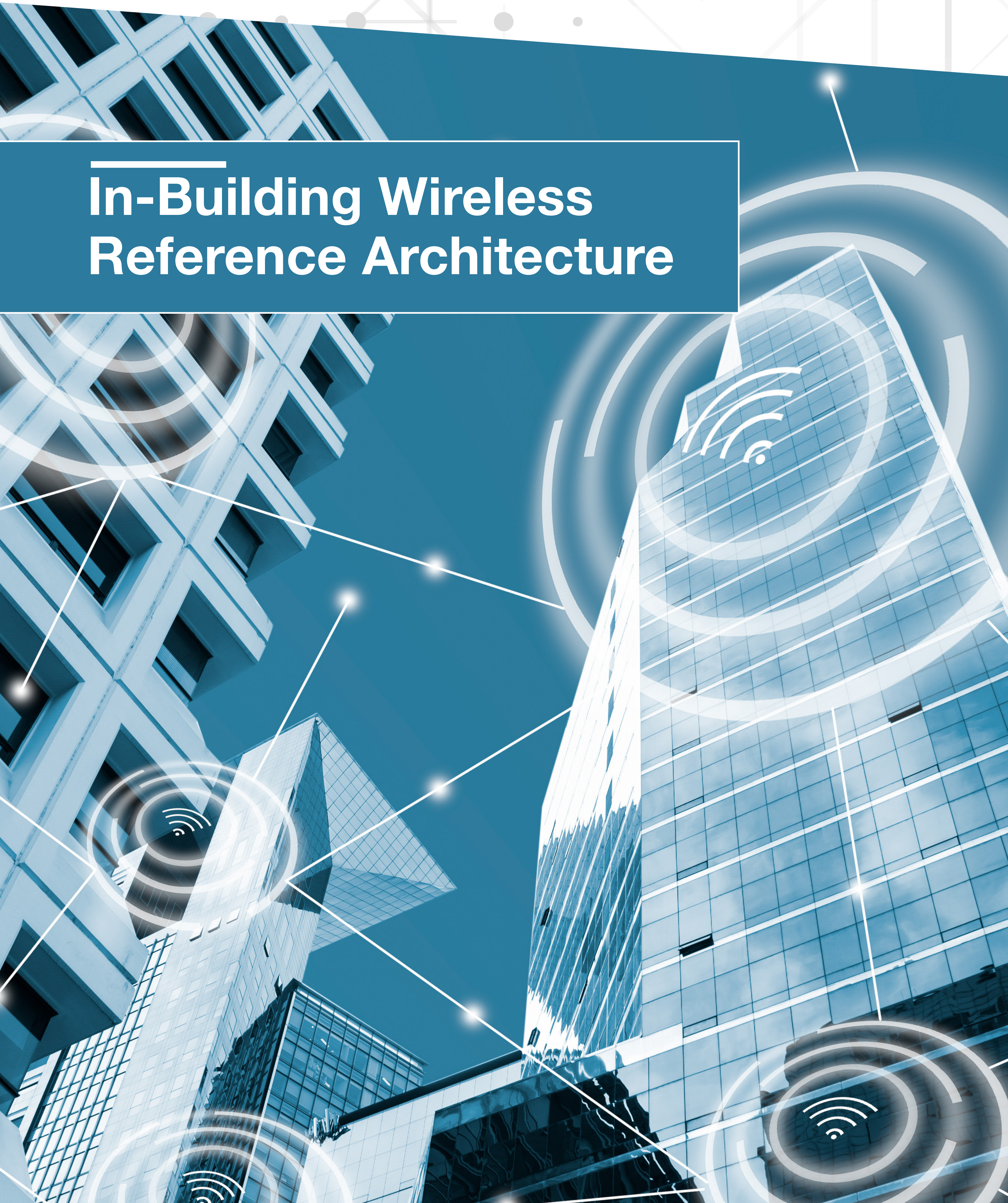
PanGen®
STRUCTURED CABLING SOLUTIONS

In-Building Wireless Reference Architecture



Contents

Overview

In Building Wireless (IBW) involves the distribution of wireless signals inside buildings to provide end users with both data and voice connectivity. IBW can provide a direct wireless signal from cellphone carriers into the building using small cells or a Distributed Antenna System (DAS). A DAS is a network of antennas that sends and receives cellular signals on a carrier's licensed frequencies, thereby improving voice and data connectivity for end users.

Another method of providing data and voice capabilities without the need for a cell provider signal is to use WIFI. WIFI is commonly known and used for data but can also provide voice capabilities through Voice-Over-WIFI (VoWifi). The industry views WIFI to be complementary to DAS and small cell deployments, and both will be needed to cover the rapid increase in data and voice use indoors.

The IBW market is in continuous change, with new technologies emerging such as CBRS, MulteFire, LTE-Advanced Pro, and LAA/LTE-U. These new technologies are outside the scope of this document.

Why Use IBW?

Lack of capacity and/or coverage are the two main performance issues that an IBW deployment can resolve. Understanding what they mean is essential to comparing and choosing the right IBW technology.

- **Capacity:** Some locations experience significantly more cellular data usage than others, including sports stadiums, airports, and large music venues. If the venue relies on a nearby cell tower to provide coverage to its users, the tower and the local network would quickly become overwhelmed and unstable. Users may have full signal but limited to no access to either data or voice.
  In such applications, an IBW system with high capacity is the primary need.
- **Coverage:** If there simply is not enough usable signal reaching users, either because the cell tower is too far away or because building materials such as low-E windows are blocking the cell signal, the primary need is coverage.
  For example, a newly-built LEED-certified (Leadership in Energy and Environmental Design) hospital with concrete walls might have no indoor coverage and require an IBW system. High rises often use IBW deployments because the radio frequency noise levels at higher altitudes make the signal unusable.

Identifying one of these needs as the primary requirement at a building is an important first step to choosing the right IBW technology, which usually requires making trade-offs between coverage, capacity, and price.

IBW Signal Sources

The signal source for an IBW system is one of the most important factors in determining both the coverage area and capacity. No matter how well the distribution system performs, an IBW is always limited by the performance of the signal supplying the network. The three main signal sources are:

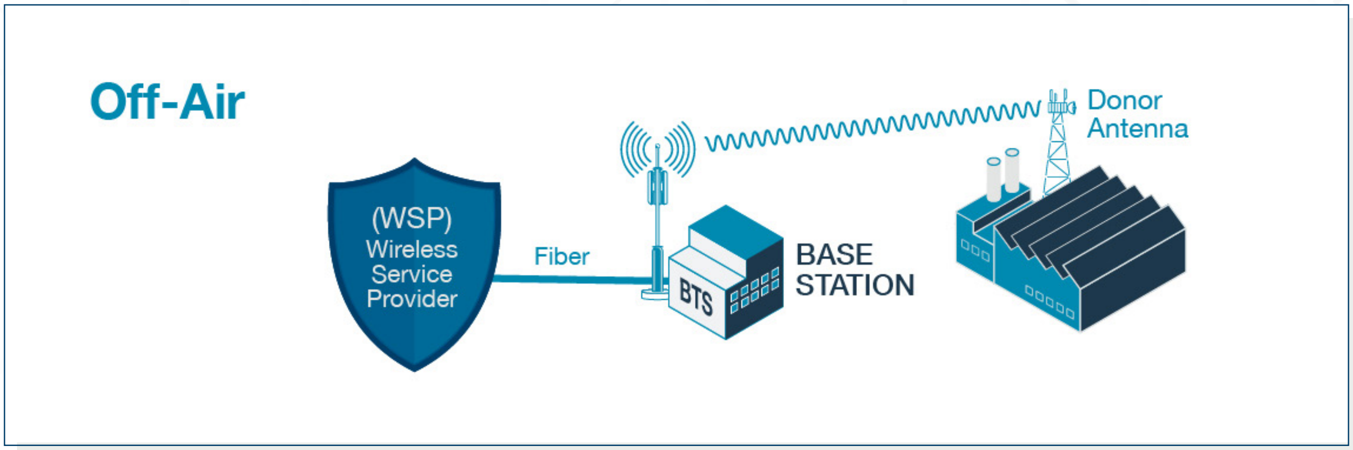
Off-Air

A DAS that uses an off-air signal (sometimes called a repeater or bi-directional amplifier) utilizes a donor antenna on the roof to receive and transmit signals from a cell carrier. Off-air signals were the most common signal sources for a small-building DAS. If the signal at the donor antenna is weak or the nearest tower is congested, using an off-air signal isn't typically feasible. But if the donor signal is strong and clear, then an off-air signal is often the easiest and most cost-effective signal source.

