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Best Practices for In-Building Communications

by

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

Stu Overby, Chair
Stu.overby@motorola.com

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

Contents

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I. Executive Summary and Background

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, supplementing coverage in specific buildings with a variety of "in-building" coverage solutions such as, bi-directional amplifiers(BDAs), off-air repeaters, PicoCell/Microcells or Fiber based DAS (distributed Antenna Systems) are options that may be considered. In addition, some jurisdictions have enacted ordinances to help ensure that construction of commercial buildings include 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. Finally, 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.

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. In building systems generally are designed to operate over an entire spectrum band, not just a specific channel. 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 with out-of-band filtering 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 have grown in number and continue to do so.

- Commercial building owners and commercial wireless service providers have increased 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.

- While in the early stages, some commercial real-estate management companies are focusing on both the business and safety benefits of in-building wireless coverage.

- 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.

- Reports of interference from “rogue” (un-coordinated/un-approved) 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 interference environment, 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.

II. Local Ordinances Regarding In-Building Communications

A number of jurisdictions have enacted or are considering enactment of local ordinances which require a requisite level of public safety communications reliability in-building as a condition for occupancy. The specifics of these ordinances 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.

Table 1: Sample of Local Ordinances on In-Building Communications for Public Safety

Local Jurisdiction	**Ordinance Reference**	**Key provisions**
Boston, MA	- Fire Dept. In-Building Radio Spec. - 5/21/01	• Min signal -95 dBm, 95% of each floor • UHF band
Broward County, FL	- Ord. 99-22 - 5/25/99	• No interference to public safety comm. • Add'l facilities at no cost to county
Burbank, CA	- Ord. 3265, Sec 7-616.1 - Effective 9/21/91	• Min signal -107 dBm, 85% of each floor • 90% reliability factor • UHF band
Folsom, CA	-City Code -Chapter 14.18	• Min signal -95 dBm, 90% of each floor • 100% reliability factor • 800 MHz band • 12 hour battery backup
Grapevine, TX	-Ord. No. 109.2	• Min signal -107 dBm, 95 % of each floor • 800 MHz band • Adjacent band filtering • 8 hour battery backup
Roseville, CA		• Min signal -95 dBm, 90% of each floor • 100% reliability factor • 800 MHz band • Adjacent band filtering • 12 hour battery backup
St. Petersburg, FL	-Draft under development	• Min signal level -100 dBm 95 % of each floor; -95 dBm in stairwells & below grade • 90% reliability • 800 MHz now • 700 MHz band by 1/2/2012 • 12 hour battery backup
Scottsdale, AZ	-Section E, 810-90	• Min signal level -107 dBm, 85% of each floor • 90% reliability factor • 800 MHz and VHF bands • 2 hour battery backup
Tempe, AZ	-Ord. 2001.25 -Chapter 9 -Section 9-21 to 9-32 -9/13/01	• 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.

III. 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% of the electricity consumption in the U.S., and that with improved monitoring and control could provide a 30% 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:

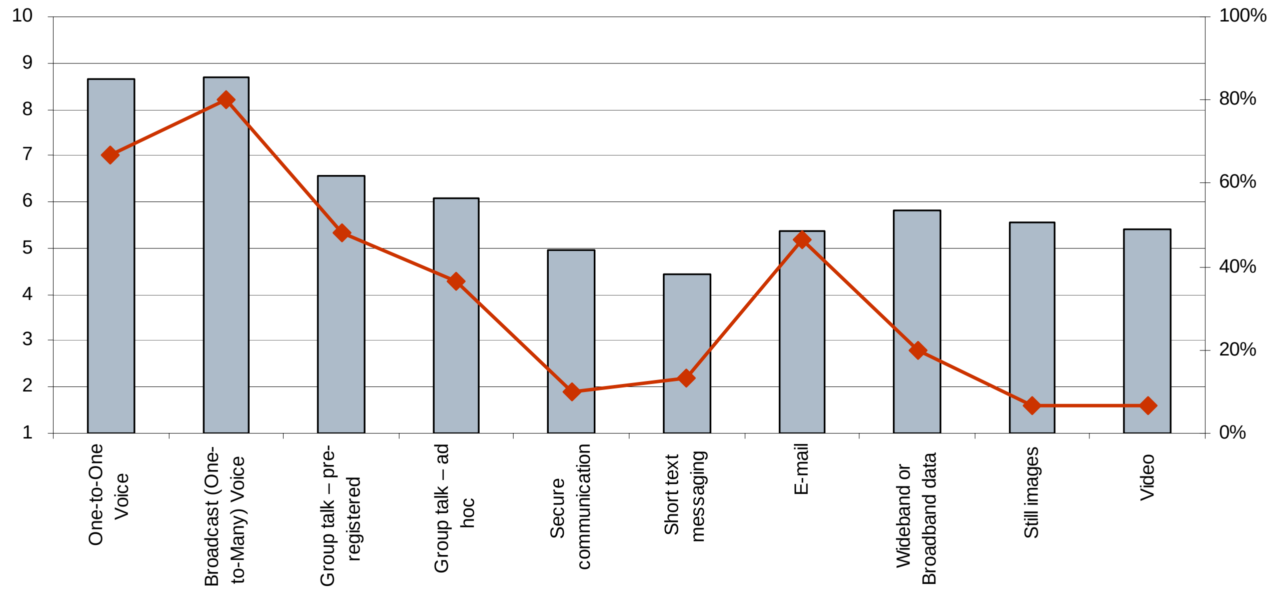
- Productivity gains
- A mobile workforce enabled to be responsive to their customers
- Seamless mobility and coverage from car to office
- Single phone number for business use
- Decreased cost of cabling

