TECHNICAL BRIEF

# Deployment Considerations: Canopy® 900 MHz Indoor Subscriber Module

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## OVERVIEW

Accelerating the delivery of wireless broadband services to customers located in hard to reach areas while simultaneously reducing installation costs has proven an extremely difficult and oftentimes impossible undertaking. Building limitations, aesthetic restrictions and natural barriers such as trees and foliage are all potential obstacles to a successful wireless broadband deployment.

The wi4 Fixed Point-to-Multipoint Canopy® 900 MHz solution can help circumvent these impediments and enable connectivity in a gamut of conditions. Offering a broad range of deployment options, including both outdoor and indoor customer premise equipment, the 900 MHz Canopy solutions provide carrier grade broadband access exactly when and where it is needed with minimal installation costs.

This technical brief focuses specifically on the 900 MHz indoor customer premise equipment and the issues that may impact radio performance. Appendix A provides a list of acronyms. Appendix B contains a brief tutorial for calculating the Fresnel zone radius. Appendix C highlights the results of Motorola's own field trials conducted at the company's worldwide headquarters in Schaumburg, Illinois.

## REACHING THE OUT OF REACH

The Point-to-Multipoint Canopy system is an innovative wireless broadband solution that is ideal for residential, business, institutional and municipal locations. Designed for outdoor wireless broadband networks, the system is available in a wide range of frequency choices — 900 MHz, 2.4 and 5 GHz — and helps ensure exceptional performance no matter which spectrum is best for the network.

Canopy solutions deliver scalable, interference-resistant, high-speed connectivity to multiple residential, business, institutional and municipal locations. The platform combines exceptional reliability with robust performance, scalability, multiple layers of security, ease-of-use, accelerated deployment and remarkable affordability. It also integrates seamlessly with existing network systems and management tools, making it easier and cost efficient to extend existing networks.

## EMANATING FROM THE OUTSIDE IN

Recognizing that the same benefits that enable 900 MHz to penetrate obstructions could be extended to provide in-building coverage, Motorola developed the 900 MHz Indoor Subscriber Module (SM). The indoor modules can be installed in minutes, providing a quick and easy solution that reduces time and costs for network operators and may reduce and/or eliminate the need for professional installations.

The 900 MHz Indoor SM receives signals from a Canopy Access Point (AP) located up to one mile, depending on environmental conditions, from the Indoor SM. Housed in an attractive enclosure and weighing less than two pounds (.8 kg) the module can deliver up to 4 Mbps of aggregate throughput. Figure 1 depicts the front view of the Canopy 900 MHz Indoor SM.

***Figure 1. Canopy 900 MHz Indoor Subscriber Module (Front View)***

Built to the same rugged standards exhibited in the Canopy system components, the indoor modules can be installed in minutes, providing a quick and easy solution that reduces time and costs for network operators.

## A Room with a View

Ideally the indoor subscriber module is situation on a desktop, table or windowsill with the front side facing into the building. As shown in Figure 1, the front of the module is readily identifiable by the embossed Motorola logo in the center along with the Light Emitting Diodes (LEDs) on the lower left. The LEDs, shown in Figure 2, are used to assist in the initial alignment of the unit and contain status lights for the Ethernet link, data activity, synchronization and DC power. The back of the Indoor SM is labeled *antenna side* and should be oriented toward the outdoors and the corresponding 900 MHz Canopy AP.


***Figure 2. Subscriber Module LEDs Indicating System Status***

To install the module, the unit is positioned on a flat surface with the back facing the radio tower. The installer slowly shifts the orientation and/or location of the SM to find registration. During scanning and registration, the modem can take one or more seconds to respond to changes in position. If initial fine-tuning is required, a rotary *polarity dial,* as shown in Figure 3, is used to rotate the antenna encased in the SM. The antenna is typically in a vertically polarized orientation. When changes occur in the radio signal due to interference in the radio path, the antenna can be adjusted to optimize the signal. These conditions are discussed in the section entitled *Issues Impacting Radio Performance*.

