



NPSTC

National Public Safety Telecommunications Council

Best Practices for In-Building Communications

National Public Safety
Telecommunications Council (NPSTC)
In-Building Working Group

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November 12, 2007

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Acknowledgement: The Chair would like to acknowledge the significant contributions to this report from Jack Daniel, President, Jack Daniel Company; Ken Monro, President, Dekolink Americas and his team; and Anand Iyer, President of the In-Building Wireless Alliance (IBWA) and his team. Additional contributions were made by Chris Baker, Roseville, California Fire Department; Sam Greif, Fort Worth, Texas Fire Department; David Holmburg, National Institute of Standards and Technology (NIST); John Horst, New York City Police Department; Kevin Kearns, iXP Corporation; Jerry Napolitano, Motorola, Inc.; and Jim Tidwell, International Code Council.

1 Executive Summary and Background

The need for reliable communications does not stop at the door of a building. Increasingly, public safety entities, commercial wireless service providers, and wireless users require reliable communications inside buildings and, where applicable, inside tunnels. For public safety, reliable coverage is often essential throughout a broad jurisdiction, including coverage on-street, in-building, and in-tunnels. In such cases, there is no substitute for a properly designed dedicated mission-critical communications system with sufficient transmit sites to provide the level of signal required for reliable coverage anywhere within the jurisdiction, whether on-street or indoors.

However, where other limitations, e.g., lack of spectrum or inadequate funding prevent the deployment of such ubiquitous coverage throughout a jurisdiction, there are ways to supplement the outdoor coverage in specific buildings with a variety of “in-building” coverage solutions. These include bi-directional amplifiers (BDAs), off-air repeaters, PicoCell/Microcells, fiber-based Distributed Antenna Systems (DAS), or temporary deployable communications systems at a specific incident scene. Also, coverage deep in a subway tunnel may require the use of bi-directional amplifiers and specialized antenna systems such as “leaky coax,” regardless of the level of signal above ground. Deployment of solutions for reliable in-building or in-tunnel coverage must consider the spectrum environment, building or tunnel parameters, and the users’ operational needs. This paper covers the basics of in-building systems, techniques to minimize the risk of interference, and engineering best practices to provide robust in-building coverage.

Some jurisdictions have enacted ordinances to help ensure that construction of commercial buildings includes provisions for radio coverage of public safety signals within the building as a condition of occupancy and some of the methods noted above are usually allowed to meet these ordinances. In addition, initiatives are underway to develop and implement nationwide model codes that address public safety in-building communications. Sample local ordinances and the overall elements of national level codes under discussion are addressed herein.

The increasing business and consumer demand for wireless service also requires that commercial wireless systems increasingly provide in-building coverage. In-building systems boost both the signal to be received by a wireless device and the transmit signal from that device. To minimize interference, these systems must be properly designed and properly installed. A wide range of in-building systems are on the market, from high-quality units to low-cost consumer grade units with little if any filtering. In addition, installation practices vary, especially between knowledgeable and expert companies and consumers who often have minimal knowledge of proper installation and interference mitigation techniques.

This environment has led to the following trends:

- In-building deployments for public safety have grown in number and continue to do so.
- Commercial building owners/managers and commercial wireless service providers are also increasing their focus on the value propositions of in-building coverage for both commercial and public safety.
- Some local governments are addressing in-building coverage for certain types of buildings. While there are common elements across various ordinances adopted, there is not yet a common set of parameters invoked nationwide.
- Efforts are underway to develop and implement national level model codes for public safety in-building communications.

- The growing requirement to meet local codes regarding public safety communications as well as the need to serve customers on commercial systems are converging to increase interest in “neutral host” systems aimed at addressing both applications as one option to consider.
- Reports of interference from “rogue” (uncoordinated/unapproved) deployments have been relatively few in number but are cause for great concern to all mobile network operators and public safety entities, as they can be devastating when they do occur.

These trends have led to the need to examine the various in-building solution options, address interference concerns, define best-practices for the design and implementation of in-building systems, and develop recommended regulatory actions. The NPSTC In-Building Working Group has undertaken this initiative and the paper herein provides the preliminary results of this examination. The In-Building Wireless Alliance (IBWA), an organization which is evaluating the benefits of in-building wireless services for both commercial and public safety needs, has also been instrumental in partnering and coordinating with the NPSTC In-Building Working Group.

2 Attaining In-Building Coverage

There are three primary approaches to achieving in-building coverage: 1) Increasing the signal level through deployment of additional antenna sites within the jurisdiction; 2) Supplementing coverage in a specific building with a permanent system that boosts the signal level received from and transmitted to the outside; and 3) Using deployable systems which can boost coverage in a building for a specific incident scene on a temporary basis. There are tradeoffs across each of these approaches and it is likely that a combination of all three will be used in any given jurisdiction.

2.1 Increasing Signal through Deployment of Additional Antenna Sites

There is no substitute for a properly designed dedicated mission-critical communications system with sufficient transmit sites to provide the level of signal required for reliable coverage anywhere within the jurisdiction, whether on-street or indoors. With the exception of sub ground level floors, a properly designed and funded system can provide in-building coverage across multiple buildings within a jurisdiction for which it is designed. However lack of spectrum, inadequate funding, and/or the inability to approve sufficient transmitter sites can prevent the deployment of such ubiquitous coverage throughout a jurisdiction. Also, there is simply no 100 percent foolproof radio system. In a majority of urban environments even the best radios and radio networks cannot always penetrate high-rise buildings, subway tunnels, and other difficult subterranean environments. Coverage on underground floors or deep in a subway tunnel may require the use of other options regardless of the signal level available above ground.

2.2 Supplementing Coverage in Specific Buildings

The focus on in-building communications has spurred the use of “in-building” coverage solutions. These solutions include bi-directional amplifiers (BDAs), off-air repeaters, PicoCell/Microcells or fiber-based Distributed Antenna Systems (DAS), which are permanently installed and supplement coverage in a specific building. Such systems are particularly useful to provide day-to-day coverage in an underground parking garage or a subway tunnel where public safety entities need to communicate. The primary tradeoff of such systems is that they must be installed in each building where coverage is needed. As discussed more fully in this paper, these in-building systems also must be properly designed and installed to avoid interfering with other communications systems.

