7.3 Wireless Configuration

7.3.1 Signal Source and Site Orientation

In planning the deployment of a DAS, the wireless designer should consider the technical aspects of the installation. These include the RF signal source and various site orientation considerations. The RF signal source should be placed where it will best reach the intended coverage area without interference from other RF signals present. Conducting RF measurements will identify existing signals and their frequency and strength.

7.3.1.1 Radio Frequency (RF) Measurements

7.3.1.1.1 Introduction

An on-site survey of the radio environment (site survey or RF audit) is necessary to the wireless designer and is especially important if the goal is augmentation of existing coverage. During a site survey, benchmarking is done to document the existing RF environment within the coverage objective, concurrently continuous wave (CW) testing is performed to characterize the propagation models used throughout the objective.

7.3.1.1.2 Benchmarking

The following items should be benchmarked:

- Macro network cellular signals
- Public safety frequency
- WLAN APs
- Television (TV) towers
- Radio towers/repeaters/paging systems
- Medical equipment (e.g., X ray, magnetic resonance imaging [MRI], computed tomography [CT], radio frequency identification [RFID])

7.3.1.1.3 Continuous Wave (CW) Testing

The propagation and path loss of radio signals in the target environment can be sampled using portable transmitters to provide continuous test signals. Signals can be measured using simple radio power meters or examined with more sophisticated receivers that demodulate and decode actual broadcasts and reveal more detailed characteristics specific to an air interface standard. The use of broadband spectrum analyzers makes it easier to detect and characterize spurious signals, intermodulation products, and noise sources.

If a site survey is feasible prior to design, the resulting information can help the wireless designer set expectations of RF propagation and path loss. If the goal of the design is to fill in where existing coverage is weak, a site survey is essential to define the boundaries of the problem. The site survey also allows the wireless designer to assess and quantify interference and noise sources.

Radio propagation simulation software often is used to design wireless networks in buildings, tunnels, and other structures. CW surveys can be used to tune the behavior of indoor RF propagation models, calibrate wall losses, and assess fading and other margins. Model calibration is the process by which a set of data is synthesized into a propagation model of the environment with the lowest possible standard deviation and zero mean. When the model built from a set of data collected in one location generates a zero mean and low standard deviation when examined against a data set collected in a different location but of the same morphology, the model is said to be validated. Nominal data collections confirming acceptability of the model under other circumstances is verification. However, pre-design site surveys often are not feasible because of financial or time constraints. Wireless designers can NOT rely on modern software tools to provide high-quality simulation results without site survey input.

7.3.1.2 Existing Structures

Once the RF measurements have been conducted, the wireless designer needs to identify how the DAS signals will behave when they are propagated in the existing structure. Testing is one method to determine how and where the antennas should be deployed.

If the models created cannot keep up with frequently changing morphological conditions as indicated by the standard deviations between measurements and predictions being greater than 8 dB, then it may be beneficial to test the antenna location for its ability to deliver the coverage intended. This type of testing can be performed only in existing structures. This testing consists of placing DAS transmitters in various sample locations that will be expected to serve intended coverage areas. Measurements then should be taken to determine the specific antenna or radiating cable location in the final design.

The primary means of planning a DAS is to employ indoor RF coverage modeling tools to estimate signal propagation. These tools are commercially available and aid in validating hypothetical designs. Modeling tools typically create three-dimensional simulations of planned structures and calculate various scenarios based on design consideration inputs in which simulated results can be achieved. The accuracy of the results varies depending on the inputs into the model, but results can precisely predict the expected coverage of a DAS.

7.3.1.3 Planned Structures

While testing RF propagation is feasible in an existing structure, it is not feasible in an incomplete structure. When only architectural drawings exist, different testing methods can and should be used. Similar to an existing structure, the wireless designer may employ indoor RF coverage modeling tools.