An off-air DAS does not add any extra capacity to the carrier's network and is primarily used to extend coverage at the edges of the network. As the nearest tower becomes congested, the capacity of the DAS system using off-air signal will degrade. These deployments are often the lowest cost option but are not used as frequently due to their capacity limitations. Their infrastructure is not future proof and would not match the future speeds of 5G and beyond.

The diagram below illustrates how an off-air antenna provides a signal source to a building.

The table highlights the strengths and weaknesses of an off-air signal source.



Off-Air - *(continued)*

Strengths
• Fast deployment times (minimal carrier involvement required) • Lowest cost • Can work with multiple carriers
Weaknesses
• Performance depends on strength and quality of donor signal, as well as level of congestion on macro network • If donor signal changes, system performance will change • Does not add any capacity – relies on existing carrier cellular networks • Optimizing signals for multiple carriers can be difficult • Retransmit agreements are often required (per carrier) prior to installation • Not future proof; not 5G ready

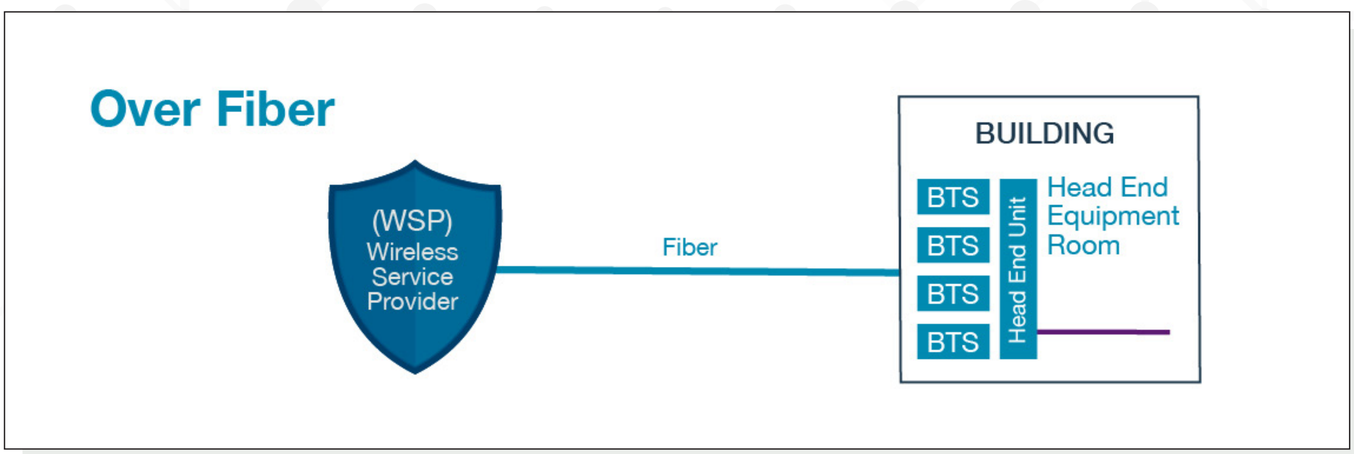
BTS Signal Source

BTS, NodeB, and eNodeB refer to the technology used inside cell phone towers to generate a cellular signal. For simplicity, these technologies are often referred to simply as a BTS signal source.

The connection between a cell carrier's BTS and the core network typically requires a dedicated fiber connection that is usually installed by the carrier. A DAS in a large stadium or airport may even connect to multiple BTSs – one for each carrier – to handle the load of tens of thousands of users calling, texting, and using data simultaneously. DAS systems that use BTS signal sources provide the highest level of performance, but they typically take longer to deploy and are more expensive – each carrier must run its own fiber and the BTSs themselves are typically at least $50k+ each.

The diagram below illustrates how a BTS provides a signal source to a building.

The table highlights the strengths and weaknesses of a BTS signal source.



BTS Signal Source - *(continued)*

Strengths
• Highest performance • Can provide as much capacity as needed for venue • Future proof and 5G ready
Weaknesses
• Much more expensive than other options • Long deployment times: can often take months (up to a year) for carrier to provide equipment • Require careful planning around hand-off zones for users as they enter and leave the building • High OPEX costs • Space, cooling, and power requirements

Small Cells (Femtocells, Picocells, Metrocells, and Microcells)

Small cells are the latest technology used by carriers to provide cellular service inside buildings. There are several variations of small cells, including femtocells, picocells, nanocells, and metrocells. These are all basically the same technology—they create a secure tunnel back to the carrier's network over a normal Internet connection and generate a high-quality wireless signal.

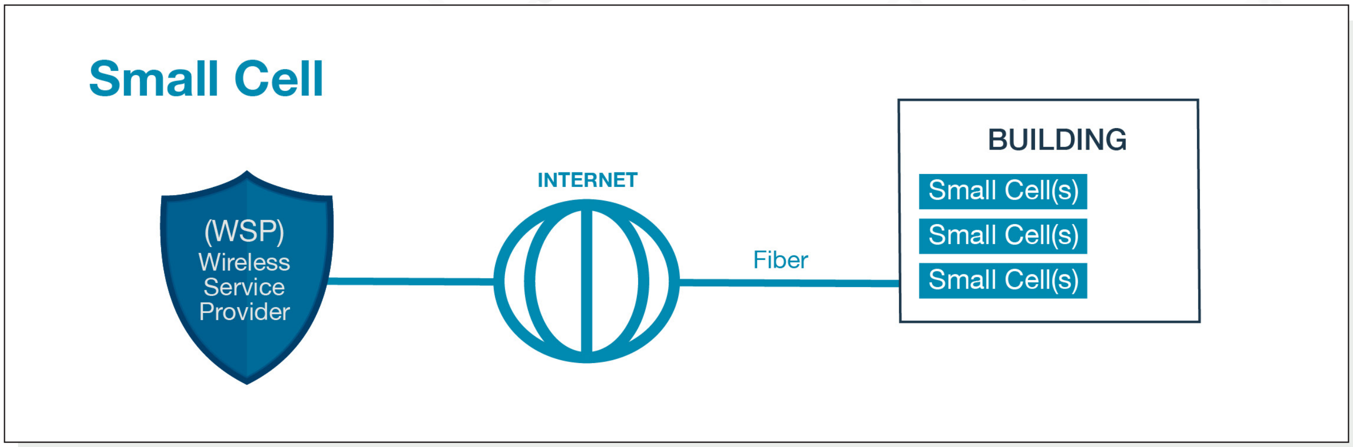
Small cells can be used both as a signal source or a stand-alone IBW solution. When used as an IBW solution, their coverage radius ranges from 60 ft. – 5,000 ft. and their capacity can handle 6 - 1,000 simultaneous users. To this day, small cells are single carrier solutions despite efforts by multiple vendors to have multi-carrier small cells. Using small cells as the IBW solution for a large venue can be costly as one would need one small cell per carrier every 60 ft. - 5,000 ft. (depending on the type of small cell used). The table below shows coverage and capacity limitations based on the type of small cell.

Type	Power	Coverage Radius	Capacity	Primarily Used
Femtocell	<0.1 Watt	Up to 60 ft.	Up to 6 users	Indoors
Picocell	<1 Watt	Up to 750 ft.	Up to 64 users	Indoors
Metrocell	<5 Watts	Up to 1,000 ft.	Up to 200 users	Indoors/Outdoors
Microcell	<10 Watts	Up to 5,000 ft.	Up to 1,000 users	Indoors/Outdoors

Small Cells (Femtocells, Picocells, Metrocells, and Microcells) - *(continued)*

A small cell coverage can be greatly expanded when used as a signal source to a DAS. This is becoming more common especially for the enterprise market. Most carriers are willing to provide a small cell to a building as a signal source given that they are less costly than a BTS and offer greater performance than an off-air antenna. One limitation of small cell technology is that it requires a reliable backhaul Internet connection to connect. Each enterprise-grade small cell typically supports around 200 users. The diagram below illustrates how a small cell provides a signal source to a building.

