XONA PARTNERS

Innovations in RF Distribution Networks:

Evolution of Distributed Antenna Systems

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Overview

The market for in-venue communication systems continues to expand steadily with the promise of accelerating growth in the future. Distributed antenna systems (DAS) have been the primary type of system deployed in venues, but alternatives are available on the market. While this growth is a direct response to ever increasing demand for mobile data services, there are a number of trends that combine to shape and influence the development of this market in the short and medium term. In this report, we seek to identify the trends that shape the market for in-venue communications with particular focus on the evolution of DAS and its outlook over the next 2-5 years. We also argue that it is the business model and applications enabled by DAS and competing technologies, as well as operators' attitude towards such business model that would shape the outcome of the competitive landscape. Seen from this perspective, DAS has had the advantage of allowing operators to share a common infrastructure. The evolution of DAS provides for new applications and opportunities that are outlined below.

Market & Technology Drivers

Demand for mobile data service concentrates indoors and in venues[1] where as much as 85% mobile traffic is generated. Subscriber behavior enabled by the proliferation of smartphones and other types of mobile computing devices ,such as tablets, coupled with social networking applications are especially bandwidth consuming. For perspective, data traffic first exceeded voice traffic on mobile networks at the end of 2009 when traffic was 100 petabytes per month. At the end of 2013, traffic ran at 2,000 petabytes per month and is expected to surpass 15,000 petabytes per month in 2018. Wireless network performance cannot help but be adversely impacted by such high localization of indoor traffic because of factors such as propagation losses into structures as well as high oversubscription to limited capacity resources. Placing wireless transceivers at the venue becomes mandatory as mobile network operators (MNOs) look to improve service performance in the venue as well as to free adjacent cell sites covering the venue from a singularly demanding traffic hotspot. This has been, and continues to be, the primary motivator for in-venue solutions – a market valued at $10 billion in 2018[2] . However, trends in mobile communications targeted to improve broadband data services as well as divert traffic away from loaded macro cell would increase the demand for in-venue solutions.

To validate our position, consider the following:

1. It is more difficult to penetrate buildings with broadband wireless coverage than narrowband coverage. Wide channels have reduced coverage footprints and lead to a shorter range of service in comparison with narrow channels (Figure 1). This becomes more acute in technology like LTE where the channel bandwidth reaches 20 MHz, or 4 times that of 3G and 100 times that of GSM. While LTE does include other techniques that reduce some of the lost system gain due to channel bandwidth such as convolutional turbo codes, multiple antennas, and hybrid ARQ, these techniques do not combine to improve capacity where the communication link is weak.

[1] In this paper, the term venue refers to a high concentration of subscribers indoors or outdoors in facilities such as stadiums, airports, train stations, campuses, large commercial buildings, hospitals, etc.

[2] Mobile Experts, "Mobile Experts Identifies $100B In-Building Wireless Infrastructure Opportunity," April, 2014.

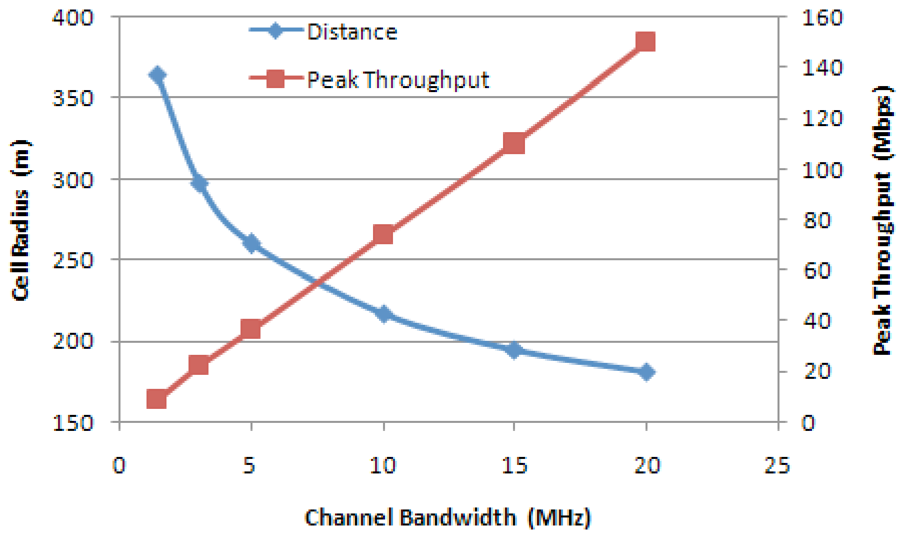

Figure 1 Distance and peak throughput performance for 2x2 MIMO LTE micro cell in urban clutter.

2. The challenge of serving venues is increasing in magnitude as regulators release spectrum in higher frequency bands for mobile service such as 2300, 2600 MHz, and soon 3500 MHz as in Japan by the end of this year. Propagation and wall penetration losses increase with frequency, resulting in consecutively smaller coverage footprint for higher frequency bands.