7.3.1.4 Post-Installation Verification

After a DAS has been installed, a final site survey for verification and validation is an important step for quality control. During the final site survey, the signal quality provided by the installed system is assessed and later compared with the anticipated signal quality of the design. A record drawing survey also provides a point of reference for future troubleshooting efforts.

7.3.2 Antenna

7.3.2.1 Antenna Selection

Antenna selection should be based on the type of radiation pattern, frequency, and signal strength needed to meet the coverage area requirements. The type of antenna may also be affected by the location where the antenna will be installed (e.g., roof-top, ceiling, along a wall, in a corner).

7.3.2.2 Environmental Conditions

As environmental factors, such as chandeliers, can generate passive intermodulation effects, antenna locations need to be free of such conditions. Radiation power, found in hospitals and some manufacturing facilities, will also impact the decision for discrete antennas or radiating cable. Chemicals or other substances (e.g., fuel, electrically initiated devices) in the DAS environment that may react from the presence of RF energy or ignite, from RF-induced arcs should be identified, with one or more mitigation strategies provided.

7.3.2.3 Location

The location of the antenna should be based on the area needing coverage, elevation, and away from structures that would block the RF signal. Perform a physical site inspection for line of sight (LoS) and possible rooftop space management issues. This includes optimizing space and lease revenue potential while minimizing conflicts because of zoning, installation and construction, and interference. Other location considerations include the aesthetics of the environment where the antennas will be installed and the location of the users they are intended to serve. Identifying traffic patterns of personnel who will use the DAS is vital to proper antenna location.

7.3.2.4 Safety

Applicable regulations (e.g., FCC 47 CFR 1.1310) and requirements of the AHJ shall be met.

For installers and building personnel, job duties often require being in close proximity to operational antennas. Safety needs to be considered, especially for rooftop antennas. The antennas must be located so as to minimize RF hazard risk to workers. One method is to paint a line on the roof around the antenna at a safe distance to create a buffer zone and place signage warning workers not to enter the zone without authorization.

Several countries have enacted guidelines or regulations providing limitations on the type and amount of wireless energy exposure for the occupants of specific buildings. The most notable building function where these limitations are present is within educational facilities, and designs should reflect the requirements and directives of local, state/provincial, and country AHJs.

7.3.2.5 Security

Security, theft, and vandalism concerns should be considered. Antenna, equipment, and cabling infrastructure should be installed at a secured height and location.

7.3.3 Power (Link) Budgets

The term *link budget* also is called *operating margin*. It refers to the sum of gains and losses in a DAS, beginning with the transmitter and continuing to the receiver, including transmission line loss and antenna gains. When performing a link budget calculation (See Equation 7-1), add the losses and gains to determine whether there is excess signal (operating margin).

$$\text{Link budget (operating margin)} = P_R = P_T - L_T + G_T - L_P + M_f + G_R - L_R \qquad (7\text{-}1)$$

Where:

P_R = Received power
P_T = Transmitter power output (same units as P_R)
L_T = Transmission line loss between transmitter and transmit antenna (dB)
G_T = Transmit antenna gain (dB)
L_P = Free space path loss between antennas (dB)
M_f = Morphology factor, which includes differences in the path loss decay between free space and the actual venue conditions
G_R = Receive antenna gain (dB)
L_R = Transmission line loss between receive antenna and receiver input (dB)

When considering the DAS operating margin for things like cellular transmissions, the path loss is an important concern and normally will be affected by the path the RF takes to reach the intended coverage area. This may include open areas that are unobstructed or areas that are densely populated with objects that may reflect, refract, or absorb the DAS signals.

To make a link budget calculation, the wireless designer must:

- Identify all of the equipment specifications and additional applicable losses (e.g., path loss, building losses).
- For downlink link budgets, determine what the power per carrier will be. This may depend on the equipment manufacturer's rated composite output power, 1 dB compression point of the amplifiers, optical path loss reduction to RF power, and coaxial cable losses.
- For uplink link budget calculations, calculate the noise figure depending on the system noise, which is based on the number of active elements in the system, cascaded noise figure, and antenna gain.
- Add the specifications and applicable losses together to determine whether the total value exceeds the minimum signal level required by the system.