The following diagram provides a depiction of a very simple in-building system:

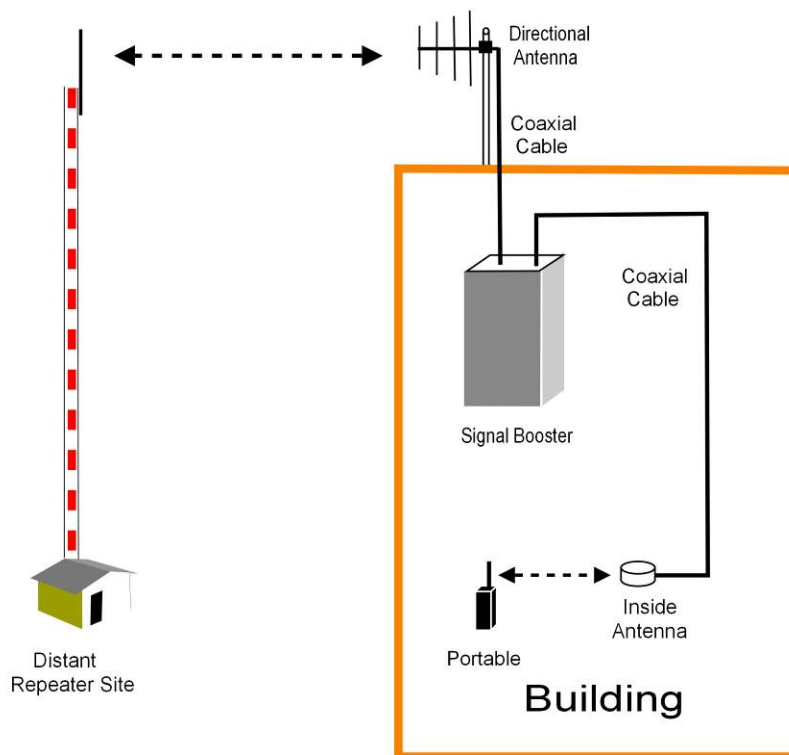


Figure 1 Simple In-Building System

2.3 Using Deployable Communications Systems

Many large urban fire departments do not rely solely on fixed repeater networks or tactical simplex channels for direct unit-to-unit use communications among each other at a fire scene. Supplementing these approaches with deployable systems provides increased reliability when land mobile portables are used in high-rise buildings or subterranean environments where coverage is challenging to maintain. Deployable solutions that normally consist of the land mobile portables familiar to firefighters through day-to-day use, along with high-powered transportable radios are designed to fit in a specially designed hard-shell case light enough to be carried by fire personnel arriving at a scene. Such transportable systems normally have a self-contained power source and can be used at any assigned post within a high-rise building or underground location.

Building and tunnel fires can damage the critical components of a communications network such as antenna lines and power lines. Lightweight deployable systems have the advantage of not relying on any pre-set infrastructure. This minimizes the concern about infrastructure that may have been damaged at the incident scene or may not have been properly maintained by a third party since a previous incident. During an emergency, crews can move these deployable repeaters to the scene of an incident to provide a dynamic communications solution for public safety personnel. The incident commander could also utilize mobile repeaters to support communications at the site and to link up with the rest of the network, providing a communications path to an operations center. Such deployable systems give agencies the potential to improve radio coverage in any location on short notice and can also serve as a useful backup when other systems have been damaged.

3 Ordinances and Codes for In-Building Communications

3.1 Local Ordinances and Codes

A number of jurisdictions have enacted or are considering enactment of local ordinances and codes which require a requisite level of public safety communications reliability in building as a condition for occupancy. The specifics of these ordinances and codes vary, but most include:

- A minimum signal strength limit;
- Application of the limit over a specified percentage of each floor;
- A specific level of reliability;
- A specified frequency band or bands for public safety coverage;
- Testing requirements and procedures;
- Provisions for penalties; and
- Provisions for waivers of the requirements.

Sample of Local Ordinances and Codes re In-Building Communications for Public Safety:

Local Jurisdiction	Ordinance Reference	Key Provisions
Boston, MA	<ul style="list-style-type: none"> - Fire Dept. In-Building Radio Spec. - 5/21/01 	<ul style="list-style-type: none"> • Min signal -95 dBm, 95% of each floor • UHF band
Broward County, FL	<ul style="list-style-type: none"> - Ord. 99-22 - 5/25/99 	<ul style="list-style-type: none"> • No interference to public safety comm. • Add'l facilities at no cost to county
Burbank, CA	<ul style="list-style-type: none"> - Ord. 3265, Sec 7-616.1 - Effective 9/21/91 	<ul style="list-style-type: none"> • Min signal -107 dBm, 85% of each floor • 90% reliability factor • UHF band
Folsom, CA	<ul style="list-style-type: none"> - City Code - Chapter 14.18 	<ul style="list-style-type: none"> • Min signal -95 dBm, 90% of each floor • 100% reliability factor • 800 MHz band • 12 hour battery backup
Grapevine, TX	<ul style="list-style-type: none"> - Ord. No. 109.2 	<ul style="list-style-type: none"> • Min signal -107 dBm, 95 % of each floor • 800 MHz band • Adjacent band filtering • 8 hour battery backup
Roseville, CA		<ul style="list-style-type: none"> • Min signal -95 dBm, 90% of each floor • 100% reliability factor • 800 MHz band • Adjacent band filtering • 12 hour battery backup
St. Petersburg, FL	<ul style="list-style-type: none"> - Draft under development 	<ul style="list-style-type: none"> • Min signal level -100 dBm 95 % of each floor; -95 dBm in stairwells & below grade

Local Jurisdiction	Ordinance Reference	Key Provisions
		<ul style="list-style-type: none"> • 90% reliability • 800 MHz now • 700 MHz band by 1/2/2012 • 12 hour battery backup
Scottsdale, AZ	- Section E, 810-90	<ul style="list-style-type: none"> • Min signal level -107 dBm, 85% of each floor • 90% reliability factor • 800 MHz and VHF bands • 2 hour battery backup
Tempe, AZ	<ul style="list-style-type: none"> - Ord. 2001.25 - Chapter 9 - Section 9-21 to 9-32 - 9/13/01 	<ul style="list-style-type: none"> • Min signal level -107 dBm analog; -93 dBm digital, 85% each floor • 8 hour battery backup

More recent local ordinances have acknowledged and included provisions for 800 MHz rebanding system capabilities, 700 MHz expansion capacity, use of factory-certified suppliers, and remote alarms and control of active devices such as signal boosters.

3.2 National Model Code Initiatives

The growing acceptance of and need for in-building wireless communications has recently spurred initiatives to develop national model codes by such authorities as the National Fire Protection Association (NFPA) and the International Code Council (ICC). The NFPA and the ICC already have an established process and record of developing codes used by various jurisdictions. Codes issued by these groups include the National Fire Code, National Electrical Code, International Fire Code, and International Building Code. Almost every city and county in the United States subscribes and complies with one or more of these codes.

The NFPA and ICC are in the process of developing national level model codes focused on in-building public safety communications. There is still much work to be done and the first issuance of such a national level code is expected in 2009. NPSTC endorses the concept of these overall national level model code initiatives as they are beneficial to public safety. The result of these national level model code initiatives will help enable every jurisdiction to implement in-building wireless requirements without developing a new local code for each jurisdiction. National level model codes should also lead to standardization of the quality of equipment and to additional qualified in-building system engineers and installers. Because these NFPA and ICC code initiatives are designed to be technology neutral, they will also encourage continued innovation by the communications industry that also will benefit public safety users.