Typically, the Indoor SM is connected via an Ethernet cable to a computer or router. Today, many home routers include multiple Ethernet LAN ports, a printer port, WiFi access point and even a Voice Over (IP) VoIP gateway RJ11 connection. Increasingly, the 900 MHz Indoor SM will likely service a complete home broadband network rather than just a single computer.

## ISSUES IMPACTING RADIO PERFORMANCE

The Canopy system operates in unlicensed or managed frequencies. As such, the radio signals can be subjected to a high degree of interference from other wireless equipment operating in the same frequency bands as well physical obstructions that can impede the RF signal. This section provides an overview of these issues.

### Fresnel Zone

The first step in considering the issues impacting radio performance begins with a discussion of the Fresnel zone. While an in-depth discussion is beyond the scope of this document, a very brief explanation is included herein. Appendix A contains a more detailed discussion for calculating the Fresnel zone radius.

The line-of-sight path between two antennas is the Fresnel zone. It is an elliptical zone between two antennas where the total path distance varies by more than half of the operating wavelength.[1] There are a number of Fresnel zones each representing the places in which the arriving signal is either reinforced or nulled. The odd numbered Fresnel zones represent the places in which an arriving signal is nulled or reduced to effectively zero signal strength.

Line-of-Sight locations feature both visual line-of-sight and clear radio line-of-sight (Fresnel zone). In near Line-of-Sight (nLOS) locations, there is clear visual line-of-sight but the Fresnel zone is blocked. In Non-Line-of-Sight (NLOS) locations, both visual and radio lines-of-sight are blocked. Taking into account the Fresnel zone and the capabilities of the broadband equipment is imperative when designing a network.

Due to the improved RF propagation characteristics at lower frequency bands, the Canopy 900 MHz system is less susceptible to signal degradation due to obstructions and supports LOS, nLOS and NLOS environments. Figure 1 depicts these conditions and highlights the applicable Fresnel zone.

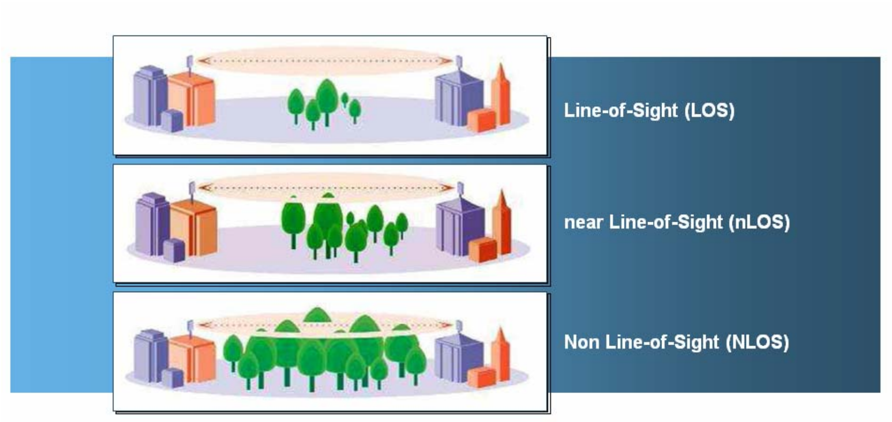


***Figure 3. The Fresnel Zone***

### Propagation Phenomena

Determining the RF attenuation properties and locations of obstructions is required to characterize the true performance of the 900 MHz systems. All indoor modules are subject to unwanted impacts on the radio signal due to a number of degradations including reflection, diffraction and scattering. All of these degradations result in a receiver getting the same signal from different directions and in different phases, polarity and strength. Often the combined effect

[1] Harry Newton, *Newton's Telecom Dictionary* (California: CMP Books, 2006) p. 407-408.

of these is termed *multipath* reception. In the Canopy Graphical User Interface (GUI), this information is displayed as *jitter* value.