7.3.4 RF Signal Conversion and Combining

Modern DAS equipment often distributes signals from multiple donor systems, including cellular/PCS signals from multiple WSPs, as well as WLAN and land mobile radio transmissions on the same physical network. Combiners, filters, and other devices are used to combine and separate the signals in a DAS and to minimize intermodulation effects and other negative consequences of mixing RF signals.

The DAS must use components designed to properly handle all of the signals being transmitted. Because component performance is often frequency specific, the design performance must be analyzed for each frequency. The antennas must be suitable for multiple frequency bands unless remote units separate the signals in the system. The radio path loss also is frequency specific, so the propagation portion of the design must consider each broadcast frequency to provide proper coverage for each wireless network using the DAS.

Some typical considerations for frequency conversion and combining are:

- Diplexing
  Combine the output of two transmitters into a single antenna system while achieving the desired signal strength and system performance. The objectives of diplexing are to:
  - Maintain proper transmission limits set by the manufacturer or regulatory body
  - Provide adequate bandwidth at each frequency that is diplexed
  - Control and minimize signal loss
- Duplexing
  Combine the forward and reverse signal paths onto a single cable
- Amplifier/repeater selection:
  - Frequency ranges
  - Power requirements
  - Band-pass filter performance

7.4 Project Coordination Factors

7.4.1 Host/Donor

The architecture selected for distributing the services within the facility must be matched to the performance specifications of the system participants. The DAS design process may include "co-engineering" efforts between the equipment manufacturer and the venue's solution designer to ensure optimal performance and guarantee host compatibility. In a host-neutral installation, multiple coordination efforts may be necessary, including a detailed review of each performance specification the DAS will support.

7.4.2 Cellular Service Providers

Because licensed spectrum cellular service providers are regulated by national and international agencies, systems that radiate into bands of licensed spectrum must do so only after receiving permission from the service providers who are gatekeepers for the spectrum they control. These entities have coordination departments that act as liaisons for the connection of private DAS equipment to the public cellular network.

The wireless designer should consider this requirement and identify those responsible for ensuring that the appropriate approvals have been secured. Approval from the service providers normally is based on a value proposition that evaluates their investment, the subscribers in need of service, and the impact on network statistical performance. Even when service provider investment is not required, the quality of the system deployed must still meet the performance objectives to be accepted as part of the network.

Under favorable circumstances, WSPs will often provide the installation of the infrastructure from the remote units to the headend and from the headend to the cell site or RF source locations. However, coordination between the wireless designer or DAS installer and the participating service providers will be required in all cases. If providing service from multiple service providers, each service provider will likely require separate RF source feeds to the DAS. Once service is provided to the headend equipment, traffic from all service providers will run concurrently over the DAS.

7.4.3 Antenna Coordination

Donor antenna placements on the roof level are considered structural and may impact numerous factors relating to roof stability. Typical areas affected are as follows:

- Wind loading and seismic structural performance
- FCC required painting or lighting because of elevated structures
- Penetrations required for coaxial transmission cables and antenna structure installation
- Grounding and surge arrest/protection system requirements
- Roof membrane warranties as a result of riser penetration
- Structural mounting attachment method used
- Antenna and RF coupling device placement, including physical mounting method
- Collocation impacts with other RF-based transceiver equipment (e.g., land mobile radio, RF repeaters, WAPs, other RF devices)

It is important that the DAS designer knows which of the items above is applicable to the design and each must be coordinated with the appropriate authority prior to installation.