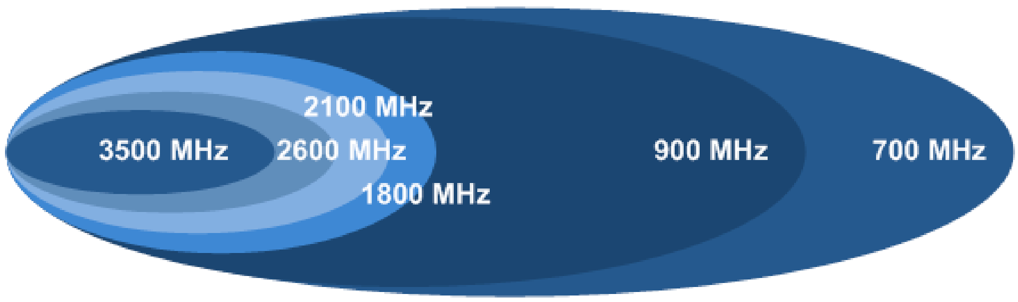

Figure 2 Coverage distance for different spectrum bands.

3. High throughput requires high signal quality. Efficient modulation such as 64QAM (6 b/s/Hz) and MIMO spatial multiplexing necessitate high signal to noise and interference ratio, for example, exceeding 18 dB. The ability to achieve the high signal quality and level required to engage these features degrades as the signal attenuates upon entering the venue.

In summary, the emergence of LTE coupled with the drive to supply ever higher capacity to concentrations of subscribers in venues is set to accelerate the in-venue communication market. Operators view such venues as strategic service locations which they cannot easily surrender service within to a competitor. Complementary to this, serving a traffic hotspot venue is a means to offload key cell sites of traffic and allow them to operate for their intended service target.

There are several options for mobile network operators to provide service in venues which we review next. The critical aspect is that operators have been covering large venues for almost as long as the mobile industry existed, but the trend is clearly aimed to deliver service to smaller venues. Today, dedicated in-venue service is available in many large venues such as stadiums, convention centers, airports, train and subway stations, and other large facilities that have high subscriber concentration. The challenge is to scale the service to cover smaller venues that include hotels, hospitals, and medium sized-industrial complexes. The proliferation of in-venue options is a response, or perhaps more accurately an anticipation, of the migration to provide service in smaller venues.

The Options

The options to provide wireless services to venues and buildings include:

Distributed Antenna Systems: Traditional DAS consists of passive RF devices and coaxial cables strung through a venue to distribute signals from a base station (Figure 3). Where losses are high, such as the case when the venue is large and the cables are long, or when the signals are split too often, bi-directional amplifiers are used to boost the signal strength. Passive DAS has a low cost-point but cannot scale effectively for large venues or multiple operators and frequencies. Active DAS solutions are best used to service such cases whereby the RF signals from the base station are converted to optical signals which are then transported over fiber a long distance to a remote radio where the reverse operation is done (Figure 4). Often, active DAS is combined with passive DAS for a hybrid deployment scenario. The extent of this practice depends on what the operator believes would work best in terms of project economics. When a hybrid deployment is considered, high RF-power remote radios are used to feed the passive network. Alternatively, the operator can consider a pure active deployment with low-power radios that are strategically located to meet the service level requirements for a venue. Active DAS systems are specifically targeted at large venues and can accommodate multiple technologies, frequency bands and operators with relative ease.

The active DAS worldwide market is valued at $2 billion in 2013, up 2% over 2012, with a total of 1.2 million DAS nodes shipped. The global DAS market is forecast to grow at a 3% CAGR from 2013 to 2018, when it will top $2.3 billion, and node unit shipments will pass the 2-million mark[3]. The overall DAS market including both equipment and services is estimated at $4.4 billion in 2014 with forecasted growth to $8 billion in 2019, of which a total of 60% will be on active DAS solutions[4]. North America remains the leading region for active DAS deployments followed by Asia and Europe.

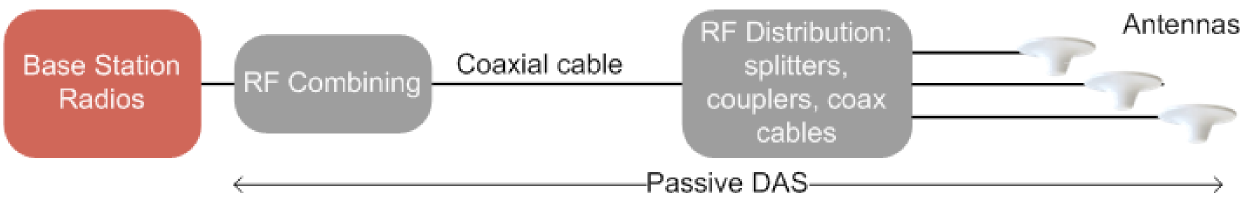

Figure 3 Passive distributed antenna system.

[3] Infonetics, "DAS market growth in N. America and Brazil offsets China slowdown," May 2014.
[4] ABI, "In-Building Wireless Market Reaches $8.5B in 2019," February 2014.

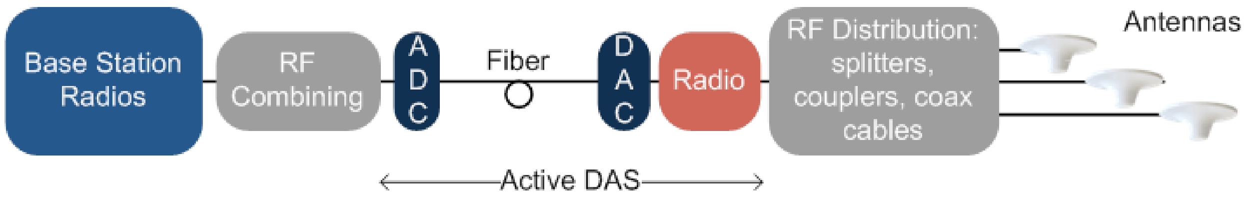

Figure 4 Active distributed antenna system.