The table highlights the strengths and weaknesses of a small cell signal source.



Strengths
• Fast to deploy • Future proof and 5G • Create high-quality, fresh signal • Relatively low cost compared to a BTS • Ideal for buildings with hundreds of users
Weaknesses
• Hard to scale to provide coverage for thousands of users • Relies on a venue-provided Internet connection • Not all carriers have enterprise small cells available • Independent connector and antenna for each carrier • Requires careful planning of hand-off zones between small cells and the macro network

DAS Signal Distribution System

Regardless of the signal source a system uses, a DAS is required to distribute the cellular signal throughout the building. There are three main types of distribution systems:

Passive

A passive DAS amplifies a Radio Frequency (RF) signal at the head end room and uses passive RF components such as coaxial cable, splitters, taps, and couplers to distribute the signal inside a building.

Hybrid

A hybrid DAS combines characteristics of passive and active systems. The system uses fiber optic cable to transmit signals to remote radio units located in the Equipment Room (ER). The signal is converted back to an RF signal and is distributed using coaxial cable throughout the building to passive antennas.

Active

An active DAS converts analog radio frequency cellular information from the cellular signal source in the Head End room to an analog or digital optical signal transmitted over fiber to the ER. This signal is passed through either fiber optic (for example, Single Mode OS1) or copper category cable (for example, Category 6A) to active antennas. Active antennas have both a built-in antenna and remote radio to convert the signal back to RF and transmit it.

Advantages and Disadvantages

Below is a list of advantages and disadvantages of each DAS described previously and small cell when used as an IBW solution. The Design section of this document takes a detailed look into the architecture of these systems and the products that are best suited for each.

		Advantages	Disadvantages
DAS	Passive	• Multi-carrier solution • Low cost • Simplified maintenance • No extra equipment required to support multiple carriers	• Distance limitation due to signal loss • Expensive installation • Requires precise link budget calculations • No dynamic allocation of capacity • Not flexible. Once in place, can not be moved • Not IT friendly • Not future proof; not 5G ready
DAS	Hybrid	• Multi-carrier solution • Less expensive than an active DAS • No limits to length of cables in the digital backbone (uses fiber for vertical distribution) • Better coverage and capacity than a passive DAS	• More expensive than a passive DAS • Requires link budgeting on each floor • More complicated and expensive to install • Limited dynamic allocation of capacity • Not flexible; once in place, can't be moved • Not IT friendly • Not future proof; not 5G ready
DAS	Active	• Multi-carrier solution • IT friendly, Wi-Fi like architecture • Ethernet or fiber optic cable can be shared with Wi-Fi infrastructure • No limits to lengths of cable for entire deployment • Easily expandable • Dynamic allocation of capacity when needed • Future proof and 5G ready	• Typically more expensive than hybrid DAS due to active gear
Small Cell		• IT friendly, Wi-Fi like architecture • Ethernet or fiber optic cable can be shared with Wi-Fi infrastructure • Less expensive than DAS for small deployments • Faster deployment and less design-intensive compared to DAS • Dynamic allocation of capacity when needed • Future proof and 5G ready	• Typically single carrier solution • More expensive than DAS for large deployments • Not as scalable as DAS; requires a new small cell every time coverage or capacity is needed

iBwave Design

iBwave Design Solutions is an RF design software for in-building wireless networks. It is used by telecom operators, system integrators, and equipment vendors to design and deploy high-performance indoor wireless networks that comply with the user's KPIs. iBwave Design includes the following features:

- Support for DAS and Small Cell networks for voice and data services
- Supports worldwide frequency bands for 2G, 3G, 4G, 5G, CBRS, Wi-Fi, and Public Safety 5G and CBRS networks, moving through active DAS, passive DAS, coax, or fiber
- Used for designing simple networks or complex heterogeneous networks
- Database of more than 29,000 network elements users can choose from to design their networks
- Detailed network diagrams with automated link budget calculations
- Advanced predictive analysis of coverage, throughput, and capacity
- Automated proposal reports, construction plans, and closeout package
- Can generate an automatic Bill of Materials (BOM)
- Troubleshoots a network before it's deployed to reduce project costs, using the automated air-checking functionality
- Allows the user to interconnect components, automate RF calculations, and simulate the network's performance

Designing the Solution

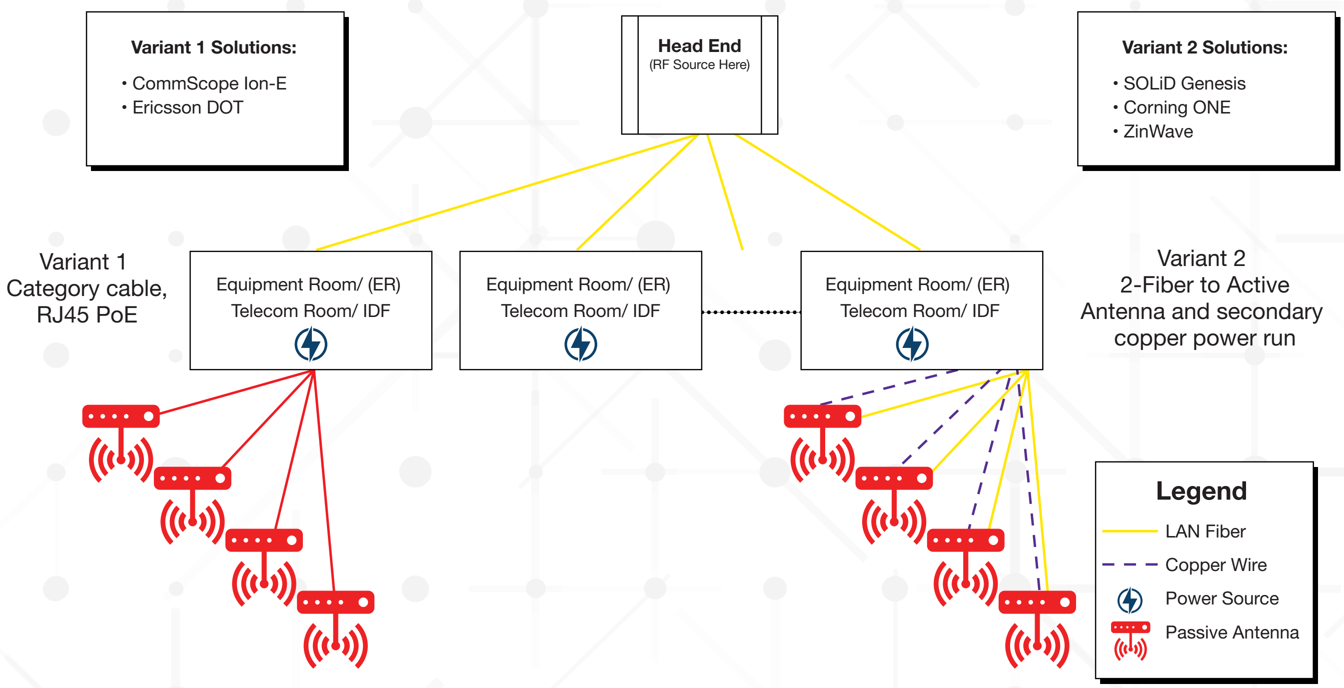
Active DAS Architecture

In an IBW active DAS architecture, the active antennas are powered from the equipment room (ER), which is known as distributed power. (See the diagram on the next page.) In **Variant 1**, the active antennas are powered through Power over Ethernet (PoE). In **Variant 2**, the active antennas are powered through copper cables, typically 18-2 AWG. The copper cables may run separate from the fiber or can be combined in one cable known as hybrid fiber copper cable, also known as composite cable.

Active DAS Architecture - *(continued)*

A new alternative architecture – using centralized power* – has also been introduced. In this architecture, the active antennas are powered using copper cables from the head end room, typically 18-2 AWG. Like Variant 2, the copper cables may run separate from the fiber, or can be combined in one composite cable.