### *Free Space Loss*

As a radio signal travels through space, the waveform spreads out and begins to loose strength. As the waveform spreads, so does its power. This is a computation related to signal attenuation caused by distance and is fundamental to any analysis of indoor path loss analysis.

### *Reflection*

Radio waves can reflect off hills, trees, bridges, buildings, windows, and walls – essentially anything. As shown in Figure 4, reflections allow radio signals to bend around objects to reach their targets and may vary in phase and strength from the original wave.[2]

Reflections from a flat surface cause a signal strength loss and a change in phase. If this reflected signal is received by a radio it is combined with other signals of different phases. If two signals of opposite phase and equal strength combine they destructively interfere creating a *null signal*. The locus of all such reflection points, in regard to a LOS signal, is the first Fresnel zone. It is important to avoid the electromagnetic nulls. Moving the Canopy 900 MHz Indoor SM from place to place and changing its orientation can accomplish this goal. Small movement, such as change in height or position, can result in greatly improved signal strength.

If the reflected signal is further from the LOS path, then the signals may constructively reinforce each other and arrive *in phase* creating a stronger and better signal. The focus of all such reflection points is the second Fresnel zone. Consequently, the various Fresnel zones are those reflection points in which two signals destructively combine (the old Fresnel ones) and constructively combine (the even Fresnel zones) compared to the LOS.

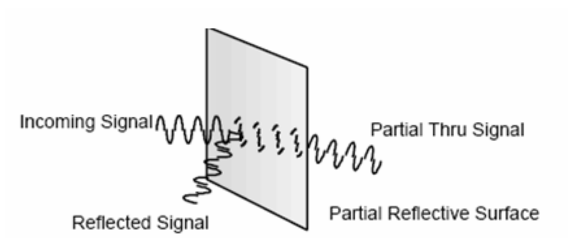


***Figure 4. A Reflected Signal***[3]

### *Diffraction*

When an opening or an edge restricts a waveform, the waveform deviates from its path in what is known as diffraction. Waveforms bend as they pass through a narrow opening.[4] Diffraction of radio waves due to relatively sharp edges such as rooflines or building corners is also possible. While weakened, a diffracted signal is sometimes useable even though true LOS is not possible. Figure 5 shows diffraction of a signal.

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[2] Newton, p. 762.
[3] John C. Stein, *Indoor Radio WLAN Performance, Part II: Range Performance in a Dense Office Environment,* Intersil Corporation, Palm Bay, Florida, p. 2.
[4] Newton, p 298.

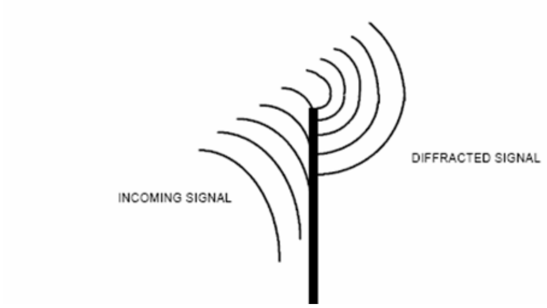


***Figure 5. Diffraction of a Signal[5]***

***Scattering***

If the radio signal reflection hits multiple facets, the signal is said to be scattered and therefore does not arrive at a radio receiver. In particular, right angle reflections send signal power in almost random directions. For example, if three mutually right angle reflections meet than the signal is sent directly back toward its source. This is a *corner reflector.* Figure 6 illustrates an example where a signal hits the steel I-beams contained in the wall supports of a modern office building. When the signal hits the I-beams, the wavefront is broken apart in many directions. The resultant signal scatters in all directions and adds to the constructive and destructive interference of the signal.