Distributed Radio Systems (DRS): Are a relatively new breed of systems that extend the distributed base station architecture, a base station that features baseband processing module connected to a remote radio head through an optical interface (Figure 5). In the first type of DRS systems (Type 1), the baseband processing unit is connected through fiber to a low-power remote radio head (RRH) over an interface such as CPRI, which is most typical and exceeds OBSAI in adoption. An alternative system (Type 2) is the one recently introduced by Ericsson (DOT) and Huawei (LampSite) which uses an intermediary module to convert optical CPRI signals from the macro cell baseband modules into IF signals for distribution over CAT-type Ethernet cables to low RF-power remote radios. DRS provide the benefit of coordinating the operation among the low-power access nodes as well as between them with the overlay macro cell which can result in substantial gain in performance. DRS are also easier to plan, configure and manage compared to small cells, because a central baseband unit controls operations. However, DRS are limited in operating bandwidth to a few tens of MHz and in distance to a maximum of approximately 200 m, where CAT-type cables are used. The distance for fiber would reach up to a few kilometers. DRS are targeted at single operator deployments in medium-sized venues, especially ones where fiber is available.

The market for DRS is emergent at the time of writing this report with limited deployments as the solutions have recently been released on the market.

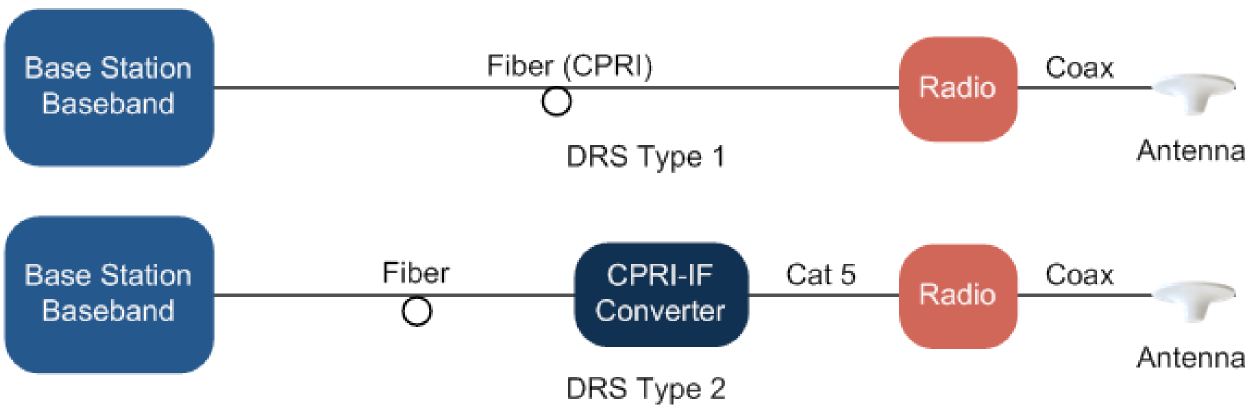

Figure 5 Distributed radio system of Type 1: low power remote radio, and Type 2: CPRI-IF conversion.

Small Cells: Small cells combine the baseband and radio frequency functions into one compact enclosure (Figure 6). They operate at different RF output power levels, ranging from a low of 0.2 W for indoor residential deployments to 5 W for outdoor carrier deployments.

Small cells can be deployed in two general network architectures. The first includes a gateway that performs certain management and security functions, which is typical for a residential and enterprise application. The second architecture is based on direct connectivity to the operator core network which is typical of carrier deployed small cells. Small cells are targeted at relatively small venues where DAS would be too expensive to deploy. Small cells are deployed typically by a single operator unlike DAS systems which are often shared by multiple operators.

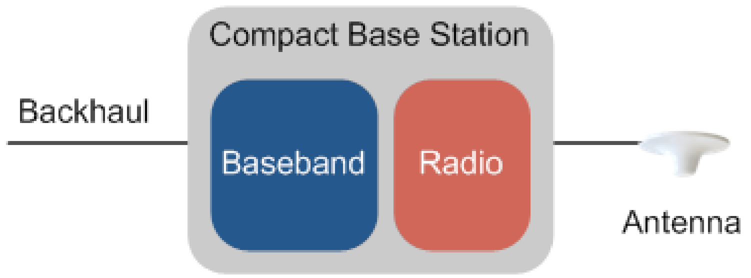

Figure 6 Small cell base station.

Wi-Fi: Wi-Fi is used extensively in the enterprise, SME and home as offload technology. Wi-Fi is also deployed in larger venues. Because Wi-Fi provides a low-cost point, it is believed that it will gain more popularity with operators to become an integral part of the radio access network. This objective is facilitated by recent technical developments such as the Hotspot 2.0 initiative which facilitates subscriber access to Wi-Fi based on the mobile SIM for authentication and security functions. However, Wi-Fi does not offer the same quality of service that LTE does, often because of poor planning or simply because of the high concentration of Wi-Fi access nodes. Hence, in deploying Wi-Fi, the network operator is faced with a classic trade-off between cost and quality. Nevertheless, Wi-Fi is a strong option for operators, and the technology has a rich roadmap that it is following, which will allow it not only provide better throughput performance, but more critically to better integrate with radio access networks.