***Note:** While no solutions on the market today use the centralized architecture, it is possible to use existing solutions (Corning ONE, Zinwave, SOLiD Genesis, and more) with this centralized power approach. This approach may be used to provide redundant power only at the head end room rather than providing redundant power in each ER.

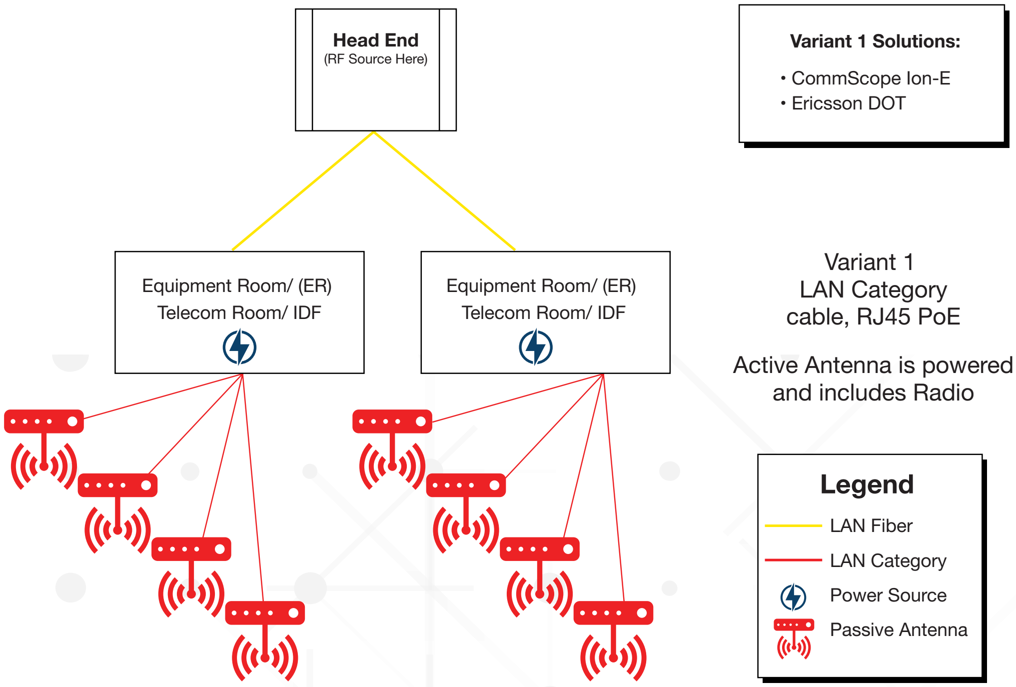


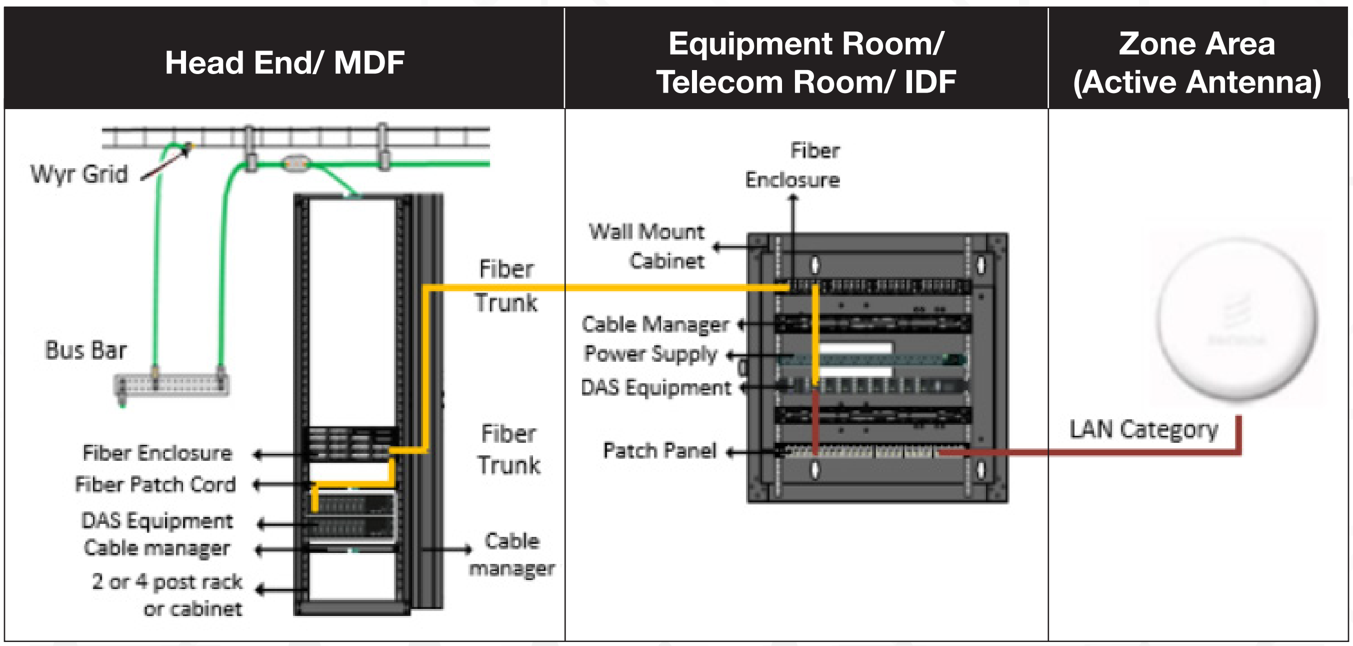
The DAS owner may want to measure power usage (metered power) within the building to charge back to the cellular carrier. You can employ a metered PDU to implement this feature, but note that since the footprint for the equipment in the ER is typically very small, a full 1 rack unit (RU) metered PDU might not fit, depending on the type of equipment housing used.

In the ER, 3 deployment options are typically utilized: rack-mount, wall-mount (typically <12 RU), and ceiling mount (typically <4 RU).

New frequencies such as 5G bands can be engineered for both variants and may include CBRS technology.

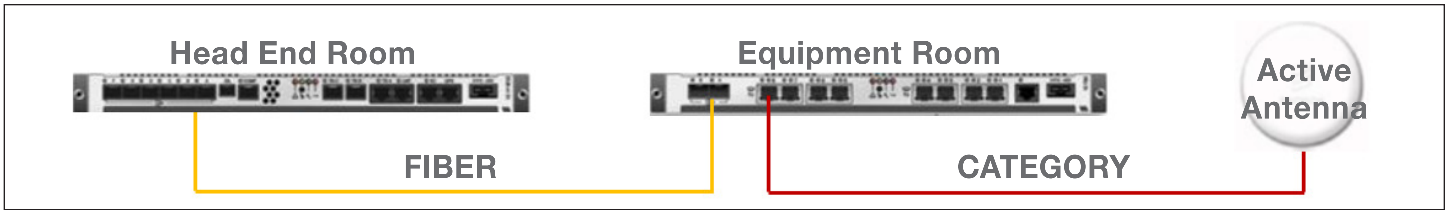
Active DAS Architecture Variant 1





	Head End Device	Media (Protocol)	Equipment Room Device	Media (Protocol)	End Device (Antenna)	Carrier Support
Ericsson DOT	Digital Unit (DU)	SM Fiber (CPR)	Indoor Radio Unit (IRU)	CAT Cable (I/F and PoE)	Radio DOT	Dual-Carrier
CommScope Ion-E	Central Area Node (CAN)	SM Fiber (CPR)	Transport Expansion Node (TEN)	CAT 6A Cable (Ethernet and PoE)	Universal Access Point (UAP)	Multi-Carrier

Active DAS Architecture Variant 1 & Representative PanGen BOM



PanGen products supporting this architecture are shown below.

