS (4G AND MULTI-STANDARD SMALL CELLS)	BENEFITS	KEY CHALLENGES
eNodeB Local Gateway: Access point with local gateway	As per above • Local gateway enables intelligent traffic management (shaping user admission between small cells) and uses algorithms to improve handoffs between access points for improved access point to access point call drop KPIs. This functionality is gained through proprietary vendor implementations. • Local gateway provides interference coordination function for both the macro/metro interface for LTE, as well as the intra-venue interference management (much like the proposed benefits from centralized baseband) • Local gateway enables local breakout for integration with enterprise IT and for limiting signaling back into an operator's network	As per above, but also: • Cost of additional gateway in an enterprise environment limits solution to large deployments • Ensuring secure separation of IT functions from an operator's network functions in a common gateway

3 SELECTING THE RIGHT ARCHITECTURE

To optimize wireless networks for in-building coverage, operators must map the architectures listed above to a set of use cases. The actual deployments that operators design to are varied and complex, ranging from small to large enterprises, venues, public service spaces, convention centers, and outdoor environments. Below is a list of in-building use cases that are typically served by wireless operators, along with the options they might consider for deployment.

The choice of in-building architecture must account for the limitations of the in-building cabling, future capacity that the network must support over the next five years, and total cost. It is assumed that LTE will be the primary service for these deployments, while 3G may still remain important for voice coverage until voice over LTE (VoLTE) becomes ubiquitous. It is estimated that today's market penetration in indoor environments with basic coverage is less than 10 percent globally across all segments and operators will invest to grow that coverage. Additionally, operators will invest to provide networks with sufficient capacity to meet the growing consumer demand for wireless data indoors.

While the deployment scenarios can vary widely, they can be segmented into one of three categories:

- **Public venues**, which have strong neutral host requirements and do not allow for operator-specific systems to be deployed or for an operator to significantly differentiate in a market. Examples of such facilities include some stadiums or municipal-funded venues. Systems for these environments must often support all available standards — 2G, 3G, and 4G — so as to not discriminate service for consumers.

- **“Sponsored” public spaces**, which allow for operator differentiation or operator-unique systems to be deployed in parallel to a neutral host solution. Underlying requirements are still present for host neutrality, but operators can differentiate on coverage and capacity by deploying their unique hardware, rather than being limited by the functionality of a common and shared DAS. Examples include operator-sponsored stadiums, or enterprises with unique service contracts.
- **Private or enterprise spaces**, which allow for single-vendor or mono-vendor deployments.

Based on extensive Alcatel-Lucent experience with in-building installations and discussions with operators, these three categories can be further segmented by venue (Table 7).

Table 7. Segmentation of deployment category by venue

CATEGORY	VENUE
Public Spaces	• Some retail/shopping malls • Airports/train stations • Parking structures/underground tunnels • Most sports venues/stadiums
Sponsored Public Spaces	• Some sports venues/stadiums • Most retail/shopping malls
Private or Enterprise Spaces	• Offices/corporate campuses • Healthcare/hospitals • Manufacturing/industrial • Hotel/resorts • Universities/educational institutions • Government/municipal facilities

3.1 Expected deployments

Table 8 illustrates how Alcatel-Lucent believes the choice of in-building solutions to provide RF coverage and capacity will evolve over the next three to five years. Alcatel-Lucent believes that providing basic coverage dominates today’s decision criteria. In the next five years, as user demand for data grows, the decision criteria will shift towards providing capacity. This will create a demand for distributed radio and small cell technologies. The timing of this shift depends on the operator, the geography, and the venue. The table below is color coded to represent whether a venue can be appropriately addressed by a particular technology, assuming that in-building wireless capacity grows significantly over the next five years. Green indicates that a solution readily exists, yellow indicates that a solution may exist but with some technology constraints, and red indicates an unlikely fit for the solution. Note that cost effectiveness, market trends, and likelihood are not factored into this analysis.

Table 8. Typical in-building deployment categories (2014/2015), assuming small cells in technology/band exist