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.

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 already 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 will be closed as new systems supporting wideband and broadband data, still images and video are implemented in the 700 MHz band. This of course will require proper specification of the systems and sufficient sites to provide for in-building coverage throughout a jurisdiction. Alternatively, coverage on a specific building-by-building basis may be attained through bi-directional amplifiers, distributed antenna systems, etc.



Bar graph: Importance
Red line: % respondents already having 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 is 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. 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	• Low cost	• 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	• 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	• Does not require line of sight to function	• 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	• Can be a low-cost solution	• Weak resolution
Bluetooth	Very short range RF standard	1-3 meters	• Increasing popularity of the standard	• 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 (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 eb 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 place 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 terrorists event or other disaster.

Hospital wireless systems providers are also interested in the possibility of adding patient monitoring and 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 has created a draft “Operational 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. A separate presentation of the IBWA draft Operational Scorecard is on the NPSTC web site at

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III. Interference Concerns

There have been some instances of interference from in-building deployment of bi-directional amplifiers, 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. The results of the survey to date are:

- The Jack Daniel Company estimates that the survey was viewed by approximately 1500 to 2000 such entities.
- A total of 57 responses have been received as of Oct. 17, 2006
- 54 of the respondents reported they had experienced some interference
- 12 of the 57 responses relate to different events reported by the same person, a cellular service provider tech.
- 47 of the 54 responses (87%) indicated that "oscillating" BDAs were the cause of the interference
- Only 6 % 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.
- 16 respondents said BDA installations should be licensed. 10 said they were undecided.

Unfortunately, the low number of responses makes any solid conclusions from the survey 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. 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.

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. [1] 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 receive antenna located outside the building. This interfering signal impacted a large number of cell sites as shown in the map in Figure 1. 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 and it underscores the need for proper deployment as well as design to minimize interference risks.