HEAD END ROOM

R4P	Four Post Rack
WMPV45E	Dual Sided Vertical Cable Manager
WMPFSE	Single Sided Horizontal Cable Manager
RSHLF	Four Post Rack Shelf
FCE2U	Fiber Enclosure
FAPB	Blank Fiber Adapter Panel
FAP12WAGSCZ	Fiber Adapter Panel
FSCS2/9SOCA9AG	Fusion Splice Fiber Optic Connector
F923RSNSNSNM003	Fiber Optic Patch Cord
P12B01M	Basic PDU
P08E14M	Monitored Switched Rack PDU
GJ672UH	Equipment Bonding Jumper
GACBJ618U	Auxiliary Cable Bracket Jumper Kit

BETWEEN HEAD END ROOM AND EQUIPMENT ROOM

F9TYL5E5EAAM050	OS1/OS2 Fiber Trunk Cable Assembly
AP00121PNU	Gen*SPEED* OS2 Fiber Indoor Distribution Cable

EQUIPMENT ROOM

PZWMC12P	Wall Mount Cabinet
Z22C-S	Pre-Configured Network Zone System
FCE1U	Fiber Enclosure
FAP12WAGSCZ	Fiber Adapter Panel
FSCS2/9SOCA9AG	Fusion Splice Fiber Optic Connector
F923RSNSNSNM003	Fiber Optic Patch Cord
CPP24FMWBLY	Modular Patch Panel
UTP28SP8INBU	Category 6 Patch Cord

EQUIPMENT ROOM (CONTINUED)

CJ688TGBL	Category 6 Jack
GJ672UH	Equipment Bonding Jumper
GACBJ618U	Auxiliary Cable Bracket Jumper Kit
P12B01M	Basic PDU
P08E14M	Monitored Switched Rack PDU

BETWEEN EQUIPMENT ROOM AND ACTIVE ANTENNA

7141849	Gen*SPEED* 10 MTP Cat 6A Copper Cable

ACTIVE ANTENNA

FP6X88MTG	Field Terminable Plug
JP131SBC50-L20	J-Hook Cable Support
NWSLC-2Y	Identification Sleeve
S100X160YAJ	Identification Label

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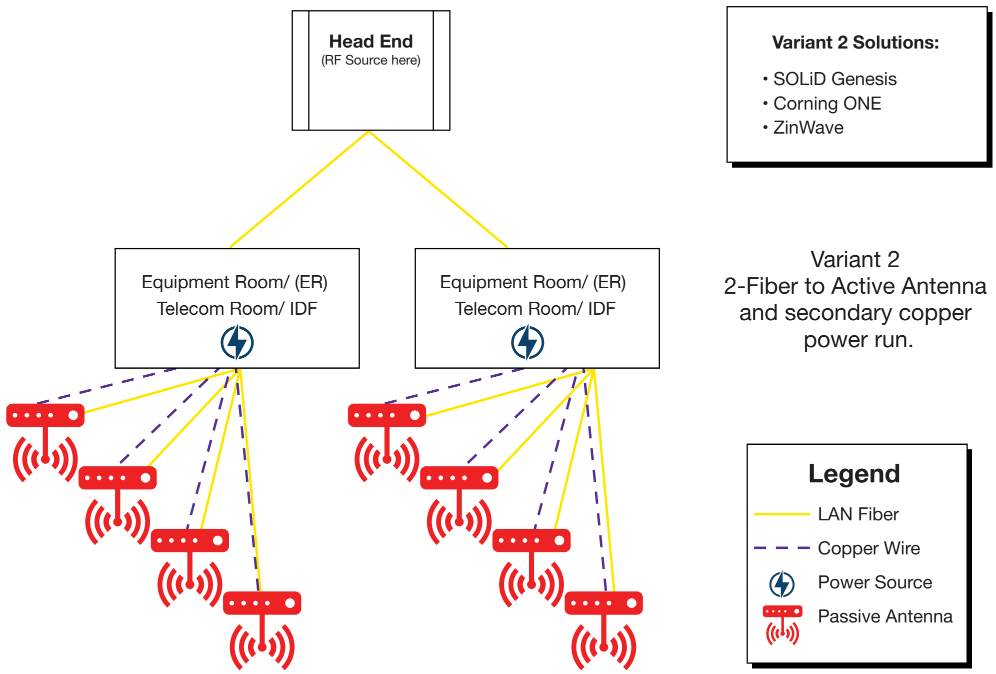
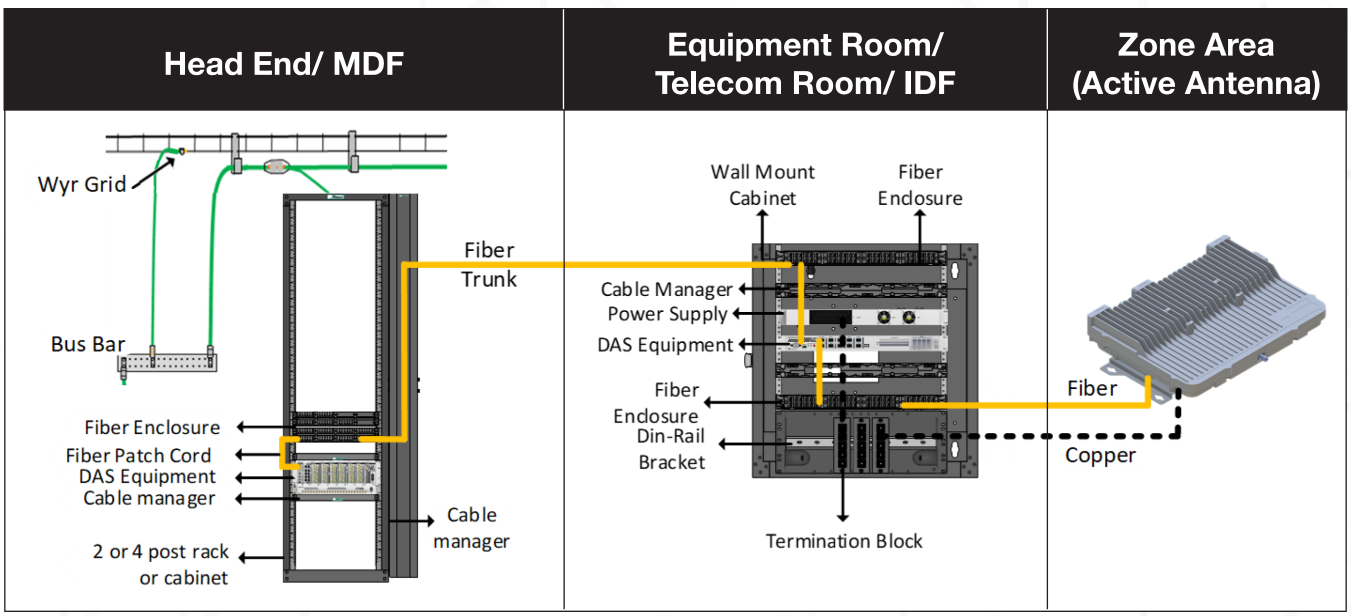
Active DAS Architecture Variant 2



Active Antenna is powered and includes Radio



	Head End Device	Media (Protocol)	Equipment Room Device	Media (Protocol)	End Device (Antenna)	Carrier Support
SOLiD Genesis	Distribution and Agg. Unit (DAU)	SM or OM Fiber	Hub Optical Unit (HOU)	SM or OM Fiber	Low Power Radio Node (LRM)	Multi-Carrier
Corning ONE	Head End Unit (HEU) & Optical Interface Unit (OIU)	SM Fiber (CPR)	Interconnect Unit (ICU)	SM Fiber	Remote Access Unit (RAU)	Multi-Carrier
Zinwave UNITIVITY	Primary HUB	SwM Fiber (CPR)	Secondary HUB	SM Fiber	Remote Unit	Multi-Carrier

A Panduit fusion-spliced connector is preferred, because it eliminates the need for cable spool trays. Hybrid fiber-copper cable can be very useful in this application for the connection from the ER to the Active Antenna.

The majority of DAS systems that address public safety typically leverage Variant 2 design.

Active DAS Architecture Variant 2 & Representative PanGen BOM

PanGen products supporting this architecture are shown below.