The NFPA and ICC national level model in-building code development is being driven primarily by fire jurisdictions. However, the initiatives are expanded to involve all public safety, including law enforcement and emergency medical services. The NFPA and ICC initiatives are separate but complementary. While the precise provisions of the draft codes vary between the two code development groups, key specifications involve significant commonality across the two initiatives. In addition, all the features of existing local codes are permissible under the new draft national level code framework. Each jurisdiction can “customize” the national level model code to meet any unique local requirements such as frequencies, donor levels, maximum acceptable delay, documentation, etc.

Key elements under discussion in the national level in-building code initiatives include the following:

- Equipment flexibility – No specific technology is favored or endorsed. Technical specifications do restrict the use of problematic consumer grade signal boosters for public safety installations that meet code.
- Environmental specifications – The draft code specifies splash tight NEMA-rated cabinets to prevent equipment failure resulting from wash-downs during a fire event.
- Minimum indoor coverage signal levels – Building owners will be given the choice of using wireless instead of wired fire communications in most situations. Using wireless may reduce costs to the building owner. Coverage is classified in “critical” and non-critical areas and different percentages of coverage are required. Additional details regarding coverage are under development.
- Redundancy and Reliability – 12 hour battery back up would be required as part of the code. In addition, the draft code requires supervised alarms for signal booster fault, AC Failure, DC Charger Failure, and Low DC battery conditions. These alarms are required on every signal booster, amplifier, battery charger, etc. regardless of how many devices may be installed in the structure. Note “supervised” in fire terminology means the alarm connecting circuits must be monitored for opens or shorts continuously. In one version of the draft code, the alarms will be wired to a fire type wireless alarm annunciator panel in the fire control room. The wireless alarm panel may or may not be connected to the central fire annunciator panel. Note that the wireless alarm panels must be powered by the 12 hour battery back up. Typically the central fire annunciator panel has much less back-up time.
- Interference to the public safety wireless system by other wireless devices in the structure is prohibited and must be corrected immediately upon detection. This code especially applies to shared commercial/public safety RF distribution systems which, if not properly designed, may distribute signals that interfere or degrade the public safety system performance.
- No public safety amplifiers, signal boosters, etc. may be installed without agency approval. This provides an opportunity to qualify the equipment quality. Also, the jurisdiction must approve any revision or change in an existing wireless distribution system and the results must be retested for continued code compliance.
- Building owners are informed that frequency changes may be dictated by changes in FCC rules, acquisition of additional bands or channels, etc. 800 MHz rebanding is specifically cited as a known process that involves frequency changes in the public safety community.
- A standardized methodology of testing coverage, interference, and antenna isolation is included, leading to more accurate and repeatable performance testing.
- All new systems must be compatible with both analog and digital modulations.
- FCC equipment certifications and compliance to all applicable FCC rules is required.
- Personnel must be certified for in-building wireless communications by a nationally recognized training organization or manufacturer.
- Maintenance response time is cited.

NPSTC believes these new standards and model codes will further the objectives of public safety to have reliable communications wherever first responders operate and therefore

supports these national level code initiatives. These nationwide model codes should have benefits for building owners and managers as well. First and foremost, owners and managers will have the benefit of providing a safer environment for their tenants and first responders. In turn, this may also help reduce any losses if a building incident does occur and moderate insurance rates. In addition, having a national level code that provides a common framework across all jurisdictions should help provide improved efficiencies in both the building design and permit process.

4 The Value Proposition of In-Building Wireless

A significant amount of work has been done by the In-Building Wireless Alliance (IBWA) to address the value proposition of in-building wireless for the commercial real estate management community. This is relevant to public safety because commercial real estate recognition of the benefits of in-building wireless may also lead to a cooperative environment that assists public safety attain in-building coverage as well. Therefore, it is important to understand motivations and benefits the commercial real estate community attaches to in-building wireless, even though the specific frequencies for public safety mission-critical use and commercial services are distinct.

The following are some of the key benefits that can be attained for building owners and operators:

- Operational efficiency
- Ability to respond quickly to tenant calls
- Improved tenant safety and security (e.g., wireless coverage in parking garage and stairwells)
- Improved mechanism to track and record service calls in real time
- Wireless sensors for building equipment
- Reduced cost of installs and cabling
- Reduced energy costs by monitoring and controlling energy usage
- Marketing differentiation of an “information-enabled building”

The reduction in energy costs by monitoring and controlling energy usage is very significant, especially as government and industry take steps to implement environmentally responsible “green” buildings which reduce energy usage. A June 2007 IBWA presentation at Realcomm in Boston indicated that operation of commercial buildings account for 70 percent of the electricity consumption in the U.S., and that with improved monitoring and control could provide a 30 percent savings in that consumption.

Tenants of these building, i.e., the primary customers of the building owners and operators, also can see the following benefits from in-building wireless:

- Productivity gains
- A mobile workforce enabled to be responsive to their customers
- Seamless mobility and coverage from car to office
- Single phone number for business use
- Decreased cost of cabling

The IBWA is currently conducting a pilot building test of the benefits of in-building wireless at a commercial office building in Washington, D.C., and preliminary results already indicate the value of in-building wireless to the building operator and its tenants.

For public safety, in-building communications can help save the life of a firefighter, police officer, emergency medical responder, or the public they all serve, a value which cannot adequately be quantified in terms of dollars. The IBWA, which also includes a public safety working group, assisted NPSTC with 1) a 2006 survey for public safety to determine the priorities among various in-building wireless uses, and 2) a subsequent draft matrix summarizing a "Public Safety Scorecard" which indicates a number of ways in which in-building communications can assist public safety and the public. Some of these benefits are obvious today and others provide a future perspective. This Public Safety Scorecard is still being finalized based on input from the public safety community and should be available at a future date.

The survey of priorities targeted to public safety entities, in which some NPSTC members participated, revealed the following results. From a public safety perspective, it showed that voice communications is the highest priority and already has the highest capability in place. The survey showed that wideband or broadband data, still images, and video are viewed as a somewhat lower priority than voice but that these are areas with the largest gap in current capabilities. Therefore, such advanced features are more likely to be desirable if basic voice needs are already met.

NPSTC believes that this gap could be closed in major urban areas as a new nationwide system supporting broadband data, still images, and video is implemented in the 700 MHz band. The rules have been finalized for use of the 700 MHz spectrum and the nationwide broadband system. These rules call for a hybrid broadband system serving both public safety and commercial entities. The system is to be deployed in a combination of public safety and commercial 700 MHz spectrum segments. The system will be developed under a public/private partnership between a nationwide Public Safety Broadband Licensee (PSBL) and the auction winner of the adjacent D block 700 MHz band spectrum. The system requirements will be negotiated between the PSBL and the D block auction winner. Closing the gap on in-building coverage for data, imaging, and video of course will require the system specification to call for the coverage and data rates necessary to do so.