7.4.4 Coordination with Site Owner(s)

Coordination with the site owner is a fundamental requirement for all DASs. The site owner coordination will be specific to the real estate involved in the DAS design. The primary items to be discussed with, and agreed to by, the owner are:

- Identification of a secure space for the DAS backend equipment installation
- Whether and where a rooftop donor antenna is installed; whether and where the membrane will be penetrated for cables and antenna supports
- Existing and surrounding RF sources and their location
- Owner requirements for the DAS (e.g., radio systems for supporting site security and maintenance personnel)
- Existing cable pathways
- Potential new pathways
- Requirements and sources for power, grounding, air conditioning, fire protection
- Owner policies and procedures concerning personal safety, access to secure areas, contractor work permits, contractor work hours, noise mitigation requirements
- Staging area location and secure storage of contractor tools, equipment, and materials
- Aesthetic requirements (e.g., low visibility antennas, color coordination)
- Exclusion zone
- Intrusion plan

7.5 Security

Security is a broad subject that needs to be considered and included in all phases of a DAS project including:

- Planning
- Design
- Installation
- Operation

The overarching goal of a security system is to avoid loss of assets, loss of data integrity, and loss of uptime of a DAS. The planning, design, installation, and operation of a DAS should be developed in accordance with the overall security plan of the building.

In addition to the requirements and recommendations found in this standard, standards such as ANSI/TIA-5017 provide other measures that can be taken to improve the physical network security of telecommunications cabling infrastructure.

The traffic that rides on the DAS usually has a wide variety of logical security requirements, ranging from essentially none to life-safety critical. Each application using the DAS should include the appropriate security functions within its operation.

7.6 Software and Management Systems

7.6.1 Overview

System management software is used to view and adjust settings on various DAS components via a direct connection, local network connection, or remotely. In most cases, the system management software resides on a particular piece of DAS equipment, usually a headend component. In some cases, the system management software will reside on an external computer such as a laptop.

7.6.2 Requirements

A DAS must be configured properly in order to ensure that it is operating in accordance with the WSP's frequency and power specifications. The DAS must also be configured so that it is providing coverage for the areas specified in the design. In a passive DAS, this configuration is accomplished by physically installing various signal and power conditioning devices. In an active DAS, the configuration is accomplished using system management software.

7.6.3 Connections

7.6.3.1 Introductions

Connections to the DAS for system and component configuration can be made several ways. The most common is a physical connection using a jumper (serial cable or patch cord). In this method, the technician will use a jumper to connect an external computer's communications port to the designated communications port on the DAS. Once connected to the DAS, a technician can then configure the DAS settings per the design requirements and then download and save the settings for the DAS.

7.6.4 Remote Access Configuration

If the DAS is SNMP capable, connections to the DAS can be made remotely through a local area network or via the Internet. SNMP capability provides several benefits when managing and maintaining a DAS. When dealing with a large DAS, SNMP allows for a central point for configuration, thus eliminating the need to travel back and forth between multiple buildings or long distances to configure each component. Also, if the DAS goes into an alarm state, the SNMP feature can allow for remote access for diagnosing potential issues. This could reduce the number of costly site visits associated with issues that could be handled remotely.

7.6.4.1 Requirements

For remote access, the DAS shall be SNMP capable.

7.6.4.2 Recommendations

Security measures should be taken whenever a DAS has remote network access capabilities. Anyone accessing the system should be prompted for an identification credential. When the credential is validated, the person accessing then has the ability to make changes to the DAS components.

7.7 Emergency Calls and Services Communications

7.7.1 General Requirements

Where a DAS is used to support emergency service communications, the DAS shall meet the requirements of applicable codes, standards (e.g., NFPA 72, 1221, *IFC*) and the AHJ. For jurisdictions where requirements are not present, DAS systems shall meet the requirements of NFPA 1221 or the IFC for the following items:

- Signal strength and coverage area
- Pathway survivability and cabling properties
- Lighting protection
- Mounting and isolation of donor antenna, if present
- Backup battery types and duration
- System monitoring
- Cabinets and enclosures for equipment and battery backup

Within jurisdictions utilizing FirstNet, DASs supporting FirstNet shall meet the requirements for both the contracted WSP and as an emergency services communication system. Where requirements are in conflict, the stricter of the two shall be met unless otherwise stated by the AHJ.