Table 1 Comparative analysis of different in-venue wireless systems.

	Small Cells	**DSR**	**DAS**
Venue size	Small	Medium	Large
Management	Per module – controller/SON functions to reduce complexity	Per sector – through the macro base station. Follows general operator practices and systems	Per sector – through the macro base station. Follows general operator practices and systems
Potential for interference	High – requires coordination; SON functions can reduce complexity	Medium – requires planning. The distributed radios are coordinated among each other and with the overlay macro cell to reduce interference	Medium – requires planning. The remote DAS modules are extension of the base station sectors and coordination is possible to reduce interference

Distribution media	Fiber or copper	Mix of fiber and copper, or fiber only	Fiber
Potential for system sharing between MNOs	Low: depends on MNO attitude on sharing active infrastructure	Low: depends on MNO attitude on sharing active infrastructure	High: allows MNOs to install their own base stations which can be managed separately
Capacity capability	Supports single or dual frequencies with limits on number of users, typically up to ~60 for enterprise small cells, with new models reaching 200-400 users	Supports single or dual frequencies with higher limits on number of users than small cell. Limits per architecture and type of distribution network (e.g. copper)	Scalable with number of base station sectors installed. Cost as well as space requirements increase for large systems
MIMO	Inherent in the design and function of small cell	Inherent in the design of the RRH	Requires additional modules to support MIMO function that increases cost. New systems are addressing this with fully integrated modules, sometimes at the expense of lower RF power
CoMP capability	Low – the backhaul link would not provide sufficient capacity and jitter accuracy	High – intra site CoMP capability as distributed radios belong to a single sector of a multi-sectored base station	High – DAS extends base station sectors by operating at the antenna interface.

To round-up our review of in-venue communication options, it is important to mention Cloud RAN, an emerging technology that can play a significant and disruptive role once it matures over the next 3-5 years. Cloud RAN centralizes and virtualizes the baseband processing of the base station. This enables features such as coordinated multipoint (CoMP) where a mobile base station can communicate with multiple base stations simultaneously resulting in improved performance especially at the cell edge (Figure 7). From this perspective, Cloud RAN can be considered as an evolution of DRS to a higher level of integration and sophistication. In this report, we focus on delving deeper into the evolution of DAS to map its expected trends and development in the short and medium term (up to 5 years).

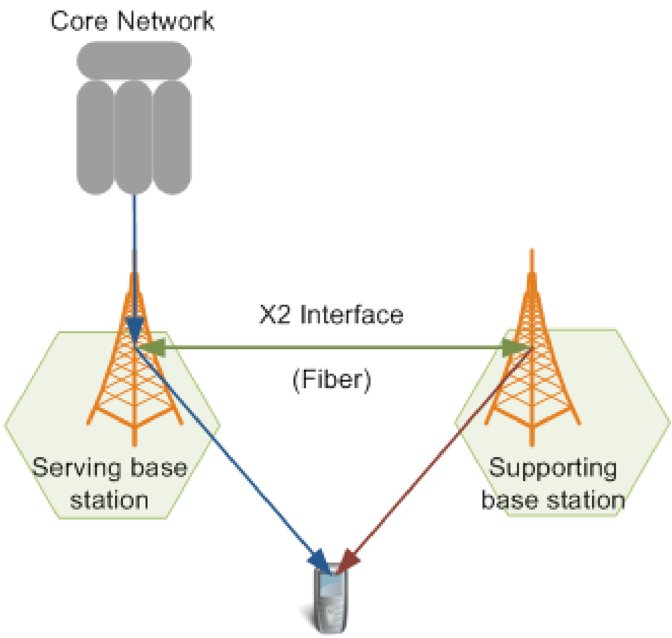

Figure 7 Coordinated multipoint.

Evolution of DAS Systems

A Perspective

It is perhaps useful to pause and review some of the history of DAS systems to frame the future evolution on what one can expect within the next few years. The roots of DAS are almost as old as the mobile industry. In the 1990's, operators started deploying what we now refer to as passive DAS as we introduced earlier. These systems consist of a network of coaxial feeder cable with taps to connect to antennas in different locations or alternatively a network of 'leaky feeder' cables which is a coaxial cable with gaps in its exterior conductor used to radiate energy (effectively slot antennas). Passive DAS performs relatively well for technologies such as GSM and for voice services running on 800 and 900 MHz where attenuation in coaxial cables is still relatively manageable, and the link budget would allow a distance up to a couple of hundred meters between the antenna and the base station. In cases where longer distances are required, bi-directional amplifiers (BDAs) are used to boost the signal strength in both the downlink and uplink paths (path imbalance is another major issue in passive DAS).