The Federal Communications Commission (FCC) rules require that the Network Sharing Agreement and system parameters be finalized by the PSBL and the D block winner within 6 months of the auction close. The 700 MHz auction is scheduled to begin on January 24, 2008, and is expected to take up to several weeks to conduct. Therefore, the Network Sharing Agreement and system requirements should be finalized by the August/September 2008 timeframe. As in other bands, system coverage may need to be supplemented on a specific building-by-building basis by the use of 700 MHz bi-directional amplifiers, distributed antenna systems, and temporary deployable systems at incident scenes, etc.

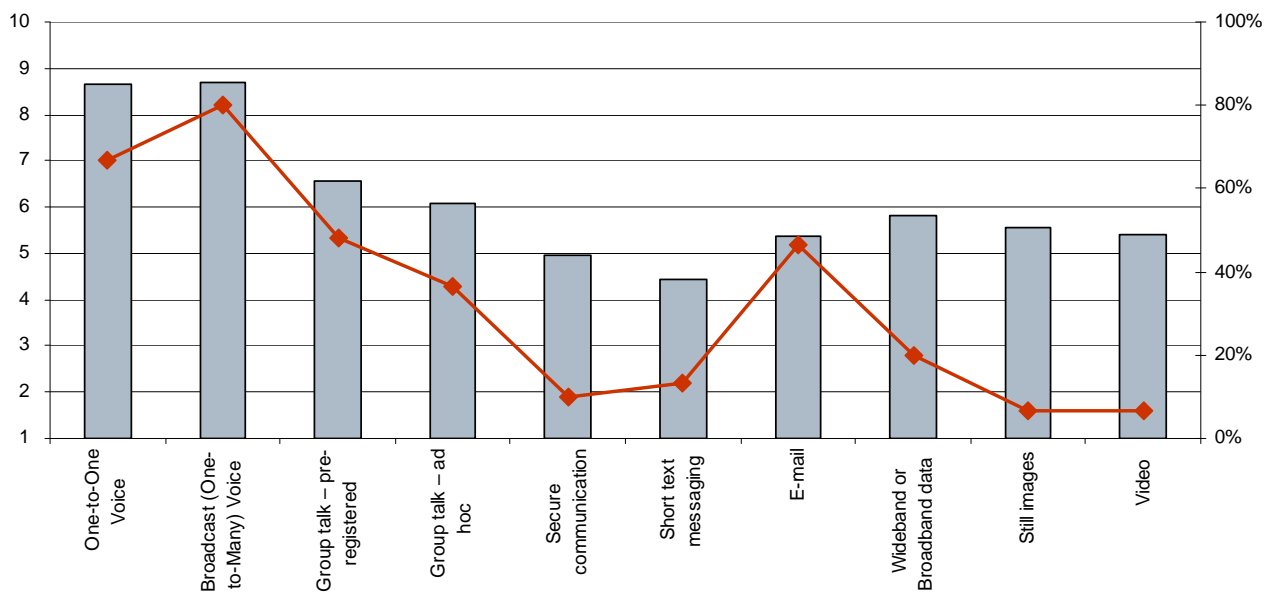


Figure 2 Bar graph shows level of importance per respondents; Red line shows percent respondents who already have this capability

Another area that has significant interest, especially from the fire community, is in-building location services. While GPS location is prevalent outdoors, GPS signals emanate from a satellite and are generally of insufficient signal strength to penetrate into buildings on a reliable basis. Furthermore, GPS provides location in the horizontal plane, but not the vertical plane, i.e., it would not show the floor where a firefighter is located. Therefore, some additional means are needed to help locate firefighters in a building. The IBWA conducted a preliminary review of various technologies for in-building location as summarized in the attached chart. The chart shows there are tradeoffs among the various location technologies. Overall, no in-building location technology has yet emerged that fully meets public safety expectations and needs. However, as various in-building location technologies mature, performance improvements should be possible. There may also be some synergies with technology development expected to occur as a result of increased requirements for E911.

Technology	Description	Precision	Strengths	Challenges
Infrared	Infrared sensors placed throughout a building can be used to detect a person wearing a device	Few meters	<ul style="list-style-type: none"> • Low cost 	<ul style="list-style-type: none"> • Requires visual line of sight to function • Not very accurate • Cannot work if the device is in a pocket
Ultrasound	Beacons send signals to a receiver allowing the device to calculate its location based on proximity	~1 foot	<ul style="list-style-type: none"> • Can achieve high accuracy to the point of determining target orientation 	
Basic RF	Target transmits low power RF signal which is detected by receivers strategically placed around the building	2-3 meters	<ul style="list-style-type: none"> • Does not require line of sight to function 	<ul style="list-style-type: none"> • Signal strengths at higher frequencies are very sensitive to conditions (e.g. people, furniture) • Resolution may be limited
WiFi	Determine which users are being served by a particular base station	~50 meters	<ul style="list-style-type: none"> • Can be a low-cost solution 	<ul style="list-style-type: none"> • Weak resolution
Bluetooth	Very short range RF standard	1-3 meters	<ul style="list-style-type: none"> • Increasing popularity of the standard 	<ul style="list-style-type: none"> • Requires target to be within very short range

At a recent major in-building conference focused primarily on building owners, the National Institute of Standards and Technology (NIST) and others discussed a potential for on-scene building automation systems monitoring by fire agencies. This would provide an incident commander with wireless access to HVAC, security, power, and other data upon arriving at a commercial building location.

The NPSTC In-Building Working Group notes that one means of such access might be through the use of broadband 4.9 GHz systems that are tied into the building automation systems. Relatively small unobtrusive 4.9 GHz access points could be placed on the outside of the building so that public safety personnel, both fire and police, could access building information as they arrive at an incident scene. The 4.9 GHz band is limited to public safety use and with proper authentication techniques could provide public safety responders a secure link over which to access information from inside the building, including video from security cameras, location of elevators, temperatures at various locations, etc. Such information could be very useful in a fire or hostage situation, as well as some terrorist event or other disaster. As of November, 2007, over 1,200 public safety agencies in the U.S. have obtained 4.9 GHz licenses.

Hospital wireless systems providers are also interested in the possibility of adding patient monitoring, hospital administration and security to an in-building RF distribution system. The specific design of the system would need to be matched to the hospital requirements.

As noted above, the IBWA, under its own Public Safety Working Group is in the process of developing a "Public Safety Scorecard" for public safety in-building wireless use. The purpose of the scorecard is to address benefits and the value proposition of in-building wireless for public safety in a number of operational areas and, where possible, propose the use of quantitative data to assess improvements in operations from in-building wireless services. These areas include department education/training, preparedness, situational awareness, response time, cost per incident, lives saved/lives lost, and customer productivity lost due to an incident.