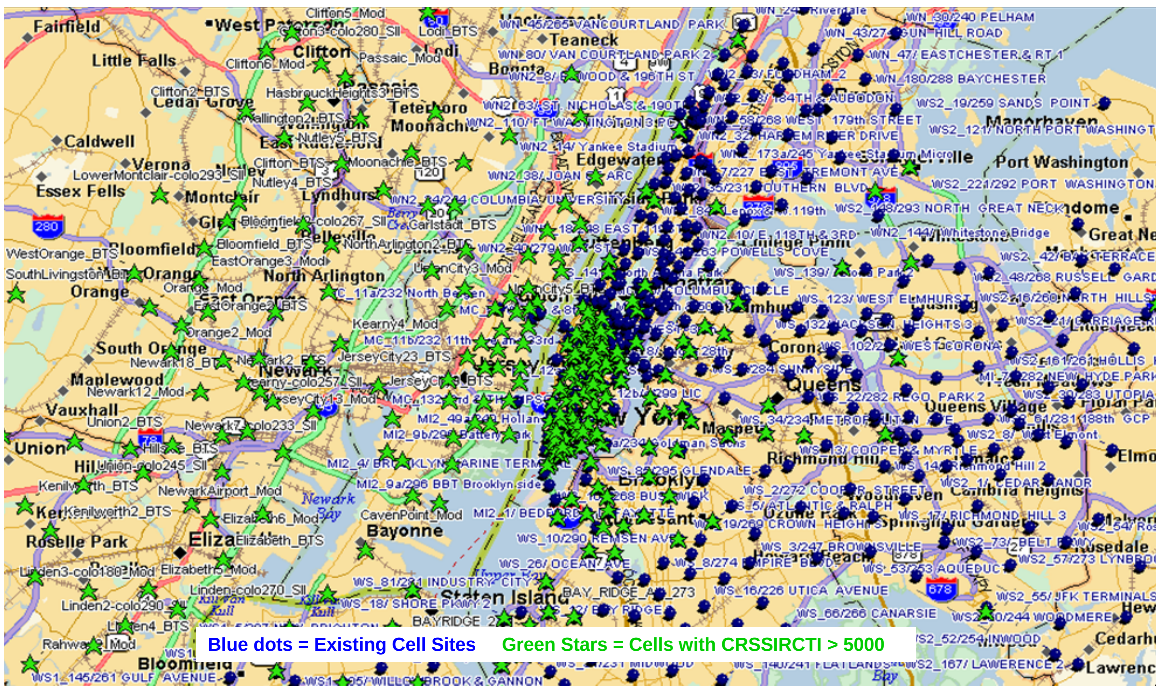


Figure 1: Effects of Interference from a Self-Oscillating BDA – Sample Case

In summary, the instances of interference have not been great in number, but the effects of even one situation can be significant. Therefore, NPSTC offers the following "good engineering practices" to help minimize the potential for interference.

[1] [Cite statistics on increase in wireless 911 usage]

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

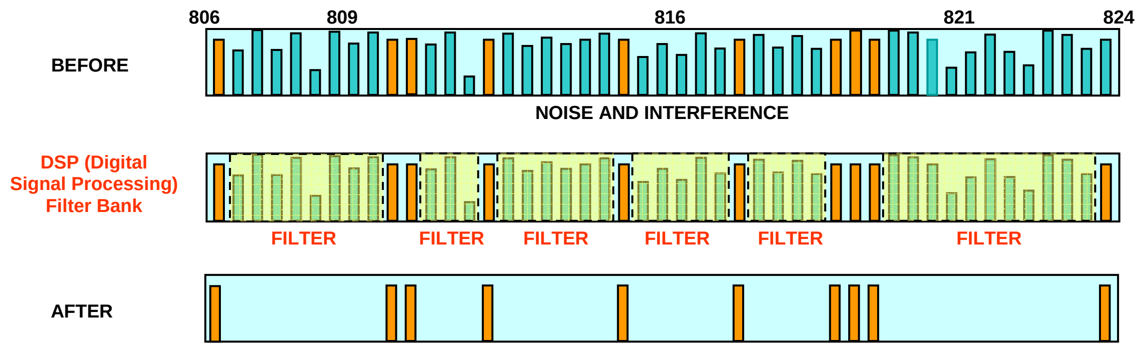
- Number of users in building
- Number of "foreign" networks, i.e., networks other than the one for which the BDA system is being installed
- Density of walls and ceilings
- Proximity of windows relative to the parent system donor site
- Existing signal strength in the building
- A floor plan with accurate 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 RFP's for in-tunnel systems should seriously consider an evaluation of any existing leaky coax and replacement is necessary as part of the system implementation.

The use of bi-directional amplifiers which incorporate channels selective filtering can also help minimize interference in some cases. All signal booster systems have both benefits and limitations and the specific type of system deployed needs to be matched to the requirements. The following depicts the potential benefits of channel selective filtering.



Further detail on these good engineering practices and appropriate filtering is available from reputable manufacturers of quality bi-directional amplifiers.

Given the relatively low number of interference cases documented, the In-Building Working Group does not recommend any specific FCC action at this time. The Working Group does recommend that NPSTC establish a location on its web site where public safety entities can report any cases of interference to/from in-building systems.

V. 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 Requests for Proposals (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.

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. Agencies should also monitor efforts underway to develop common "ordinance" provisions or standards that can be implemented nationwide.

4) 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.

5) 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.

6) Parties deploying in-building bi-directional amplifiers should adhere to defined good engineering practices for the deployment of such systems. These practices are available from a number of sources in industry, including reputable bi-directional amplifier manufacturers. Some of the key provisions, summarized as follows, are covered in more detail in Appendix C of this document.