VENUE CATEGORY	SIZE	2014/2015 FOCUS: COVERAGE					2017/2018 FOCUS: CAPACITY				
		DAS	MONO-OPERATOR DAS	DRS	ALCATEL-LUCENT SMALL CELLS	TWO GATEWAY IUB	DAS	MONO-OPERATOR DAS	DRS	ALCATEL-LUCENT SMALL CELLS	TWO GATEWAY IUB
Public Space (Strong Neutral Host Requirement – No Vendor Differentiation)	Example: Stadium with a single DAS solution for all vendors										
	1,000,000 to 3,000,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
	500,000 to 1,000,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
	250,000 to 500,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
	100,000 to 250,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
	50,000 to 100,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution may exist but with some technical constraints	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
	10,000 to 50,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
	<10,000 square feet	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit
Sponsored Public Space (Vendor Differentiation Allowed)	Example: Stadiums/Public Venues where operator differentiation is allowed through sponsorship.										
	1,000,000 to 3,000,000 square feet	Solution readily exists	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints
	500,000 to 1,000,000 square feet	Solution readily exists	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists
	250,000 to 500,000 square feet	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists
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	<10,000 square feet	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit
Private Enterprise Space or Other Mono-Vendor Deployment Allowed	Examples: Enterprise campuses, large office complexes, operator controlled facilities, New York City Freedom tower is 2.6 million square feet, Google Complex [Googleplex] is 3.5 million square feet.										
	1,000,000 to 3,000,000 square feet	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists
	500,000 to 1,000,000 square feet	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists
	250,000 to 500,000 square feet	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists
	100,000 to 250,000 square feet	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution readily exists	Solution readily exists
	50,000 to 100,000 square feet	Solution may exist but with some technical constraints	Solution may exist but with some technical constraints	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution may exist but with some technical constraints
	10,000 to 50,000 square feet	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit
	<10,000 square feet	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution is an unlikely fit	Solution readily exists	Solution is an unlikely fit

Solution readily exists · Solution may exist but with some technical constraints · Solution is an unlikely fit

Today, the most common solution for providing in-building coverage is DAS because it supports all major cellular technologies and most bands. DAS is viewed as being expensive to deploy (dedicated carrier grade backhaul, dedicated cabling, large ancillary equipment needs) and operate (site rental and cooling), and accordingly, Alcatel-Lucent expects that there will be an opportunity for new entrants to begin addressing the in-building market for coverage. Because DAS supports multiple operators and technologies, its most critical asset (in-building backhaul, which is shared by the operators) becomes a limiting factor with respect to scaling to higher capacities in the future, requiring the investment for more backhaul. As in-building demand for wireless capacity grows, it will become increasingly more challenging for DAS systems to scale technically or economically to meet the demand.

DRS will mostly address large venues like stadiums when very high capacity is needed. The solution is not intrinsically neutral host. It will be limited to where operator differentiation is allowed or in environments where parallel operator systems can be deployed. Small cells will become important for environments where operators can deploy their own infrastructure without having to support other operators, and where capacity will become a significant need.

4 ALCATEL-LUCENT APPROACH TO IN-BUILDING WIRELESS DEPLOYMENTS

4.1 Innovators in DAS solutions

Alcatel-Lucent and its industry partners have collaborated to deliver more innovative DAS solutions.

Alcatel-Lucent and TE Connectivity have introduced a DAS solution that dramatically reduces the cost of delivering mobile, ultra-broadband access in large public venues. The Alcatel-Lucent and TE Connectivity solution removes the need for RF processing and attenuation panels on site by integrating the radio head into the DAS head end. This reduces physical equipment required by more than 50 percent, and the cost of materials by 40 percent. Additional cost savings are also achieved because the solution uses less power (equipment consumption and cooling), space and fiber. By deploying the new solution in large, high-traffic venues, service providers will be able to meet demand for coverage and capacity while lowering TCO by as much as 48 percent over five years (see Direct BBU - DAS innovation in Table 3).

4.2 Enablers of cost-effective DRS deployments

To enable cost-effective deployment of DRS solutions in large indoor environments, Alcatel-Lucent has developed an approach that leverages a Cloud RAN-based architecture on a smaller scale. Developed in association with a Tier 1 operator in the Asia Pacific region, this solution has been successfully deployed by Tier 1 operators in North America.

A large Tier 1 operator in North America deployed Alcatel-Lucent 9768 MRO small cells for additional LTE capacity at a stadium suite. The small cell network was able to support approximately 115,000 data calls during the day with an average throughput of 5 Mbps and a peak throughput of 25 Mbps.

This DRS solution was also deployed to provide dedicated capacity to 8,000 sports fans at the Rutgers University athletic center during major sporting events. For this venue, three 9768 MRO small cells were positioned in the stadium's roof. They were connected to a single BBU in a shared carrier deployment. Together, they have greatly improved the quality of experience fans have while using their mobile devices at Rutgers events. Download speeds have improved by 100 percent, and upload speeds have shown an improvement of up to 85 percent.

In 2013, this DRS solution received an award for innovation from the Global TD-LTE Initiative.

4.3 Market leaders in small cells for any requirement

Alcatel-Lucent also offers a complete portfolio of outdoor, in-building and residential small cell products, which address specific market requirements. These solutions cost-effectively extend wireless network coverage and capacity while simultaneously offloading voice and data traffic from a wireless operator's macro network. The complete Alcatel-Lucent small cell offering is presented in Table 9.