HEAD END ROOM	
R4P	Four Post Rack
WMPV45E	Dual Sided Vertical Cable Manager
WMPFSE	Single Sided Horizontal Cable Manager
RSHLF	Four Post Rack Shelf
FAP12WAGSCZ	Fiber Adapter Panel
FCE2U	Fiber Enclosure
FCE4U	Fiber Enclosure
FAPB	Blank Fiber Adapter Panel
DPFP1	Blank Filler Panel
FSCS2/9SOCA9AG	Fusion Splice Fiber Optic Connector
F923RSNSNSNM003	Fiber Optic Patch Cord
P12B01M	Basic PDU
P08E14M	Monitored Switched Rack PDU
GJ672UH	Equipment Bonding Jumper
GACBJ618U	Auxiliary Cable Bracket Jumper Kit

BETWEEN HEAD END ROOM AND EQUIPMENT ROOM	
F9TYL5E5EAAM050	OS1/OS2 Fiber Trunk Cable Assembly
AP00121PNU	Gen*SPEED* OS2 Fiber Indoor Distribution Cable

EQUIPMENT ROOM	
PZWMC12P	Wall Mount Cabinet
Z22C-S	Pre-Configured Network Zone System
F923RSNSNSNM003	Fiber Optic Patch Cord
FCE1U	Fiber Enclosure
FAP12WAGSCZ	Fiber Adapter Panel
FSCS2/9SOCA9AG	Fusion Splice Fiber Optic Connector
IABDIN4	Industrial Automation Bracket
GJ672UH	Equipment Bonding Jumper
GACBJ618U	Auxiliary Cable Bracket Jumper Kit

BETWEEN EQUIPMENT ROOM AND ACTIVE ANTENNA	
AP0061PNU	Gen*SPEED* OS2 Fiber Indoor Distribution Cable

ACTIVE ANTENNA	
FSCS2/9SOCA9AG	Fusion Splice Fiber Optic Connector
JP131SBC50-L20	J-Hook Cable Support
NWSLC-2Y	Identification Sleeve
S100X160YAJ	Identification Label

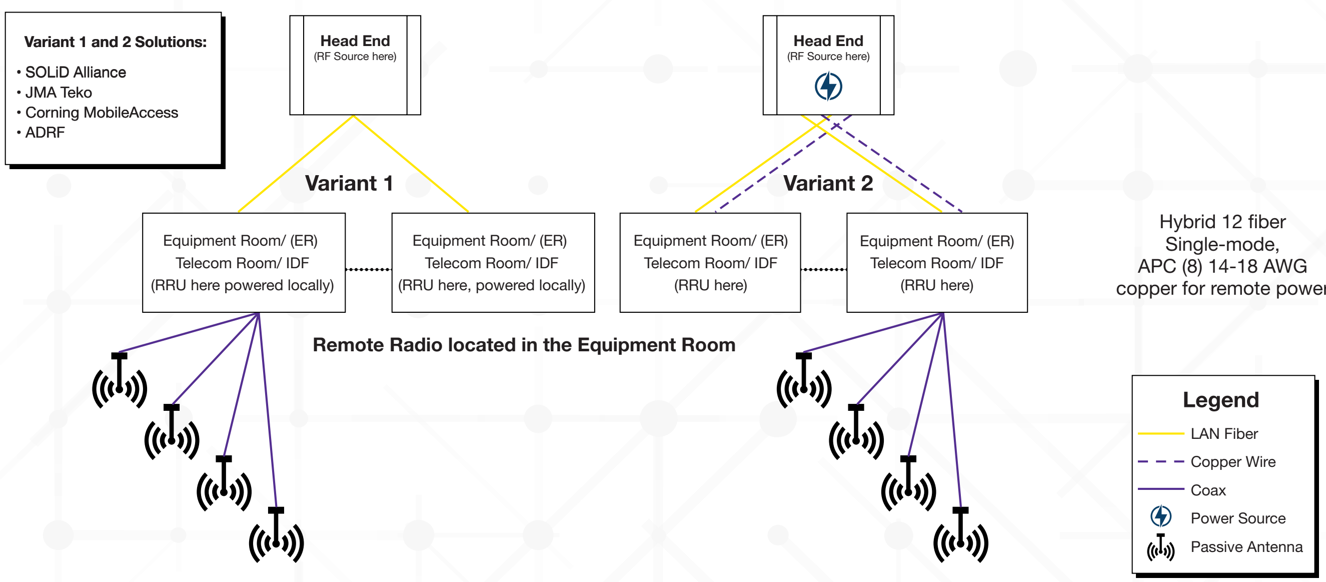
Hybrid Fiber/Coax DAS Architecture

An IBW Hybrid DAS system converts analog RF cellular information from the cellular signal source in the head end room to an analog or digital optical signal transmitted over fiber to the Remote Radio Units (RRUs) located in the ER. These remote radios convert the signal back to RF and distribute the signal through coax cables. A passive antenna is then used to transmit the RF signal inside the building.

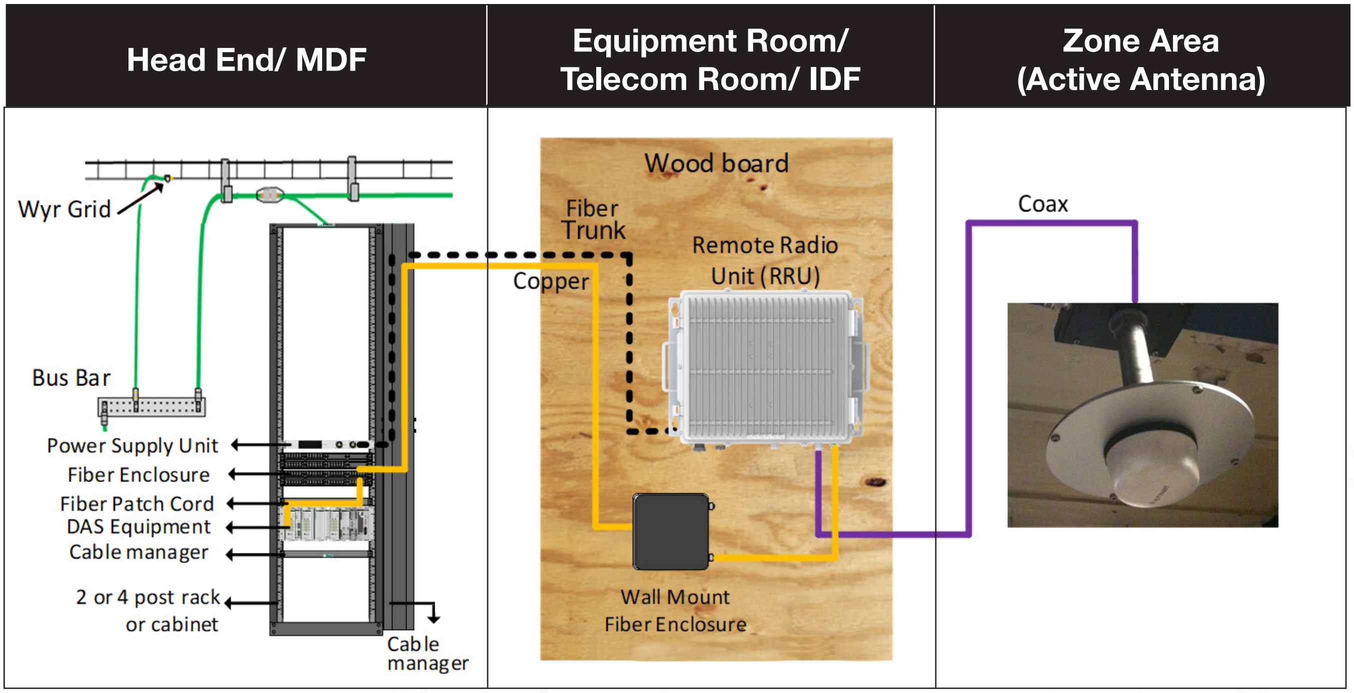
Power Distribution

In this architecture, the passive antennas do not require any power. However, the RRUs in the equipment room do require power. In **Variant 1**, the RRUs are powered locally at the ER. In **Variant 2**, the RRUs are powered through copper cables from the headend room, which is known as centralized power. The copper cables may run separately from the fiber running from the headend room, or they can be combined in one cable known as hybrid fiber copper cable or composite cable.