- A **Comprehensive Site Survey** to evaluate the existing coverage conditions;
- A **Spectral Analysis** that defines what RF energy is in the ambient environment;
- A **Scope of work** to define what is expected from those who offer to provide a solution;
- **Systems Engineering** standards that take into consideration conditions specific to RF signal regeneration;
- **Acceptance and Testing Procedures (ATP)** that defines for all parties involved the measure of success for deployment of an in building solution and the method by which that measure of success is to be determined.

7) Agencies adding in-tunnel wireless extensions to existing systems should evaluate the condition of any existing coax, including radiating coax, planned for use as coaxial cable can deteriorate over time, especially in harsh tunnel environments.

8) Any instances of interference should be reported to both NPSTC and the FCC so interference trends can be tracked. The NPSTC web site could include an interference reporting template (to be developed).

9) A minimum of 8 hours battery or emergency power is recommended.

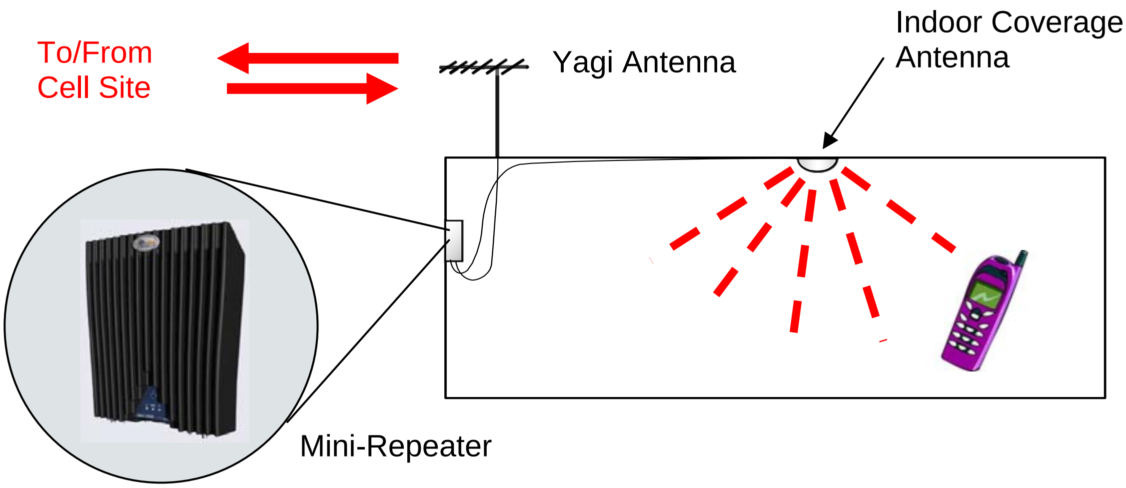
10) When sharing a "neutral host" type of system designed to extend commercial and unlicensed services in a structure, public safety agencies should develop a binding agreement that includes the following minimum conditions:

- 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.