5 Interference Concerns and Regulation

There have been some instances of interference from in-building deployment of bi-directional amplifiers (BDAs), although the number of known interference cases is relatively low compared to the estimated 20,000 BDA deployments. The Jack Daniel Company previously distributed a survey to help gain insight to the degree and types of interference being experienced. The survey, which was not scientific, was targeted primarily to public safety and private radio systems. The survey questions are contained in Appendix A in the Addendum to this paper. The results of the survey to date are:

- The Jack Daniel Company estimates that the survey was viewed by approximately 1,500 to 2,000 such entities.
- A total of 57 responses have been received as of October 17, 2006.
- Fifty-four of the respondents reported they had experienced some interference.
- Twelve of the 57 responses relate to different events reported by the same person, a cellular service provider technician.
- Forty-seven of the 54 responses (87 percent) indicated that "oscillating" BDAs were the cause of the interference.
- Only 6 percent of the responses indicated that noise was the cause of the interference.
- All of the respondents reporting interference said Internet sales to consumers should be stopped.

- All of the respondents reporting interference expressed the opinion that voluntary BDA registration was unworkable.
- Sixteen respondents said BDA installations should be licensed; 10 said they were undecided.

The low number of initial responses to the survey makes any solid conclusions speculative at this time. Note that instructions for the surveys sent early in the process requested a response only if interference had been experienced. Based on the low number of responses, NPSTC believes that a large percentage of the universe exposed to the survey either (1) had no interference, (2) did not know they had interference, or (3) did not consider it severe enough to report. On the other hand, one respondent suggested some users were so frustrated by interference experienced that they did not think the survey would accomplish anything. With regard to Internet sales, some of those responding compete with Internet sales, which might skew the survey results.

Since the termination of the survey, several more cases of oscillation type interference have been reported, indicating this is a continuing and growing problem. In at least two cases, the FCC levied fines on the signal booster owners.

FCC RULES

The FCC rules address the deployment of BDAs. These rules rely primarily on the licensee to authorize and police any BDA use. Following are the rules from 47CFR, sections 90.7 and 90.219 that apply to public safety use of signal boosters:

Sec. 90.7 Definitions

Signal booster. A device at a fixed location which automatically receives, amplifies, and retransmits on a one-way or two-way basis, the signals received from base, fixed, mobile, and portable stations, with no change in frequency or authorized bandwidth. A signal booster may be either narrowband (Class A), in which case the booster amplifies only those discrete frequencies intended to be retransmitted, or broadband (Class B), in which case all signals within the passband of the signal booster filter are amplified.

Sec. 90.219 Use of signal boosters.

Licensees authorized to operate radio systems in the frequency bands above 150 MHz may employ signal boosters at fixed locations in accordance with the following criteria:

- a) The amplified signal is retransmitted only on the exact frequency(ies) of the originating base, fixed, mobile, or portable station(s). The booster will fill in only weak signal areas and cannot extend the system's normal signal coverage area.
- b) Class A narrowband signal boosters must be equipped with automatic gain control circuitry which will limit the total effective radiated power (ERP) of the unit to a maximum of 5 watts under all conditions. Class B broadband signal boosters are limited to 5 watts ERP for each authorized frequency that the booster is designed to amplify.
- c) Class A narrowband boosters must meet the out-of-band emission limits of Sec. 90.209 for each narrowband channel that the booster is designed to amplify. Class B broadband signal boosters must meet the emission limits of Sec. 90.209 for frequencies outside of the booster's design passband.

- d) Class B broadband signal boosters are permitted to be used only in confined or indoor areas such as buildings, tunnels, underground areas, etc., or in remote areas, i.e., areas where there is little or no risk of interference to other users.
- e) The licensee is given authority to operate signal boosters without separate authorization from the Commission. Certificated equipment must be employed and the licensee must ensure that all applicable rule requirements are met.
- f) Licensees employing either Class A narrowband or Class B broadband signal boosters as defined in Sec. 90.7 are responsible for correcting any harmful interference that the equipment may cause to other systems. Normal co-channel transmissions will not be considered as harmful interference. Licensees will be required to resolve interference problems pursuant to Sec. 90.173(b).

[61 FR 31052, June 19, 1996, as amended at 63 FR 36610, July 7, 1998

The potential for interference is not confined to public safety in-building systems. The interference from improperly installed or adjusted systems in the cellular industry has been reported by the CTIA-The Wireless Association (CTIA) to the FCC. The impact of oscillating signal boosters can have a devastating impact on cellular like infrastructure. Both the public safety and commercial wireless communities have a common interest in eliminating interference. The CTIA document, entitled "White Paper on the Harmful Impacts of Unauthorized Wireless Repeaters" dated May 1, 2006, is available from CTIA, 202-785-0081 or www.ctia.org.

Also, on November 2, 2007, CTIA filed a petition with the FCC asking the agency to prohibit the sale and use of cellular jammers and the unauthorized sale and use of wireless boosters and repeaters. Notably, public safety users in Florida have also experienced interference from the deployment of rogue BDAs onboard boats being used to boost commercial cellular signals.

In addition to oscillation and noise interference, there is the potential of interference in shared service systems due to frequency conflicts and minimal filtering. The most common example of this is the relationships between 800 MHz private systems and cellular channels. Cellular band A is adjacent to the current National Public Safety Planning Advisory Committee (NPSPAC) band and filtering is usually insufficient to prevent interaction. This is especially true with the more popular fiber optic fed cellular devices. Even after 800 MHz rebanding is completed, the new public safety downlinks may interfere with the cellular B band uplink channels. This is true of all future in-building systems. One solution is to implement parallel systems with separated antennas. A paper on this subject can be found at www.rfsolutions.com/nh-wp.pdf.

NPSTC believes any instances of interference have the potential to escalate into severe consequences to public safety. Such consequences could occur as a result of interference to commercial systems, as well as to dedicated public safety mission-critical systems, since the general public increasingly relies on commercial wireless systems to make 911 calls. Therefore, the severity and reach of the interference that does occur may be even more important than the number of cases occurring.

One such situation involved interference to a wireless carrier in the New York City Metro area. A customer of the carrier had incorrectly installed a BDA, causing the BDA to self oscillate, i.e., to act as a transmitter radiating an interfering signal back out to the receiver antenna located outside the building. This interfering signal impacted a large number of cell sites as shown in the following map in Figure 3. The wireless carrier and the BDA manufacturer worked diligently to resolve the problem. However, the user had to be tracked and located so power from the BDA could be removed. In addition to impacting the quality of service during this period of time, the resolution process consumed significant resources by the wireless carrier and the BDA

manufacturer that could have otherwise been better spent. This was a situation in which the BDA was well designed, but improperly installed by an end user with little technical knowledge and it underscores the need for proper deployment as well as design to minimize interference risks.