7.7.2 Emergency Call Location

7.7.2.1 Introduction

Position determination for emergency caller/public safety is more problematic indoors than outdoors. Indoor emergency calls often cannot be located accurately because GPS satellite signals may be blocked in urban canyons; and GPS satellite signals do not penetrate many building structures. Additionally, indoor distributed antenna systems and repeaters may degrade position accuracy.

7.7.2.2 Requirements

Some jurisdictions, such as those overseen by the FCC of the United States, have established a series of escalating requirements, such as:

- Commercial mobile radio system (CMRS) providers would be required to provide horizontal location (x- and y-axis) information within 50 m (150 ft) of the caller for 67 percent of 911 calls placed from indoor environments within two years of the effective date of adoption of rules and for 80 percent of indoor calls within five years.
- CMRS providers would be required to provide vertical location (z-axis) information within 3 m (10 ft) of the caller for 67 percent of indoor 911 calls within three years of the adoption of rules and for 80 percent of calls within five years.
- As is the case with existing emergency response (e.g., E911) location rules, CMRS providers would be required to meet these indoor requirements at either the county or PSAP geographic level.
- The maximum time period allowed for a CMRS provider to generate a location fix would be 30-seconds.

Designs shall meet current requirements as established by the AHJ for emergency call location.

7.7.2.3 Additional Information

Standard practice forbids the use of measurements from BTS signals that go through fiber (not line of sight and the velocity is only 0.6 times the speed of light).

Operational paradigm forbids measurements from BTS signals that are ambiguous because of simulcasting.

Geometric techniques, such as signal strength measurements, are compromised because of the inability of tools to model small or oddly shaped DAS coverage footprints.

Currently, there are only two communication protocols that have been used with techniques for enhanced location accuracy. Several possible approaches are under consideration with LTE, but no one approach has emerged a winner and evaluations continue.

GSM service providers use uplink measurements of cell phone transmissions to determine caller position solutions. Uplink Time Difference of Arrival (U-TDOA) is the standard technique; cell phone signals are measured at the BTS. Location measurement units (LMUs) measure the relative uplink signal delays.

CDMA service providers use downlink measurements of base stations and GPS satellite transmissions to determine caller solutions. Assisted GPS (A-GPS) is part of the emergency caller solution.

Advanced Forward Link Trilateration (AFLT) is the terrestrial technique; BTS signal delays are measured at the cell phone and compared with pilot signals in CDMA carriers.

One approach to address the above issues in DAS environments is to program the system to provide specific location information, including building address and floor level information, for the origination of the indoor call. As cell sizes shrink, the location of the serving cell (or antenna) itself may suffice for a position estimate for both E911 call routing and first responder dispatch.

The problem with obtaining better accuracy of a cell caller's location while using an in-building DAS is the added time delays inherent within DAS-deployed solutions. Unfortunately, this leaves venues vulnerable to large position errors in the places likely to be in need of assistance.

Among the compounding issues that influence the location accuracy in a DAS are repeaters and the DAS environment. Repeated signals are delayed by several microseconds, distorting measurements by thousands of feet. Base transceiver station (BTS) signals used for positioning require much lower signal-to-noise ratio than those needed for communication; therefore, some non-repeated signals are heard, which can result in a pathologic condition—some signals are delayed; others are not.

7.8 Passive Optical Networks

7.8.1 Overview

A passive optical network (PON), or passive optical LAN, implements a point-to-multipoint architecture (i.e., tree topology), in which an unpowered optical splitter is used to enable a single optical fiber to serve multiple end-points. A PON consists of an optical line terminal (OLT) at the core of the network (connecting to the core switch), passive optical infrastructure (fiber optic cabling and optical splitters), and optical network terminals (ONTs), located near the area to be served. An ONT will typically have from one to 24 Ethernet ports, and will be locally powered by a low voltage power brick or remotely powered from a power injector. It can be wall, desk-top or rack mounted.