Passive DAS are susceptible to passive intermodulation (PIM) interference that result from mixing of different frequency bands, which increasingly became an issue the larger these systems got, with more frequency bands being added and more operators sharing a single system. As passive DAS systems struggled to meet the requirements in large multi-operator venues, active DAS systems emerged as a solution. Passive DAS does not support fault management capability (alarms) nor does it allow power management and control capability at the antenna level. Yet, passive DAS systems remain a low-cost option that is used whenever the size of the venue supports such deployment. Passive DAS as the name implies does not include any active modules, with the exception of BDAs which are simple, low-cost devices. Once installed, passive DAS can generally operate for many years into the future, especially inside buildings where the environment is controlled.

The Present

Active DAS systems evolved to solve many of the limitations of passive DAS. Active DAS provides long reach and better protection against PIM by converting RF through an intermediate frequency (IF) down-conversion stage to optical signals in a master or DAS head which are then transported over fiber optical cable to a remote location where the reverse is accomplished. A remote unit converts the optical into RF signals that are amplified and transmitted. While the concept is relatively straight forward, the implementation and design of active DAS systems is a basis of differentiation between vendors. The DAS systems on the market today were primarily designed to cater to the established technologies and frequency bands used by operators: GSM, CDMA/EV-DO, and 3G/HSPA running in 800/900, 1800/1900, and 2100 MHz bands. In fact, some systems are limited to a certain technology and band which is becoming a challenge for the current operating environment as operators today have increased their spectrum holdings and operate multiple technologies.

Active DAS provides the network operator with management and control capabilities including fault management. Active DAS systems connect to the base station through a Point of Interface (PoI) which consist of RF signal shaping modules (splitters, duplexers and multiplexers, couplers, attenuators, matched load, etc.) to condition the output signal from the base station which is generally at high RF power (order of Watts), to a level that is suitable for input into the DAS (order of milli-Watts). The PoI is one of the cost drivers for DAS especially for large systems that include many operators, frequency bands and carriers. Moreover, the bulk of base station RF output power is dissipated in a matched load which is inefficient use of energy. PoI modules also consume space which can be limited in many venues.

Considering there are three main elements to active DAS systems (PoI, master head and remote unit), active DAS differentiate by how these elements are designed and how they work together to form a complete system. The characteristics and the way these building blocks are assembled and interconnected to deliver on the coverage and capacity objectives for a certain venue (small or large) result in different cost structure which favors one vendor solution for a certain deployment over another. In other words, one aspect to DAS systems is that there is no single universal solution that is superior for all use cases – there is ample opportunity to differentiate and to focus on specific target markets and applications. This is evident by the path that vendors have taken in designing their systems. Here, we focus on two aspects: the optical distribution system and the remote radio.

Optical Distribution: There are fundamentally two modes for optical signal transmission over fiber cable: analog and digital. The majority of DAS solutions on the market today are based on analog modulation of optical signals by RF signals. Typically two fiber optical cables are required to connect the master unit with the remote unit with one for each direction, the downlink and the uplink. The second mode is digital modulation of optical signals. In this case, some systems use two different optical wavelengths and combine the downlink and uplink signals on one fiber optical strand. Digital systems, whose presence on the market is increasing, have the capability to deliver longer range than analog systems because of better optical power budget. This has the potential to allow new business models centered on base station hosting. Digital DAS also allow the operator to switch signals from one remote radio to another which allows them to serve different areas using the same baseband resources, thus reducing cost of deployment (Figure 8).

They also provide high flexibility in providing different deployment topologies that optimize the design of the distribution network for lower cost for example where systems can be deployed in a star, chain, loop, or hybrid topology. Analog technology, on the other hand, is widely available at relatively low cost-points and can be used effectively in scaled down DAS systems into smaller venues where sensitivity to cost increases. Moreover, some analog systems can support very wide bandwidth which allows supporting greater number of RF carriers in the optical distribution system. Specific examples of digital DAS include that of TE Connectivity and Dali Wireless. Axell Wireless and Commscope also announced digital products recently in a shift from their traditional analog systems. In all, we see a trend to deploy digital systems in larger venues and in campuses where range, capacity switching and other features combine for an effective business case. On the other hand, analog systems can scale faster in cost to serve smaller venues.