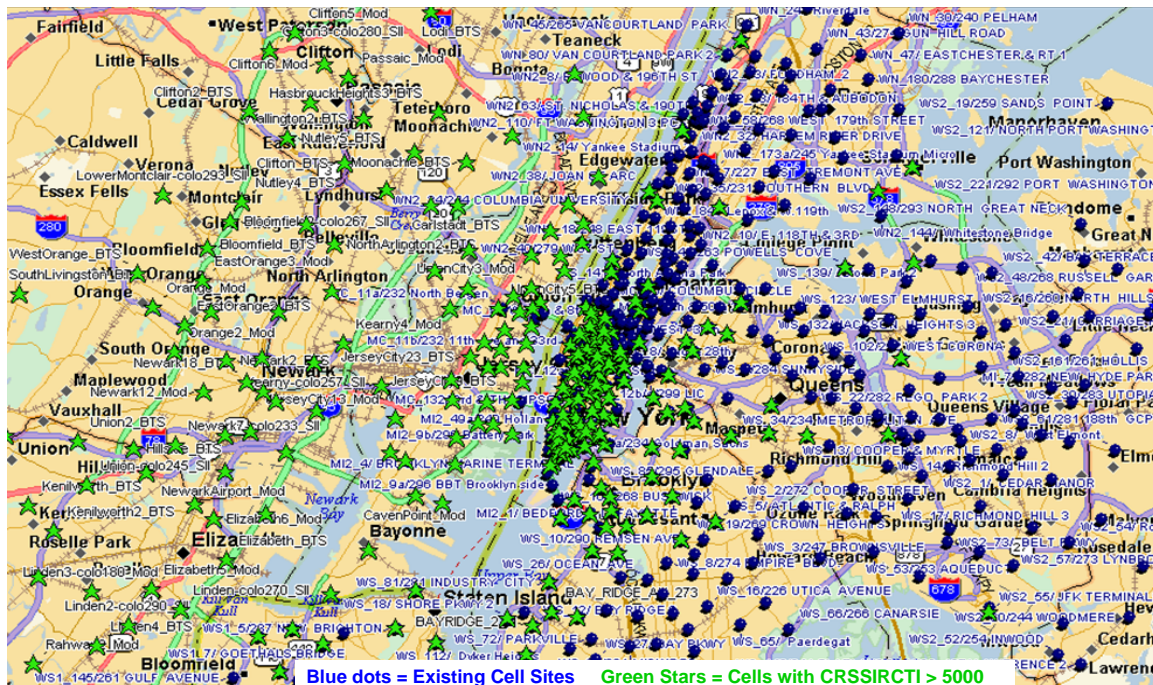


Figure 3 Effects of Interference from a Self-Oscillating BDA – Sample Case

6 Engineering an In-Building System

Deployment of solutions for reliable public safety in-building or in-tunnel coverage must consider the spectrum environment, building or tunnel parameters, and the users' operational needs. As with most systems for public safety, whether indoor or outdoor, reliable solutions require customization, high-quality products, good systems engineering, and proper installation and maintenance. Reliable public safety in-building systems are not a “cookie cutter” design with one size fits all. There are a number of options for solutions, each with their own tradeoffs and applications depending on the particular scenario involved.

NPSTC is fortunate to have the participation of industry experts in the development of this paper. Appendix B in the Addendum provides valuable information regarding the elements of in-building systems, as well as mechanisms to minimize interference and provide a reliable system. Appendix C in the Addendum covers the considerations, technology options, and tradeoffs that are part of a successful in-building design and implementation for robust coverage. We urge those involved in specifying and contracting for public safety in-building systems to take advantage of the wealth of information these two appendices provide.

In addition, public safety entities should consider the following generic requirements for successful deployments. These general requirements are technology neutral and relate primarily to the spectrum and building environment.

6.1 Site Survey

A site survey presents the opportunity for the designer/integrator to get a hands-on perspective of the facility. The primary goal is to identify a methodology to marry up a conceptual design with the realities of what is practical inside the facility.

Before starting a site walk, it is important to attempt to acquire “to-scale” floor plans in advance. While on the site survey, it is valuable to take the on-site information and correlate it to what the floor plans are illustrating. There are standard items to look for in any site walk. These include:

a) Donor Antenna Placement and Type

Several elements go into selecting the proper donor antenna placement and consequent mounting. The building manager/owner needs to be involved at this step because it needs to be determined where, if any, existing rooftop presentations are located. Ideally, the donor antenna will be in close proximity to limit the donor cable run and, consequently, its associated RF loss characteristics.

If an entry point can be identified, that will go a long way in getting the donor signal into the building. Existing penetrations should be utilized because every time you drill a hole in a roof for rack mounts or wiring you create the potential for leaks.

Flashing should encase roof penetrations and waterproof caulking should be used for smaller penetrations. Sometimes “sleds” or existing pipe fixtures can be utilized for antenna mounting. Mounts on the side of buildings are also possibilities.



Rubberized roofs present a unique challenge and the building owner will need to contact the contractor who installed the roof. This is done to either identify available penetrations for cabling use or to have the roofing contractor provide a quote to do the actual work in order to keep the roof under the terms of the warranty.

The building manager/owner will need to have a clear understanding of where the antenna should be and the pros/cons of having it in different locations. The customer may desire the donor antenna to be camouflaged or its footprint reduced (e.g., fewer elements in a yagi antenna).

Another factor to consider when choosing a location is identifying where the donor site is located. A clear line of sight to where the donor signal originates is mandatory. In urban environments, it is important to be cognizant of the noise floor differences between near street level mounts and roof tops of high rises.



Typically, the noise floor increases by a large magnitude at a higher vantage point. This may have an impact on where the donor antenna is located. Placement in close proximity to other antennas is also something that needs to be avoided so as not to create any unnecessary intermod products in the antenna’s near field propagations.

Particular care needs to be used when microwave dishes are in use on a given rooftop to avoid any unnecessary RF exposure. The use of a NARDA meter will go a long way in warning a person conducting a site walk of unseen RF dangers.

b) Cable Runs

After the outside surveying is complete, the next order of business is identifying a vertical chase that will get the cable runs from floor to floor. Once this has been identified, a network closet/IT room where the booster equipment can be parked must be located. Ideally, you would want the two elements; the vertical chase and the network closet/IT room to be as close to each other as possible – if not one and the same.



A walk through the facility should allow the DAS designer to begin to see potential cable runs in certain locations more so than others. Certain areas should jump out that would be better locations for internal antennas. These areas should be hallway juncture points and areas that are in need of strong coverage (e.g., manager's office, security office, etc.) consistently. This would mandate a dedicated internal antenna within close proximity.

Another item to look for is the method of transport for the cabling. Are there dedicated cable trays? Is conduit required? Does the local fire code mandate plenum ratings on the cable? If fiber is the method of delivering RF, is there any dark fiber available to use? If so, what type is it? Is the fiber of the single mode or multimode variety?

What do the ceilings look like? False ceilings? Hard lid ceilings? A mix? The amount of labor to get through different ceiling types will vary as will the time/cost. Ceiling types will have a huge impact on which antenna to use.

In some cases, the end customer may want the antennas out of view. Examples of what the antenna looks like should be presented to the customer for approval from a cosmetic perspective. How high are the ceilings? Will a hydraulic lift be required to gain access for antenna installation? These are items that need to be considered when doing the site walk.