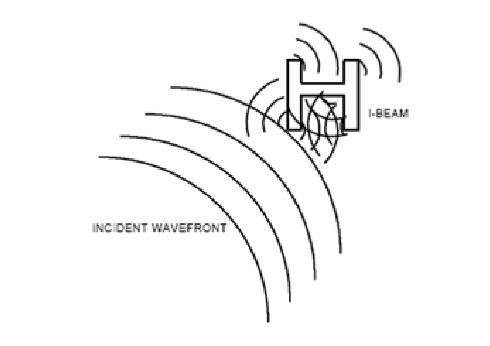


***Figure 6. A Scattered Wavefront[6]***

***Polarity***

Another degradation issue is that of the received radio signal's polarity. If the reflecting surface is at an angle, the effect is not only a phase shift but also a rotation of the signal's polarity. This is significant as radio reception depends on polarity. If the reflecting surface is not exactly vertical or horizontal the signal's polarity is received as not vertical but as rotated to an unknown angle. Therefore, the Canopy Indoor SM has a dial that allows the installer to search for the best receiving polarity angle.

## Obstructions

Overcoming physical obstructions is a common problem encountered in deploying wireless broadband networks. This section highlights information related to these obstructions and their associated impacts.

[5] Stein, p. 2.
[6] Ibid.

### *Trees & Foliage*

Trees and foliage certainly make way for a picturesque landscape but wreak havoc on a radio network. Interestingly, it is the water molecules that are held in the foliage that actually attenuate the radio signal and not the green foliage itself. Unfortunately, there is no definitive way to state the expected signal losses due to trees and foliage. Every tree and leaf is different from one another. There is no *standard tree* or *standard foliage* to measure. Since every circumstance is unique, only guidelines are realistic.

According to some experts, “At 1000 MHz, trees that block vision are almost opaque to the radio signal. Signals reaching the receiver must then diffract over or around the trees. Above 300 to 500 MHz, there is little difference in the attenuation for vertical and horizontal polarization.”

Measurements of attenuation through woods in full leaf can be represented by:

$$dB/meter = 1.29x10^{-3}(\ MHz)^{.77}$$

For 900 MHz this formula yields .00129x~188 or .24 dB per meter. Therefore, each four meters of foliage weakens the signal by about 1 dB. Thus, 12 meters of foliage drops the 900 MHz signal strength by about 3 dB that is a factor of one-half. Thus 900 MHz is much better in this regard than higher frequencies. Even 900 MHz, however, is quite opaque to green vegetation.

### *Building Materials*

Today’s construction materials vary widely and are driven by structural requirements. Of course, each material can cause the wireless signal to attenuate. Table 1 highlights average attenuation of building materials and Table 2 details approximations of attenuation values for common office construction. Please note, the figures shown in Tables 1 and 2 are for 2.4 GHz. Therefore, the attenuation for 900 MHz will likely improve dramatically.

***Table 1. Average Attenuation of Building Materials***

| Building Material | Average Attenuation<br>(High Loss to Low Loss) |
|---|---|
| Concrete | High |
| Metals | High Plus Slight Refraction<br>*Lifts, air conditioning, stairwells, racks* |
| Water | Medium<br>*Water logged wood, fish tank, rain* |
| Wood | Medium<br>*Partitions, trees, furniture* |
| Glass | Low |

*Table 2. Attenuation Values Through Common Office Construction.*

| Office Construction | Attenuation Value |
|---|---|
| Plasterboard Wall | 3 dB |
| Glass Wall with Metal Frame | 6 dB |
| Cinder Block Wall | 4 dB |
| Office Window | 3 dB |
| Metal Door | 6 dB |
| Metal Door in Brick Wall | 12.4 dB |
| Floor | 30 dB |
| Brick Wall with Window | 2 dB |
| Office Wall | 6 dB |
| Double-Pane Coated Glass | 13 dB |
| *Source: www.moonblinkwifi.com* | |

Interestingly, the propagation loss between floors begins to diminish with increasing separation of floors. The attenuation becomes less per floor as the number of floors increase. Figure 7 illustrates this phenomenon. Note, even one floor can degrade a radio signal by 30 dBm; this is much more loss than typically associated with walls and windows.