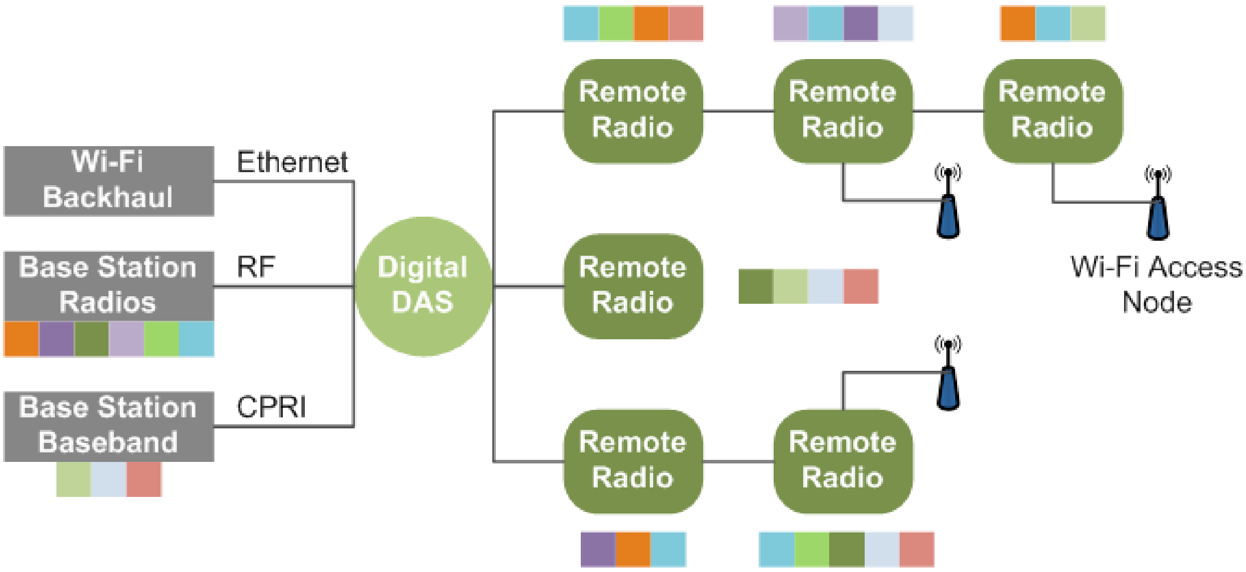

Figure 8 Digital DAS enables switching RF signals from the base stations to any remote radio and enables greater integration with the base station and Wi-Fi access nodes.

Remote Radio: Two of the main characteristics of remote radio are the bandwidth and output power. Here again, vendors have differentiated their solutions. Most remote radios on the market accommodate multiple frequency bands in different types of enclosures. Remote radios come in different RF power outputs: sub 1 W (low), between 1-4 W (medium) and 4-20 W (high). High power radios can be shared by greater number of operators because the power is divided among the different users of the system. They can also be used to feed passive DAS networks. On the other hand, low power radios have a relatively small size and can be easier to deploy and used in greater quantity to provide uniform coverage and performance. Recent DAS have implemented digital pre-distortion and crest factor reduction techniques to improve the performance and reduce power consumption, a trend that will continue to spread. Aside from output power, the bandwidth capability is another critical factor. Wide bandwidth allows greater flexibility in spares, inventory management, and flexibility of future growth. However, higher bandwidth typically comes at a price or lower RF power output. Here, we point to a specific example of Zinwave's unique wideband radios that support all wireless frequencies between 700 MHz – 2700 MHz in a single low power module.

The above exposition of active DAS systems demonstrates multiple approaches taken by vendors. Each solution provides distinct advantages, which makes it imperative to consider different options for a specific venue that accommodates service design objectives.

Evolving Trends

The evolution of DAS has to factor the evolution of market requirements such as scalability of DAS to smaller venues. This requires a reduction in cost, the simplification of installation, availability for deployment and management by third parties, as well as improvements to size, form factor and aesthetics. The challenge lies in that these requirements are accompanied with the need to support greater numbers of frequency bands and different technologies (e.g. HSPA, FD-LTE, and TD-LTE). The downward evolution towards smaller venues does not exclude continued evolution to provide higher cost efficiency for large venues. In fact, this is where digital-based DAS systems provide much value. Therefore, the evolutionary trends are two pronged with the first focused on the downward trend into smaller venues, particularly in developed economies and markets, and would have wide market implications mainly because many of the venues are green-fields with no current service. This is an area that will place DAS in competition with DRS and small cells. The second is focused on achieving greater cost efficiency for large venues, which opens up new markets in emerging markets as well as new applications in the developed economies (e.g. base station hosting service) (Figure 9). In this sense, we expect the DAS market to branch further as more use case scenarios become possible.

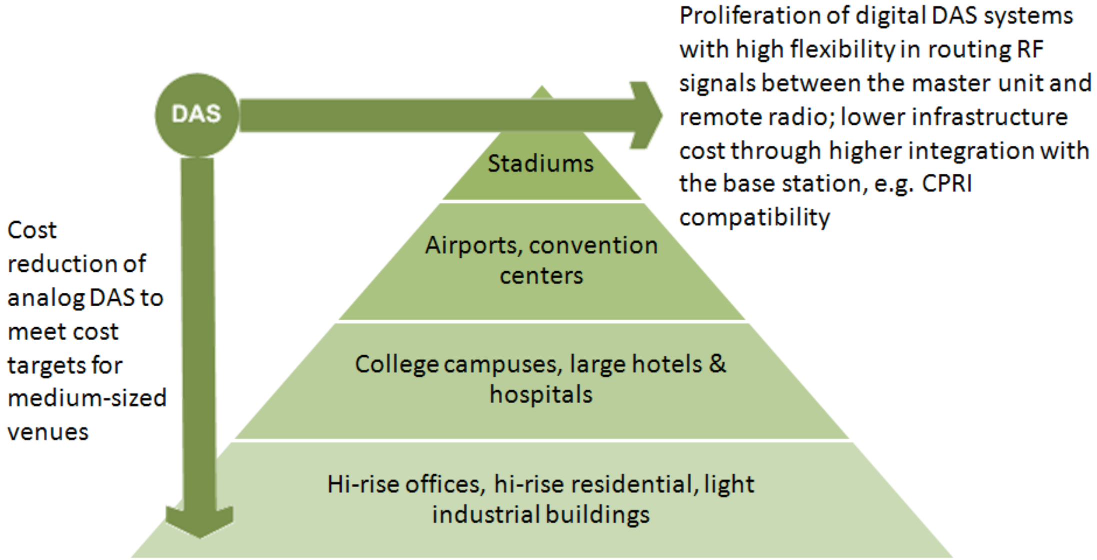

Figure 9 Evolution of DAS to reduce cost for large venues and to scale service into smaller venues.