An area where core drilling is required is an important cost/time consideration that can be identified during a thorough site survey. Firewall locations need to be identified as they require special prep work for penetrations and pulling cable from one side to the other.

c) Power of Systems

While examining the room where the booster will be installed, a survey of potential power sources should be identified. Will the outlet have power in case of a blackout? If not, it may mandate a dedicated UPS power back up module.

d) Wall Construction and Attenuation Factors

The building materials used in the construction of the building and walls should be scrutinized closely. What is the makeup of the walls? Drywall, sheetrock, cement blocks, brick? Is there any metal? In hospital environments, lead will be present in the walls near radiology units. What about insulation or ductwork? Metallic backing on certain types of insulation will strongly attenuate RF signals from propagating. Metal duct work will also have an impact on a RF signal.

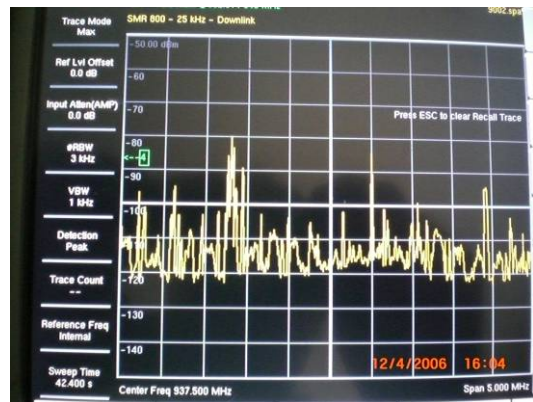
6.2 RF Survey and Spectral Analysis

For an RF survey, it is mandatory that the exact frequencies that need to be supported are obtained. The advantage of having that data allows the person who is conducting the survey to examine the ambient signal strength where the donor antenna will be located. A sweep on a spectrum analyzer may reveal potential interferers that the intended public safety frequencies that need to be supported are going up against.

Identifying the RF environment will allow the person conducting the survey to complete post-survey research to identify the owner (starting with matching the frequency with those in the FCC database) of those frequencies. The RF environment information also may lead to the selection of a particular system design to match that environment.

Taking various measurements on a rooftop may identify a stronger donor signal in one area as opposed to another. This could be due to shadowing or multipath environments in one location. An attempt to get the strongest signal with the most direct line of sight is the ultimate goal for a proper RF design.

The importance of obtaining the signal strength for the required carriers cannot be understated. This is the foundation upon which an RF link budget is built. While the frequencies that need to be supported are important, it is just as vital to identify the number of channels. The rationale being that the BDA/booster's resources will need to be shared across all the channels that pass through its input port. This translates into the power per channel (the true performance characteristic in comparison to composite power) equivalent to the composite power minus $10 \cdot \log(\# \text{ of channels})$.



If there are multiple donor sites available to choose from, the site with the clearest line of sight and strongest signal strength should prevail. Also, if separate signals from different donor sites are present – and they have different signal strengths, it may prove relevant to feed each into a separate BDA/booster to balance out the signals through gain/attenuation adjustments inside the BDA/booster. This will allow the signal for each donor site to have similar coverage patterns inside the facility.

Monitoring the integrity of the donor signal for a mild duration is also advisable. This may help to identify if the signal varies due to multi-path or fading situations. If possible, allowing the spectrum analyzer to sit and collect data over a reasonable amount of time will allow for more confidence in the acquired data.

Inside the facility, it may require a test setup of a signal generator at a defined frequency and power level while measuring that test signal at different points on the same floor and above and below it to get a better feel for how RF will penetrate through the various building materials. Drywall/sheetrock typically will have a 3 dB to 4 dB attenuation impact, while cement/brick can have attenuation characteristics of 10 to 14 dB and more.

6.3 Scope of Work Development

A detailed scope of work sets the correct expectations that both the building tenants and the entity providing the solution can agree on. These expectations must have a baseline performance to be measured against. This can be a rudimentary description of existing coverage or a more thorough grid testing pattern to verify existing signal strength and delivered

audio quality (DAQ) readings in defined intervals. This baseline testing can then provide a fair comparison for when the system is turned up.

Assumptions about what signal strength will be delivered to what percentage of the facility is notated here. An example would be a signal strength of at least -90 dBm or stronger through at least 95 percent of the facility. Other assumptions should include whether stairwells, restrooms, or elevators will or will not be covered as part of the scope of work. Any union labor, hydraulic lifts, asbestos hazards, conduit, 1st/2nd/3rd shift requirements, etc. should also be extensively detailed in this section.

A final component of a scope of work should be a matrix of responsibilities between what is expected of the building owner, the network operator, the vendor, and the contractor. An example may be who is responsible for materials on site. Will an area be designated to house these? Will it be secured? Items of this nature are typically covered here.

6.4 Engineering of Systems

The foundation of any system engineering is a RF link budget. This will account for all the gains and losses in a given system to give a reasonable expectation for what the coverage prediction should look like.

An elementary link budget will at the very least, account for the following terms:

$$\text{RxP} = \text{TxP} + \text{TxG} - \text{TxL} - \text{FSL} - \text{ML} + \text{RxG} - \text{RxL}$$

Where:

- RxP = received power (dBm)
- TxP = transmitter output power (dBm)
- TxG = transmitter antenna gain (dBi)
- TxL = transmitter losses (coax, connectors...) (dB)
- FSL = free space loss or path loss (dB)
- ML = miscellaneous losses (fading, body loss, polarization mismatch, other losses)
- RxG = receiver antenna gain (dBi)
- RxL = receiver losses (coax, connectors) (dB)

Once the link budget foundation is understood, the designer can implement a more comprehensive computer-based design tool. The advantages of a tool of this ilk are several. Essentially, it makes a link budget come alive to show the user what coverage should look like if the initial data was correctly input. The time tested saying of “garbage in, garbage out” is especially relevant.

A detailed bill of materials can also be generated with the entry of to scale floor plans. This allows ancillary part (cable runs, for example) ordering to be more precise. Special items to be considered in the engineering include an intermodulation analysis of existing frequencies to determine if harmful intermodulation products will be generated with the current RF environment.

Internal antenna placement is important also. It is important to treat the in-building situation as a macro environment. Coverage enhancements in the facility should not bleed out into the outside world. This means keeping internal antennas at least 50 feet away from windows so as to

eliminate the possibility of a regenerative feedback loop between service and donor antennas which ultimately can cause oscillations, spurious emissions, and cripple the macro network.

Ambient coverage environments in a high-rise building should also play a part in the engineering. Typically, coverage is present on upper floors but not so on the floors near street level. This assumption, along with the RF noise floor, needs to be taken into account. Understanding this information allows the designer to know how much power needs to be delivered to the antennas on various floors.

Donor antenna selection should also be determined at this time. Front-to-back ratios, gain, horizontal/vertical beam widths, and physical appearance should all be considered when selecting the correct antenna.