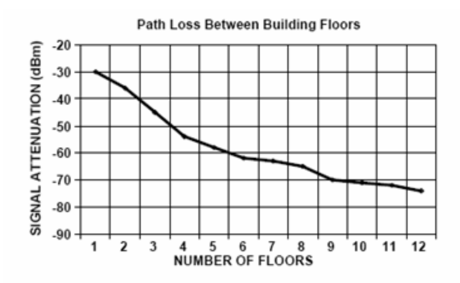


*Figure 7. Attenuation Between Floors*

### *An Illustration*

Figure 8 depicts a deployment of Canopy 900 MHz using both indoor and outdoor subscriber modules. As you will note, trees can obstruct the signal path and cause, in this case, approximately a 3 to 5 dB loss. The signal loss caused by the building infrastructure is much higher at approximately 5 to 10 dB. Of course, the reality of any particular deployment is distinct and depends on many of the circumstances highlighted previously in this document. Fortunately, in the case of 900 MHz wireless broadband systems, network operators have about 135 dB of link budget available that translates to a higher probability of a successful signal link.

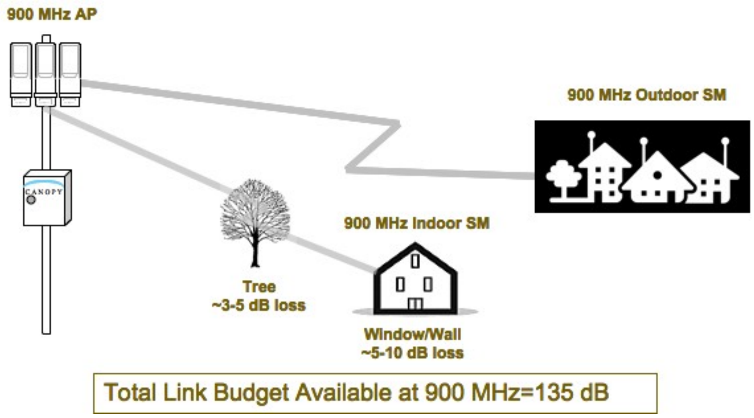


***Figure 8. Impact of Trees and Building on a 900 MHz network.***

The main difficulty with such proclamations is that the range of attenuations is typically quite large and may not be useful in the predictive sense. In one example, attenuation loss for a single building ranged from 2 dB to 38 dB. Note that this is a 36 dB range on attenuation. This amounts to a factor of $2^{12}$ or about 4,096 between low and high-received signal strength. Such estimates can be very misleading in the predictive sense.

General rules of thumb regarding placement and orientation of the Canopy 900 MHz Indoor SM are:

- Choose a location that is line-of-sight if possible.
- Select a room facing the access point and on the highest floor possible.
- Position the module near a window rather than behind a wall.
- Beware of winter trees without leaves.
- Use the lights on the LEDs to observe, scan, synchronize, register and view the Ethernet link activity.
- Read and understand the use of the modules polarization dial.

## SUMMARY

The introduction of the 900 MHz Indoor SM represents a significant addition to the Canopy product portfolio and will become a valuable asset to network operators. The Indoor SM was designed for ease of installation that, in many cases, can eliminate the need for a professional truck roll installation. Proper guidelines, such as those highlighted in this paper, must be adhered to ensure proper operation. The combination of this powerful new solution with proper installation has the potential to dramatically reduce the cost of customer acquisition and speed the deployment of Canopy broadband networks.

## MOTOWI4™ WIRELESS BROADBAND SOLUTIONS

Motorola is one of the most trusted resources for wireless communication solutions around the world. With more than 75 years of RF innovation and leadership, Motorola is one of the world's most experienced wireless communication companies. The wi4 Fixed Point-to-Multipoint Canopy solutions are part of the MOTOwi4 portfolio—a comprehensive portfolio of wireless broadband solutions and services that provides high-speed connectivity, enabling a broad range of applications in a host of environments. The MOTOwi4 portfolio also includes wi4 WiMAX, wi4 Mesh and wi4 Indoor solutions for public and private networks.