CPRI Integration: A notable emerging trend is to extend DAS to support CPRI standard directly from the baseband unit. This has an advantage in reducing the cost of deployment as it eliminates the need for a radio head at the base station which saves significant capital expense. The BTS radio, which typically accounts for as much as 50% of the base station hardware cost, and the PoI associated with the DAS, and operational expense related to energy consumption are all saved. There are, however, important consequences to implementing this approach. The first is that base station vendors control the management and control layer of the CPRI interface. The DAS vendor is required to collaborate with the base station vendor to realize full and seamless integration.

The second consequence is that CPRI consumes very wide bandwidth. For example, a single 20 MHz LTE channel with 2x2 MIMO support requires 2.5 Gbps line rate. This would quickly use up the capacity available on a fiber cable and can necessitate the use of WDM to combine multiple CPRI signal streams on the fiber cable, or alternatively use more cables. Nevertheless, CPRI integration is a significant feature that positions DAS close to DRS and creates direct competition between the two approaches. Hence, we see Alcatel Lucent opting to integrate with TE Connectivity to provide a function similar in concept to Ericsson DOT system. Another company stating CPRI compatibility is Dali Wireless. Both of these companies have developed digital DAS which is amenable to carry CPRI IQ data.

Wi-Fi/Ethernet Integration: Wi-Fi is widely available indoors in the enterprise as well as for public access. Integration between DAS and Wi-Fi is therefore a logical step, whereby the fiber infrastructure used by the DAS system can be leveraged to carry Wi-Fi backhaul traffic to a central location in the venue. Digital DAS are increasingly equipped with one or more Ethernet ports at the master and remote radio unit to multiplex Wi-Fi Ethernet backhaul signals. Some systems support only 100 Mbps, which is relatively small, but newer systems support 1 Gbps interface which provides greater capability to support Wi-Fi access node. The result is lower cost of providing wireless coverage and Wi-Fi data service inside a venue.

MIMO Support: MIMO presents a critical implementation challenge to DAS and has exposed a current weakness, where implementation requires doubling the entire distribution system which essentially doubles the cost of the deployment. MIMO requires a completely separate RF-optical conversion module, a remote radio and the fiber connecting them. This is because MIMO spatial multiplexing consists of different information bit streams transmitted at the same frequency. In DAS, the two streams are required to be separated for processing and to eliminate interference between the two steams, hence, the effective doubling of DAS hardware requirements. MIMO is a feature of LTE so while LTE networks are still lightly loaded today the pressure to deploy MIMO is not urgent, giving vendors some time to develop cost effective solutions. Nevertheless, MNOs have favored MIMO deployments in venues and consequently provisioned for MIMO in DAS deployments. With future wireless networks relying on a greater order of MIMO to achieve capacity, the challenge to support MIMO in DAS will increase proportionally. This is will be a key area where DAS, DRS and small cells will compete and differentiate.

MultimodeSupport: Today, we can find several wireless technologies operating in the market: GSM, 3G/HSPA and LTE (FDD and TDD). Additionally, the evolution of LTE comprises different operating modes such as carrier aggregation, which incorporates an additional carrier as a supplementary channel to augment the downlink path. Today, most DAS solutions on the market are limited in their ability to support the TDD mode. This presents a challenge to sharing the DAS with TDD operators. Multimode FDD/TDD support is another cause for DAS evolution.

Alongside the four developments above, there are four evolutionary trends for DAS to follow:

Frequency Axis: DAS will have to evolve to support wider channel bandwidth and a mix of different frequency bands in conjunction to increases spectral holding of MNOs. This will allow multiple operators to share a system, resulting in greater cost efficiency. The capabilities of DAS to cost effectively support a varied mix of frequencies is a key differentiation point especially valued by the DAS operators.

Power Axis: DAS will evolve to support different variations of radios with multiple output powers. Specifically, medium power modules in the range of 1 W would cater well to the smaller buildings while at the same time allowing multiple operators to share the system as the case requires. This power category of radios would see high growth.

Integration axis: To reduce the cost of DAS deployments in medium-sized venues, it is possible to use small cells as feeders into the DAS. Integration of small cells and DAS into a single operating system provides both coverage and capacity at reduced price, by eliminating the macro cell and reducing PoI requirements because small cells operate at lower power. For this to succeed, the combined solution would use high-capacity small cells (e.g. 200-400 active subscribers) that have recently become available on the market. Another aspect of integration pertains to the capability on the optical distribution network where greater use of WDM solutions is anticipated to increase the utility of DAS.

Deployment and operation axis: DAS projects are typically large and require coordination between different entities to bring about a fully deployed and operationally effective system. In scaling to medium sized venues, ease of deployment will take on added importance, as often it will be third parties who would install DAS. Means to ease deployment can take different directions, such as reduction in space required for the DAS, auto-calibration for near plug-and-play installation, capability to use different media for transport of signals between the master and remote units. In addition to this there is fiber and other features that help make the deployment process simpler and more cost effective, such as the use of single fiber for both downlink and uplink paths. Furthermore, the systems need to be managed in a straightforward manner at an independent operator level. Greater functionality in software will be a key differentiator in DAS that will gain prominence.