Note: The only distinction between Variant 1 and 2 solutions is how to power the RRUs. Variant 2 requires power to be supplied from the headend room, following a centralized power architecture. Hybrid fiber/copper cable is useful in this application.



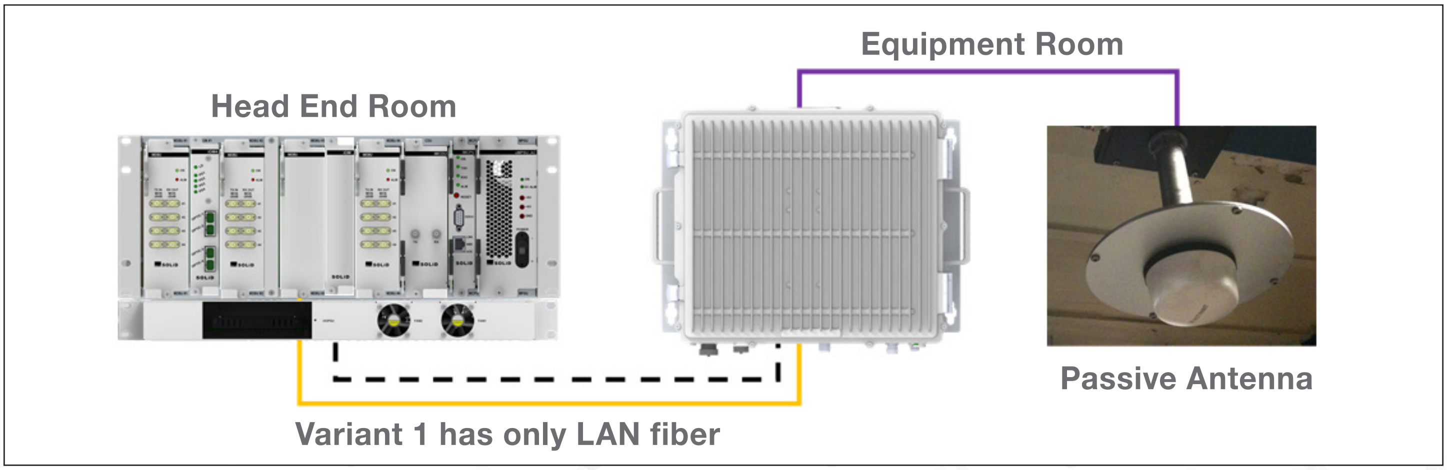
Hybrid Fiber/Coax DAS Architecture Variant 2

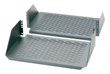
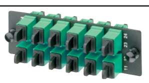
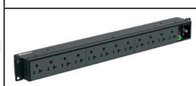


*Note: Variant 1 has only LAN fiber.

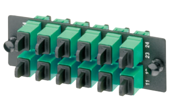
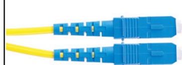
PanGen products supporting this architecture can be viewed on the next page.

Hybrid Fiber/Coax DAS Architecture & Representative PanGen BOM



HEAD END ROOM	
	**R2P** Two Post Rack
	WMPV45E Dual Sided Vertical Cable Manager
	**FCE4U** Fiber Enclosure
	**WMPFSE** Single Sided Horizontal Cable Manager
	**SRM19CMV3** Rack Mount Shelf
	**DPFP1** Blank Filler Panel
	**FAPB** Blank Fiber Adapter Panel
	**FAP12WAGSCZ** Fiber Adapter Panel
	**FSCS2/9SOCA9AG** Fusion Splice Fiber Optic Connector
	**P12B01M** Basic PDU
	**F923RSNSNSNM003** Fiber Optic Patch Cord
	**GJ672UH** Equipment Bonding Jumper
	**GACBJ618U** Auxiliary Cable Bracket Jumper Kit

BETWEEN HEAD END ROOM AND EQUIPMENT ROOM	
	**F9TYL5E5EAAM050** OS1/OS2 Fiber Trunk Cable Assembly

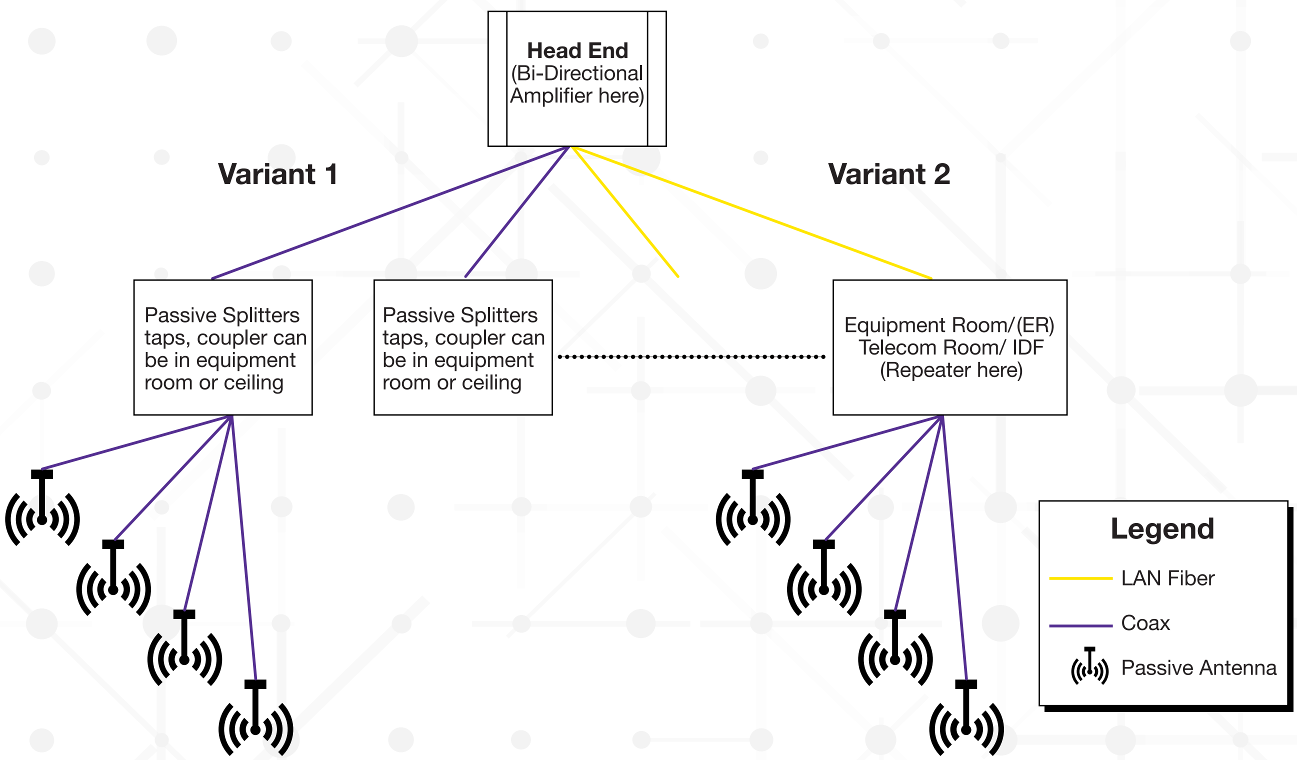
EQUIPMENT ROOM	
	**PZWMC12P** Wall Mount Cabinet
	**Z22C-S** Pre-Configured Network Zone System
	**FWME4** Fiber Enclosure
	**FAP12WAGSCZ** Fiber Adapter Panel
	**F923RSNSNSNM003** Fiber Optic Patch Cord
	**CDPP8RG** DIN Rail Mount Patch Panel
	**FSCS2/9SOCA9AG** Fusion Splice Fiber Optic Connector

PASSIVE ANTENNA	
	**R100X150V1T** Identification Label

Passive DAS Architecture

An IBW Passive DAS system amplifies an RF signal at the head end room and uses passive RF components to distribute the signal inside a building. The signal source for this architecture is typically an off-air antenna placed on the building roof that connects to a Bi-Directional Amplifier (BDA) that amplifies the signal before distribution. This architecture is commonly used for public safety deployments.