Table 9. Alcatel-Lucent small cell offerings by market segment

MARKET SEGMENT	PRODUCT	ACCESS	# USERS	OUTPUT POWER	CHANNEL	FACTORS	ALCATEL-LUCENT APPROACH TO THE MARKET
Outdoor	• Metro Cell Outdoor (MCO) • Metro Radio Outdoor (MCO)	Public, Host Specific	32-200	1W-5W	Telco	• Requires macro-like features and performance • Favors mono-vendor but open for disruption • Market share tied to incumbent macro vendor with lift based on success in multi-vendor	Beyond industry leading outdoor coverage and capacity access points, such as the 9764 Metro Cell Outdoor (MCO) family, Alcatel-Lucent has developed and continues to expand an entire partner ecosystem that addresses deployment challenges, such as site selection, site access, backhaul, installation, integration, and more.
In-building	Metro Cell Indoor (MCI)	Public, Host Specific	32-64	250mW - 1W	Telco		Alcatel-Lucent, together with certified partners, offers the industry's best in-building cellular solutions with the broadest and deepest portfolio options, which include Distributed Antenna Systems (DAS), Distributed Radio Systems (DRS), small cells, and deployment expertise.
	Distributed Antenna System	Public, Neutral Host	100+	Varied	Telco to Enterprise + Enterprise Direct (Emerging)	• Cellular equivalent of Wi-Fi for mobile data • Multi-vendor • Market share independent of existing macro vendor	
	Distributed Radio System	Public, Host Specific	100+	0.5W – 5W			
	Enterprise Small Cells	Private, Host Specific	8-32	100 - 250mW			
In-home	• Software-licensed Original Device Manufacturer products	Private, Host Specific	4-8	20 - 100mW	Telco to Consumer		Alcatel-Lucent believes in 3G and 4G software licensing to third parties so that operators can rapidly and cost-effectively create unique multi-technology offerings in their markets (i.e., combination of 3G, 4G, Wi-Fi, and DSL modem functionality). Alcatel-Lucent also believes that to simplify, scale, and speed deployment within the home, a single, multi-standard gateway is required.

5 CONCLUSION

The race is on for wireless operators to provide excellent in-building service to their customers, especially as the demand continues for ultra-broadband experiences. The challenges lie in technology as well as in deployment. Many new innovations are emerging from the industry, ranging from improvements or customizations of traditional DAS architectures, all the way to the introduction of small cell networks.

ABI Research skews in-building investment towards DAS in its forecasts through 2019 compared to small cells. It predicts a $3.9 billion spend in 2014 growing to a $5.4 billion spend on in-building DAS and repeater solutions in 2019. In comparison, the enterprise small cell category grows from $433 million in 2014 to almost $3 billion in 2019. While the rate of growth is considerable on enterprise small cells, the spend on DAS continues through 2019 and is expected to exceed the amount spent on small cell deployments indoors. The logic behind this is simple: in-building coverage is very limited today. The DAS market is expected to grow over time to provide basic coverage, while the small cell market is anticipated to grow owing to the need to provide additional capacity in those same buildings.

ABI Research also predicts that roughly 40 percent of the total spend will be in the areas defined by private and enterprise spaces from 2014 to 2019. This area has the strongest opportunity for impact from solutions like small cells, which can be supported with non-neutral host solutions, and which will have strong demands for high capacity networks. The exact split of venues where host neutrality is required but small cells may be deployed is difficult to determine, but some portion of the projected 27 percent spend associated with sports venues and retail/shopping malls represents additional opportunities for coexistence between small cells and DAS deployments.

Obviously, the in-building market will grow significantly over the next five years, and the small cell share of that market will increase as a function of time as wireless capacity becomes a key purchasing decision criteria in addition to providing basic coverage. What's clear is that DAS, DRS, and small cell architectures will coexist and be combined with today's macro to create heterogeneous networks (HetNet) delivering ultra-broadband experiences.

6 RESOURCES

Alcatel-Lucent small cells solutions:
http://www.alcatel-lucent.com/solutions/small-cells
http://www.alcatel-lucent.com/solutions/in-building

7 ABBREVIATIONS

API	Application Programming Interface
BBU	baseband unit
CAPEX	capital expenditures
CPRI	Common Public Radio Interface
DAS	Distributed Antenna System
DBS	Distributed Baseband System
DRS	Distributed Radio System
HetNet	heterogeneous networks
HVAC	heating, ventilation, and air conditioning
IPsec	Internet Protocol Security
KPI	Key Performance Indicator
LAN	Local Area Network
MME	Mobility Management Entity
OPEX	operating expenditures
RH	Radio Head
TCO	Total Cost of Ownership
vLAN	virtual Local Area Network
VoLTE	voice over LTE
vRAN	virtual Radio Access Network
QoE	quality of experience
QoS	quality of service
RAN	Radio Access Network
RNC	Radio Network Controller
SON	Self-Organizing/Self-Optimizing Network