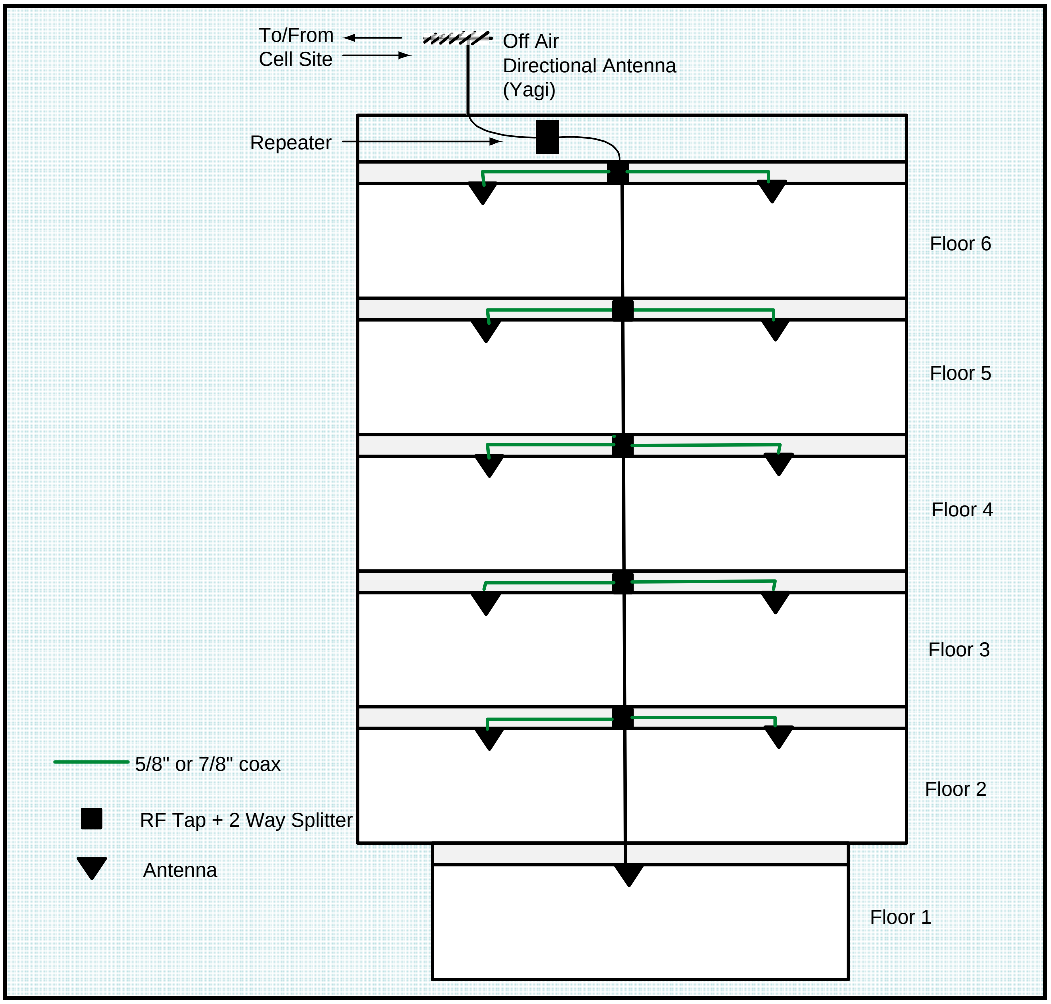
VI. Summary

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, along with assistance from industry has developed this whitepaper to help bring focus to the multiple aspects being addressed to improve in-building coverage while minimizing any interference.

Appendix A – Sample In-Building Systems



Simple Small-Site In-Building BDA installation



More Complex Multi-site In-Building BDA Installation

- Repeater drives distributed antenna system (DAS) in larger areas
- DAS distributes even coverage
- Quality systems can self optimize gain and level

Appendix B: Interference Survey

The attached interference survey was developed and has been distributed to the public safety community by Jack Daniel of the consulting firm RF Wise. Mr. Daniel is engaged in consulting on in-building communications and is a member of the NPSTC In-Building Working Group.

FCC BDA Interference Survey

Exit this survey >>

The following is a survey to gather information and statistics concerning any interference from BDAs (bi-directional Amplifiers) you may have experienced.

This survey will be used in support of petitions requesting the FCC update and revise rules for BDAs.

One such petition may be viewed at:
http://www.rfsolutions.com/bird-fcc.pdf
The intent is to get the FCC to open the rules for public input of changes needed regardless of whether you agree with the Bird petition or not.

Please email comments, questions or suggestions about this survey to:
JackDaniel@RFWise.com

1. Has BDA OSCILLATIONS (not noise) caused you any problems ?

NO	YES
○	○

2. If you answered YES to question 1, how many different BDA installations in the last 5 years

1	2	3	4	5	6	7	8	9	10 +
○	○	○	○	○	○	○	○	○	○

3. Has broadband NOISE (not oscillations) from BDAs caused you any problems (such as receiver desense)

NO YES

4. If YES to question 3, how many different BDA installations were focused on the same donor site

1 2 3 4 5 6 7 8 9 10+

5. Do you think internet BDA sales to consumers should be stopped

NO YES

6. Do you think 'voluntary' registration of BDA installations would work

NO YES

7. Should the FCC enforce existing BDA (signal booster) rules better

NO YES

8. Should FCC rules be updated and made more restrictive

NO YES

9. Should BDA installations be licensed similar to control stations

NO YES Undecided

10. Is there any place else this survey should be posted ?
(Feel free to distribute to other groups)

11. Please add any additional comments here

12. May we supply your name to the FCC with this survey ?
The FCC pays more attention to specific reports than anonymous sources.

NO	YES	Contact me first
○	○	○

This completes the survey
Thank you very much for your contribution

Jack Daniel
JackDaniel@RFWise.com

Appendix C

Parameters for Successful Deployment of In-Building Communications Solutions

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 of a site survey. 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:

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 close proximity to limit the donor cable run and consequently, its associated RF loss characteristics.