The above trends would combine to extend the capabilities of DAS to render them simpler to deploy and easier to maintain. The main appeal for DAS has been the ability to provide a single point of inter-connect to the base station which, at least in the United States, has provided a demarcation point between the mobile network operator and a third party who designs, deploys and maintains the system. This model will slowly make its way to other regions in the world and prove to be a catalyst for continued growth in DAS.

Enabling New Business Models & Applications

The evolution of the wireless base station architecture to include small cells and Cloud RAN, in addition DRSs, increases the competitive pressures on the DAS vendors as more options are available to the MNOs for in-venue service than ever before. Yet, there are distinct features and advantages to DAS that would keep it as a viable option for many venues and certain types of applications. One of the benefits is that DAS can be easily shared by multiple operators which reduces the capital and operational costs. In contrast, small cells, Cloud RAN or DRS require sharing of active infrastructure. MNOs in many markets, especially those where ARPU is relatively high, refrain from adopting this as operators continue with the strategy of differentiation based on network performance. Another relevant feature of DAS is that they can be deployed by a third party who provides MNOs with a single connection point to the base station. MNOs favor demarcation points where responsibility for service and support can be clearly identified.

With this in perspective, the advantage of DAS lies in the business model and applications that it enables. These are largely driven by an operator attitude towards system sharing and third-party engagements. The business model factors heavily into the resulting cost of deployment, which has played favorably for DAS in large venues. As such DAS will evolve to accommodate greater integration with the base station as will be required in the future, especially for large venues. At the same time, the evolution of alternatives will continue to create more tension among all these technologies as each technology progresses along its development path. The success of one over another would largely depend not only on which is better able to accommodate the preferred business model, but also on what a technology provides in new business models and applications, which are bound to vary among different regions and markets.

As an example, the new generation of digital DAS enables new business models centered on base station hosting. The high optical power budget of digital DAS allows aggregation of base station baseband in a central fiber office removed by tens of kilometers from the remote radios. This application has been used to some extent in outdoor DAS deployments, but the new systems would provide greater benefits. Such as where base station hosting can be coupled with capacity switching to serve moving traffic hotspots. This conserves base station baseband resources as these resources would be pooled and assigned dynamically to hotspots as required. In effect, the benefits are similar to what Cloud RAN provides, as it is no longer required to provision capacity for the peak value required for every location. As a practical example, DAS can be used to provide service over long stretches of railway tracks with minimal baseband resources that are switched from one remote transceiver to another as a train passes through its coverage area. This application provides a railway company or a subway operator an opportunity for additional revenues should it decide to deploy such a service. In a correlated model, a fixed access operator with fiber assets can provide base station hosting service in its fiber centers and use its access to commercial buildings to enable the MNOs to serve these buildings using its already deployed fiber. Note that such a case can also be implemented with small cells, provided operators are more amenable to sharing infrastructure.

Conclusions

There is heightened attention on in-venue communication systems as a means to improve wireless services that are taken for granted by subscribers expecting service anywhere, anytime. This attention is augmented by the need of MNOs to offload congested macro cells by eliminating traffic hotspots through the lowest cost alternative, leading to a convergence of objectives that has combined to stimulate growth of DAS solutions. While other solutions that include DRS and small cells are alternatives for in-venue solutions, DAS was and continues to be the workhorse, mainly because the business model it provides has been amenable to operators. Starting with deployments in the largest of venues, the evolution of DAS is expected to continue along two paths, one leading to lower-cost deployments and the other realizing DAS economics for smaller venues. The market for DAS is expected to continue to grow in the absence of a consensus by operators on infrastructure sharing. The evolution of DAS would center on enhancements of digital distribution technology that allows higher cost efficiency and integration with wireless base stations to reduce total cost of ownership, in addition to the introduction of low-cost analog based solutions with greater flexibility to meet the requirements for relatively small venues. The viability of DAS in the future would hinge on the new applications and business models it can enable. In this paper, we provide examples of applications that new generation of DAS enable by leveraging the flexibility of the digital architecture for cost effective new deployment scenarios.

Acronyms

3G	Third generation
ARPU	Average revenue per user
ARQ	Adaptive repeat request
BDA	Bi-directional amplifier
BTS	Base transceiver station
CDMA	Code division multiple access
CoMP	Coordinated multipoint
CPRI	Common public radio interface
DAS	Distributed antenna system
DRS	Distributed radio system
EV-DO	Evolution - data optimized
FD	Frequency duplex
FDD	Frequency-division duplex
GSM	Global System for Mobile Communications
HSPA	High speed packet access
IF	Intermediate frequency
IQ	In-phase and quadrature
LTE	Long Term Evolution
MIMO	Multiple input multiple output
MNO	Mobile network operator
PIM	Passive intermodulation
PoI	Point of interface
QAM	Quadrature amplitude modulation
RAN	Radio access network
RF	Radio frequency
SIM	Subscriber identity module
TD	Time duplex
TDD	Time-division duplex
TE	Tyco Electronics
WDM	Wave division multiplex

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