## RESOURCES

Additional information is available from a host of resources including:

- Canopy User Community at
  http://motorola.canopywireless.com/support/community.
  This resource facilitates communication with other users and with authorized Canopy experts. Available forums include General Discussion, Network Monitoring Tools, and Suggestions.
- Canopy Knowledge Base at
  http://motorola.canopywireless.com/support/knowledge.
  This resource facilitates exploration and searches, provides recommendations, and describes tools. Available categories include
  - General (Answers to general questions provide an overview of the Canopy system.)
  - Product Alerts
  - Helpful Hints
  - FAQs (frequently asked questions)
  - Hardware Support
  - Software Support
  - Tools

# APPENDIX A: ACRONYMS

AP ...................... Access Point
dB ...................... Decibel, a ratio of signal strength compared to a reference signal
dBm ................... Decibel, a ratio of signal strength compared to 1 mW
GHz.................... Giga Hertz
LED.................... Light Emitting Diode
LOS.................... Line-of-Sight
MHz ................... Mega Hertz
nLOS.................. Near Line-of-Sight (Fresnel zone partially impaired)
NLOS ................. Non-Line-of-Sight (Fresnel zone completely blocked)
RJ11 .................. Analog telephone jack
SM ..................... Subscriber Module
VoIP ................... Voice Over Internet Protocol
WiFi.................... Wireless Fidelity

# APPENDIX B: CALCULATING THE FRESNEL ZONE RADIUS

The general equation for calculating the Fresnel zone radius at any point P in the middle of the link is the following:

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

where,

$F_n$ = The nth Fresnel Zone radius in meters

$d_1$ = The distance of P from one end in meters

$d_2$ = The distance of P from the other end in meters

λ = The wavelength of the transmitted signal in meters

Of course f = 1/λ.

By far the most significant of the Fresnel Zones is the first (n=1). A signal reflected at this place arrives out-of-phase, that is, deconstructive and so is a “null”. At the half distance $d_1 = d_2$ and sum to the total distance D.

The cross section radius of the first Fresnel zone is the highest in the center of the RF LoS that can be calculated as:

$$r = 72.05\sqrt{\frac{D}{4f}}$$

Where *r* = radius in feet, *D* = total distance in miles, and *f* = frequency transmitted in gigahertz. In metric terms this becomes:

$$r = 17.32\sqrt{\frac{D}{4f}}$$

Where *r* = radius in meters, *D* = total distance in kilometers, *f* = frequency transmitted in gigahertz.

*Source: http://en.wikipedia.org/wiki/Fresnel_zone*

For example, if D = 1 mile and f = .9 GHz (i.e. 900 MHz) then the first Fresnel Zone radius at the halfway point is about 38 feet.

# APPENDIX C: RESULTS OF FIELD TRIALS
# CANOPY 900 MHZ INDOOR SUBSCRIBER MODULES

Motorola conducted field trials of the Canopy 900 MHz Indoor Subscriber Modules (SM) at the corporation's headquarters in Schaumburg, IL. Beta trials were also completed with service providers operating Canopy Point-to-Multipoint networks. This appendix summarizes the results of the Motorola field trials only. Due to privacy requirements, the results of the customer tests are not available for general usage.

## Trial overview

The Motorola field trial evaluation was conducted from the corporate campus in Schaumburg, IL. The results revealed in this section are not sufficiently scientific so are termed anecdotal. The Canopy 900 MHz Access Point (AP) was mounted atop the Motorola corporate tower. From there, testing was completed with the 900 MHz Indoor Subscriber Modules (SMs) at the following locations:

- Motorola Employee Credit Union (MECU), an office building located on the corporate campus at a range of .47 miles from the Canopy AP.
- International Village, a multi-story apartment complex located approximately .61 miles from the Canopy AP.
- College Campus located approximately 1.5 miles from the Canopy AP.
- City of Rolling Meadows, IL located approximately 1.5 miles from the Motorola corporate tower.