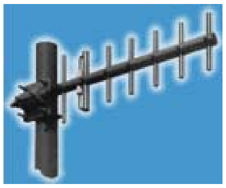
If an entry point can be identified, that will go a long way in getting the donor signal into the building. Existing penetrations should be utilized because every time you drill a hole in a roof for rack mounts or wiring you create the potential for leaks.

Flashing should encase roof penetrations and water proof 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 (ex. Fewer elements in a yagi antenna).

Another factor to consider when choosing a location is identifying where the donor site is located. A clear of line of sight to where the donor signal is originating from 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.

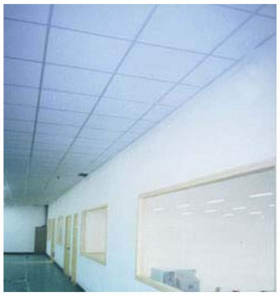
Placement in close proximity to other antennas is also something that needs to be avoided so as not to create any unnecessary intermod products in the antenna's near field propagations.

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.

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 in 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 (ex. 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.

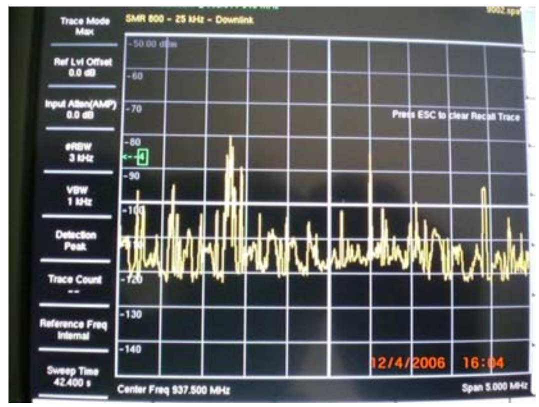
Power of systems—
While examining the room where the booster will be installed, a survey of potential power sources should be identified. Will the outlet have power in case of a blackout? If not, it may mandate a dedicated UPS power back up module.

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.

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 what is the ambient signal strength where the donor antenna will be located at. 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. If it is deemed necessary to attenuate potential interfering signals, a channelized solution may be necessary.

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. Never the less, 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 that a RF link budget is built upon. 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 though 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*log(# 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.

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 & 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% of the facility. Other assumptions should include if 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, $1^{st}/2^{nd}/3^{rd}$ 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.

4. Engineering of Systems

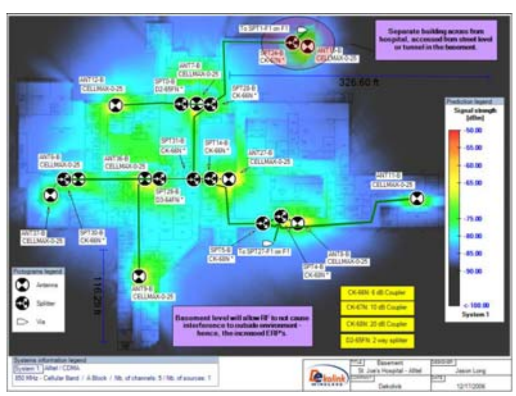
The foundation of any system engineering is a RF link budget. This will account for all the gains and losses in a given system to give a reasonable expectation for what the coverage prediction should look like.

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

RxP = TxP + TxG - TxL - FSL - ML + RxG - 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 design tool such as Wireless Valley or iBWave. 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 a inter-modulation analysis of existing frequencies to determine if harmful inter-modulation products will be generated with current RF environment.

If this is the case, it may be necessary to either "notch" out the offending harmonics through dedicated filtering or propose a channelized booster/BDA solution instead of a broad band booster/BDA. Dekolink's channelized offerings allow the user to customize the filter's performance characteristics (filter roll off, band width, center frequency, timing delay). This flexibility allows the user to implement a channelized booster/BDA solution in a wide variety of settings.

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, need 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 then 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 then or 105 dB of isolation.

5. <u>Acceptance Test Procedure (ATP) Development</u>

The agency deploying the coverage solution should develop a mutually agreed upon ATP or Acceptance Test Plan with the vendors that will supply the system and users of the system that will meet system performance specifications. There are two types of Coverage measurements when evaluating in building systems; Signal Strength Test and Voice Quality Test. Signal Strength Test is cost effective with downlink RSSI signal measurements, and Voice Quality Test is 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 qualify of a wireless systems' performance should be accomplished so that all parties involved understand the overall objective so that proposals and systems designs are in line with this ultimate objective.

6. Testing Process

A reliable, accurate wireless test device such as 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 of 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.

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