Isolation in a RF sense is very important. In all instances, the micro/in-building environment should be completely separate from the macro/outdoor coverage. It is widely accepted that 15 dB more than the gain of the booster/BDA is an adequate level of separation between the two systems. An example would be a 90 dB gain booster/BDA; the ideal isolation situation would be at least 15 dB more than or 105 dB of isolation.

In-building system design software is also available which will generate coverage patterns, equipment and antenna placement diagrams, materials lists, etc.

6.5 Acceptance Test Procedure (ATP) Development

The agency deploying the coverage solution should develop a mutually agreed upon ATP or Acceptance Test Plan between the vendors that will supply the system and users of the system to ensure that it will meet system performance specifications. There are two types of coverage measurements when evaluating in-building systems—the Signal Strength Test and Voice Quality Test. The Signal Strength Test is cost effective with downlink RSSI signal measurements, and the Voice Quality Test is a subjective performance test of Delivered Audio Quality or DAQ.

The ATP should be developed by both the deploying agency and the customer/user to verify RF coverage based on such measurements. The procedure provides an accurate, statistically valid, repeatable, objective, and cost-effective method to verify all customer/user coverage requirements are met. A definition of coverage by signal strength or DAQ figures, which define the audio quality of a wireless systems' performance, should be accomplished so that all parties involved understand the overall objective and so that proposals and systems designs are in line with this ultimate objective.

6.6 Testing Process

A reliable, accurate wireless test device such as a spectrum analyzer in conformance with industry standards should be defined as a baseline to measure coverage performance and produce repeatable measurement. The wireless test equipment should include one antenna that will be mounted on a handcart 3-4 feet in height to replicate the portable at the hip-level location. The GPS receiver will be disconnected.

Prior to taking signal strength measurements, each site must be audited to verify that the radio system is operating properly. The audits will verify the antenna configuration, the power into the antenna, the antenna installation, and the frequency of the test transmitter.

It is important to define in the ATP how the “customer” (agency buying the in-building solution) is going to test the performance of the system. Included is, of course, the decision of signal strength and/or DAQ but also type of test equipment used, settings on equipment, locations of

measurements within the building, and so on. This clear and comprehensive definition will make for fewer post-deployment problems.

First, proper design and installation of BDA systems requires a site survey/audit. A site survey and audit should identify the following parameters:

- Number of users in building
- Number of “foreign” networks, i.e., networks other than the one for which the BDA system is being installed
- Density of walls and ceilings
- Proximity of windows relative to the parent system donor site
- Existing signal strength in the building
- A floor plan with accurate building dimensions
- Complexity of the in-building environment

Once the site survey and audit is completed, design can be conducted. This includes:

- Spectrum analysis and coordination
- System design and engineering
- Installation and implementation
- Record and catalog site specifics

Coverage extension systems are also used in tunnels. A key element in the proper design and installation of tunnel systems is the “leaky coax,” normally used to help distribute the wireless signal. In some cases, in-tunnel systems have not performed as planned because existing leaky coax which had deteriorated over time was used as part of a “new” system. Agencies issuing Requests for Proposals (RFPs) for in-tunnel systems should seriously consider an evaluation of any existing leaky coax and replacement if necessary as part of the system implementation.

7 Best Practices

Based on the information collected for this report, the NPSTC In-Building Working Group recommends the following “Best Practices” with respect to the deployment of in-building communications systems.

1. Given the increased need for and benefits of in-building communications, public safety agencies should ensure that coverage for in-building operation is strongly considered when specifications for system RFPs are drafted and issued.
2. Where ubiquitous in-building coverage throughout a jurisdiction cannot be funded or provided yet, in-building coverage on a building-by-building basis should be considered through the use of properly designed and installed bi-directional amplifiers, distributed antenna systems, etc. Deployable systems can also be considered to provide temporary in-building coverage at a given incident scene when needed.
3. Jurisdictions may be able to increase in-building communications by adopting ordinances that require its implementation. Based on a number of sample ordinances already adopted, NPSTC recommends that new ordinances specify the minimum signal strength over a defined percentage area of each floor, stairwell or below-grade area, a reliability factor, testing procedures to ensure conformance to the requirements at the outset and on a periodic basis thereafter, and provisions for battery backup power.

Going forward, provisions to accommodate 800 MHz rebanding and adding coverage for the new 700 MHz band will also be important considerations.

4. Agencies should also monitor initiatives underway to develop national level model codes and standards supporting public safety in-building communications and consider providing support to these initiatives as appropriate.
5. The public safety community should continue to liaison with the commercial real estate interests as in-building coverage provides benefits to both parties. This liaison is already established primarily between the NPSTC In-Building Working Group and the In Building Wireless Alliance and should be continued.
6. Parties deploying in-building bi-directional amplifiers should seriously consider the tradeoffs of various system designs and related equipment with respect to coverage extensions of the parent system, costs, interference abatement, etc.
7. Parties deploying in-building bi-directional amplifiers should adhere to defined good engineering practices for the deployment of such systems. These practices are addressed in the previous section and in Appendices B and C of the Addendum to this document.
8. Agencies adding in-tunnel wireless extensions to existing systems should evaluate the condition of any existing coax, including radiating coax, planned for use because coaxial cable can deteriorate over time, especially in harsh tunnel environments.
9. Any instances of interference should be reported to both NPSTC and the FCC so interference trends can be tracked. The NPSTC website could include an interference reporting template (to be developed).
10. NPSTC recommends the FCC aggressively address any interference that occurs to public safety or commercial operations. NPSTC also recommends the FCC closely track interference trends to determine if any changes to the marketing and certification regulations regarding the availability and use of lower quality booster amplifiers are warranted.
11. Provisions for backup battery power or emergency power sufficient to support the in-building system during expected emergency durations are recommended.
12. When sharing a “neutral host” type of system designed to extend commercial and unlicensed services in a structure, public safety agencies should develop a binding agreement that includes the following minimum conditions:
 - No other wireless service can be permitted to interfere with or diminish public safety coverage;
 - Public safety coverage must include basements, utility rooms, stairwells, etc.;
 - Once installed, changes to the system must have concurrence from public safety prior to implementation.

8 Summary

In-building coverage is increasingly important for both public safety and commercial communications requirements. The communications needs of first responders and the general public do not stop when they enter a building. NPSTC, with assistance from industry, has developed this white paper to help bring focus to the multiple aspects being addressed to improve in-building coverage while minimizing any interference.

9 Addendum: (Separate Document)

Appendix A: Interference Survey

Appendix B: Introduction to In-Building Wireless Signal Distribution for Public Safety

Appendix C: Providing Robust In-Building Coverage in Public Safety Wireless Networks

Appendix D: Optimizing FCC Class B Band Selective (Broadband) Signal Boosters for Urban Use

Appendix E: Optimizing Class FCC Class A Channel Selective (channelized) Signal Boosters