In Variant 1, all system components are passive RF components: coaxial cable, splitters, taps, and couplers to distribute signal inside a building. Due to length limitations on coaxial cable, Variant 2 may be used to extend the signal by passing it through fiber optic cable (e.g.: Single Mode OS1) to a repeater. The repeater then transmits the RF signal using passive components as in Variant 1.



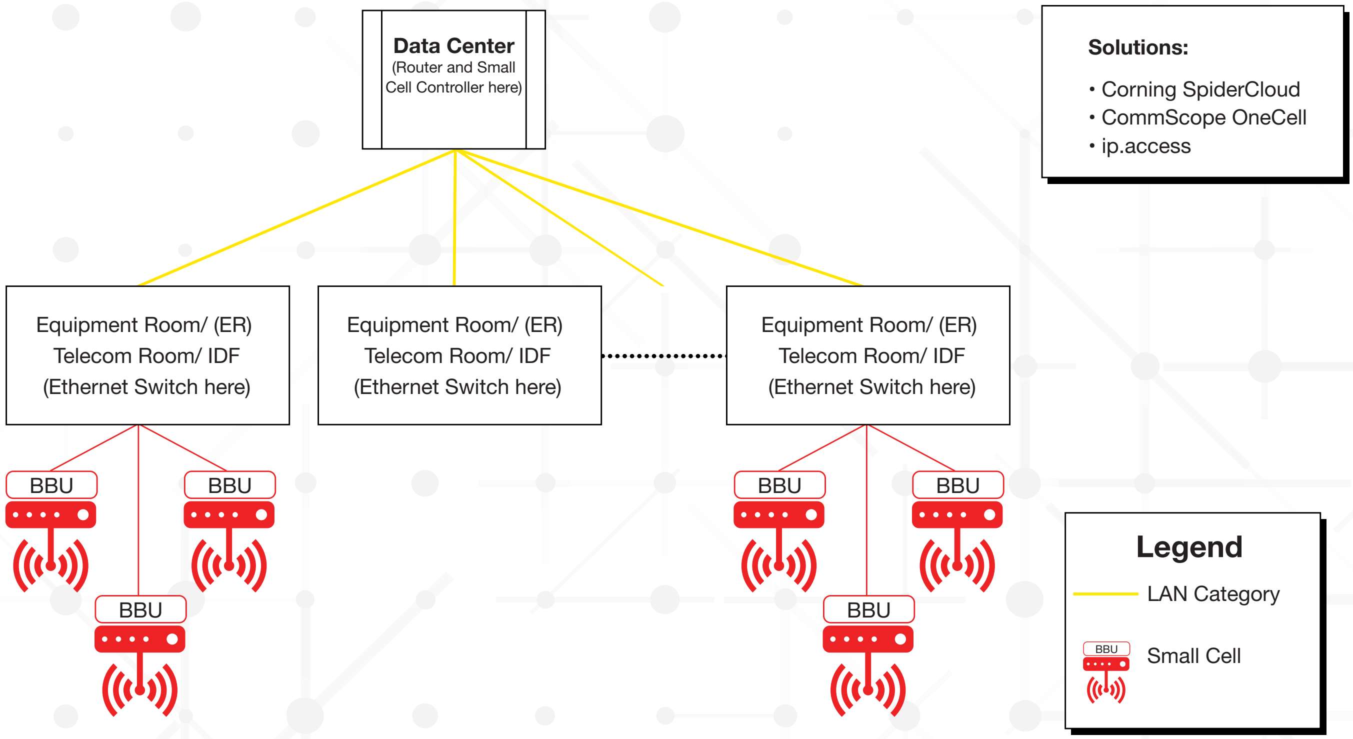
PanGen products supporting this architecture are limited. For a representative PanGen BOM, refer to the Hybrid Fiber/Coax DAS Architecture.

Small Cell Architecture

Small cell architecture looks very similar to a Wi-Fi network architecture. A router providing internet connects to a small cell controller which in turn connects to small cells using category cable. The small cell contains all three functions in one device: baseband unit, radio, and antenna. Ethernet switches can be used as aggregators between the controller and the small cells. The controller is a switch-like device that coordinates and optimizes the network of small cells.

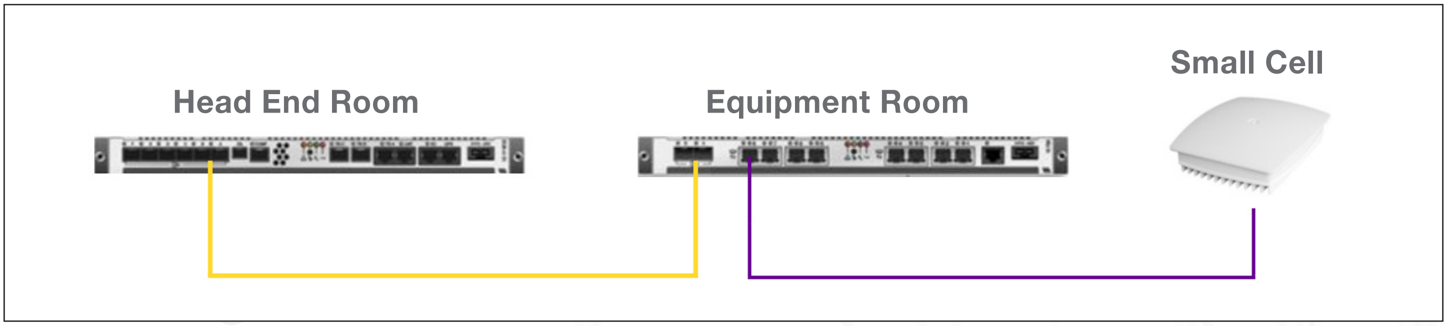
Existing ethernet-based infrastructure can be leveraged to deploy a small cell architecture, including PoE switches, patch panels, structured category cabling, etc.

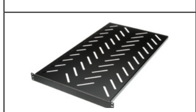
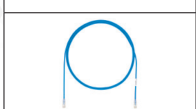
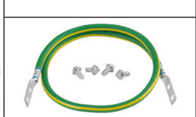
In this architecture, the small cells are powered through PoE.

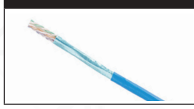


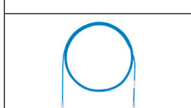
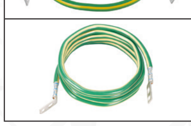
PanGen products supporting this architecture can be viewed on the next page.

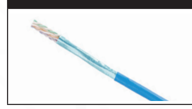
Small Cell Architecture & Representative PanGen BOM

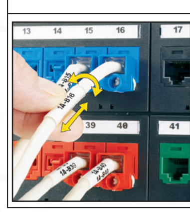


HEAD END ROOM	
	**R4P** Four Post Rack
	**WMPFSE** Single Sided Horizontal Cable Manager
	**RSHLF** Four Post Rack Shelf
	**CPP24FMWBLY** Modular Patch Panel
	**UTP28SP8INBU** Category 6 Patch Cord
	**CJ688TGBL** Category 6 Jack
	**P12B30M** Basic PDU
	**P08E18M** Monitored Switched Rack PDU
	**GACBJ618U** Auxiliary Cable Bracket Jumper Kit
	**GJ672UH** Equipment Bonding Jumper

BETWEEN HEAD END ROOM AND EQUIPMENT ROOM	
	**7141849** Gen*SPEED* 10 MTP Cat 6A Copper Cable

EQUIPMENT ROOM	
	**PZWMC12P** Wall Mount Cabinet
	**Z22C-S** Pre-Configured Network Zone System
	**CPP24FMWBLY** Modular Patch Panel
	**UTP28SP8INBU** Category 6 Patch Cord
	**CJ688TGBL** Category 6 Jack
	**P12B30M** Basic PDU
	**P08E18M** Monitored Switched Rack PDU
	**GACBJ618U** Auxiliary Cable Bracket Jumper Kit
	**GJ672UH** Equipment Bonding Jumper

BETWEEN EQUIPMENT ROOM AND SMALL CELL	
	**7141849** Gen*SPEED* 10 MTP Cat 6A Copper Cable

SMALL CELL	
	**FP6X88MTG** Field Terminable Plug
	**JP131SBC50-L20** J-Hook Cable Support
	**R100X150V1T** Identification Label

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