The cabling infrastructure used for PON allows much greater distance from the OLT location to the ONT (up to 20 km).

A PON can be used to transmit either analog or digital signals from the source or headend to a media converter or ONT near the antennas. With the use of passive elements and longer transmission distances of a PON, it is possible to serve large service areas, indoors, outdoors or a mixture from a central location with minimal equipment being placed within telecommunication rooms or enclosures.

7.8.2 Requirements

Cabling infrastructure used for PON shall follow all applicable requirements of Sections 6.6, 6.7, 6.10 and 6.11. Verify with the AHJ concerning suitability of a PON for fire-life-safety communications.

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8 Implementation

8.1 Overview

The implementation of the DAS infrastructure is critical to its long-term reliability. Once designed by a qualified DAS designer, it is important that an experienced contractor team install the system and that only qualified radio technicians connect, tune, and commission the RF portions of the equipment. Poorly adjusted equipment can cause interference, both within this system and to other systems. Such interference is illegal and can result in the client being fined and the DAS equipment being shut down.

8.2 DAS Personnel

8.2.1 Overview

Proper design coordination of the DAS installation requires extensive amounts of multi-disciplined engineering efforts because of the numerous site-based physical structural, surrounding environment, electrical, and owner/vendor entity considerations that are impacted by the implementation.

8.2.2 Division of Design and Installation Task Responsibilities

The DAS designer is responsible for the design of the system. This requires identifying which services will be supported by the DAS and the areas to be covered. The designer should create construction documents the installer will use to build the system. The designer's construction documents typically identify the location of the headend equipment, signal sources, and donor antennas. It should also include a layout of the DAS cabling infrastructure, which shows the interconnection requirements between the headend equipment and remotes as well as the locations and types of antennas required to provide coverage throughout the areas requiring coverage. The DAS designer may also provide coordination, guidance, and assistance between host and owner for contractual requirements between the host and owner entities.

The DAS installer may install the structured cabling system, which typically includes an optical fiber or balanced twisted-pair backbone and the antennas with their respective cabling (coaxial, balanced twisted-pair, or optical fiber). In addition, the DAS installer may provide the active DAS components such as the headend equipment and remotes. However, the primary responsibility of the DAS installer is to install the system components, both passive and active, according to the design and then configure, optimize, and commission the system. Once the system has been commissioned, the installer will complete the installation by performing walk testing to verify the system is providing coverage at the proper signal levels as specified by the designer.

8.2.3 Designer Qualifications

DAS designers require some key skill sets, some in common with designers of other ICT systems and others unique to this design specialty. A DAS designer may also have project management responsibilities to adjust the design during the construction and implementation phases. Therefore, a wide variety of experience and skills are required.

The basis for these skills is an understanding of radio frequency propagation and the related physics behind it as well as a knowledge of the active and passive parts from which a designer draws to craft solutions to a customer's need. In general, there is the ability and experience to use the tools of the trade, (e.g., spectrum analyzer, cable tester, testing and modeling software) as well as the ability to read, understand, and address the information that these tools make available to the designer.

DAS systems that supported regulated communications will also require the designer to possess all applicable licenses and system certifications.

NOTE: An example of a commonly required license within the United States is the FCC General Radiotelephone Operator License (GROL).

8.2.3.1 Required Skills

- Strong knowledge of wireless theories and principles
- Strong knowledge of cabling infrastructure design
- 5+ years of experience in RF design or system performance, specifically with DAS experience
- Familiar with the different host system types (e.g., LTE, GSM, CDMA, land mobile radio) and their requirements
- Excellent oral and written communication skills

List continues on the next page

- Ability to use basic office applications, such as word processing, spreadsheets, and email
- Capable of reading planimetric and elevation architectural drawings from simple space plans to complete building mechanicals
- Strong knowledge of general structure construction materials and methods
- Project management skills to ensure deliverables are met on time
- Proficiency in using and understanding the MasterFormat system of specification organization
- Ability to help conduct integration testing and acceptance testing on new systems
- Familiar with environment simulation tools (e.g., ibWave Design, Atoll, etc.), their limitations, and how to validate and verify their utility

8.2.3.2 Preferred Skills

- RCDD certification
- Ability to use software CAD and BIM tools
- Good interpersonal skills

8.2.4 Installer and Service Personnel Qualifications

Installer and service personnel, being the hands-on people actually assembling the solution and calibrating the system under the guidance of a qualified integrator, have a somewhat easier path to proficiency than the designer. The difficulty and complexity in the selection and location of the appropriate components has, in theory, already been determined prior to their involvement. Their skills are consistent with that of other mechanics in other fields—a basic capability to work with their hands and tools. Their specific role does have the unique characteristics consistent with that of some other trades in that there can be direct performance impact on their systems based on the quality and consistency with which they exercise their trade.

8.2.4.1 Required

- Proficient with wireless theories and principles
- Strong knowledge of basic electrical and electronic principles
- Trained and certified by the DAS equipment manufacturer or working under the close supervision of a more senior technician with a valid manufacturer certification
- Ability to install, terminate, and test all types of cable (e.g., optical fiber, balanced twisted-pair, coaxial) used by a DAS
- Ability to install DAS antenna components, donor antennas, coverage antennas, couplers, splitters
- Thorough understanding of all safety requirements, including RF exposure, use of personal protective equipment, and above ground risk mitigation (e.g., climbing ladders, working on roof-tops)
- Able to safely use power tools
- Ability to read and understand all documentation, including CAD and BIM-produced drawings
- Strong analytic and troubleshooting skills

8.2.4.2 Preferred

- BICSI® certified installer or technician
- Working knowledge of various types of RF test equipment, including an RF power meter and a spectrum analyzer
- Good oral communication skills
- Good interpersonal skills

8.3 Design and Implementation Coordination

8.3.1 Overview

DAS designers, project managers and installers will interface with the customers and A/E firms regarding the overall distributed antenna system (DAS) project plan. The initial meetings with the customer will involve coordinating the scope of work (SOW), organizational breakdown structure (OBS), work breakdown structure (WBS), safety plan, quality plan, scheduling plan, budget plan, and communication plan. The designer will work with the owner and the A/E firms from the beginning and make recommendations on design improvements, construction technology, schedules, and budget as the project moves forward.

It is to be stressed that the best time to install a DAS is during the construction of a building. Installing a DAS after construction has been completed is typically more expensive, labor intensive, and disruptive to business operations than if the installation is performed while the walls and ceilings are unfinished.

8.3.2 Plan Documentation

8.3.2.1 Scope of Work

A scope of work (SOW) is based on the project requirements and design documentation such as a request for quote (RFQ), design drawings, customer specifications, or needs analysis. A good SOW provides a detailed summary of the requirements for the project and is a useful tool for tracking changes to the project scope. The SOW can also be used as a checklist to confirm completion of the project with the client and will assist in getting final acceptance for the system.

A good SOW contains the following elements:

- Customer needs
- Project objective
- Project size
- Project budget
- Project schedule
- Assumptions
- Deliverables
- Reference to design documentation

8.3.2.2 Organizational Breakdown Structure (OBS)

The organizational breakdown structure identifies the people and organizations needed to complete the SOW and describes their roles in the project's work breakdown structure (WBS).

8.3.2.3 Work Breakdown Structure (WBS)

A WBS is a categorized depiction of the work that must be accomplished to complete the project. The WBS must cover the elements of the project's end product or deliverables; they can be diagrammed as a tree structure or an outline and must list all required tasks in sufficient detail to ensure satisfactory project completion. The WBS should include:

- Initiating
- Planning
- Executing
- Monitoring and controlling
- Closing