## Results

Figure C-1 is an aerial photograph of the Motorola campus and the surrounding area to the north and west. Shown at lower right and labeled “Motorola Canopy” is a 900 MHz Canopy AP atop the Motorola corporate tower office building. The three other sites are places where a Canopy 900 MHz Indoor SM was sited for testing purposes. The color-coded “dots” indicate the test results:

- Green:  Success
- Red:  No Success
- Yellow:  Partial Success

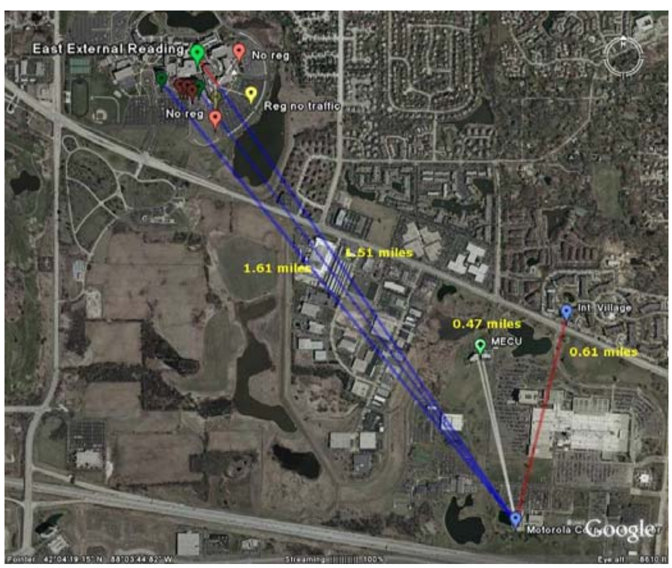


***Figure C- 1.  Diagram of Motorola’s Ad Hoc 900 MHz Indoor SM Test Points***

Table C-1 details the testing results at the MECU. Note baseline performance is shown in the second row of the table. In this scenario, the Indoor 900 MHz SM was moved behind a glass window. The SM was facing the 900 MHz AP located on top of the corporate tower building. about one-half mile away. As noted, the signal degraded about 4 dB which is consistent with published estimates for glass attenuation. Importantly, for this short range, the SM’s received signal strength even behind glass is about -53 dBm, well above the unit's minimum signal strength for 2x operation.

***Table C- 1. Results of Testing at Motorola Employee Credit Union***

| Rate | Power Level | Aggregate Throughput | Description |
|---|---|---|---|
| 2x | -53 | 4.05Mbps | Within building located near SE facing window |
| 2x | -49 | 4.16Mbps | Outside building located 88.5 feet from window SE |

Table 2 indicates the results of the tests performed at the International Village apartment complex. This is a multistory complex located about .6 miles from the 900 MHz AP.

***Table C- 2. Results of Testing with International Village***

| Rate | Power Level | Aggregate Throughput | Description |
|---|---|---|---|
| 2x | -53 | 4.51Mbps | Within building approx. 10ft from 2nd floor window |
| 2x | -52 | | Outside of entrance slightly elevated surface |
| 2x | -57 to -59 | | Just inside entrance |
| 2x | -64 | | 10 feet inside |
| 1x | -72 | | +20 feet inside |

In a second floor window the Indoor 900 MHz SM operated effectively even at the 2x rate. Another test was conducted near the apartment complex's entrance. The last three rows of Table C-2 illustrate how the signal weakens as the Indoor 900 MHz SM is moved farther into the building. At some point the unit was able only to function at the 1x rate.

Table C-3 shows the results of testing at the college campus at a distance of more than 1.5 miles from the Canopy AP. For the college campus the 900 MHz Indoor radio was placed in direct line-of-sight at multiple locations within four buildings (Buildings Z, Y, J and R). These buildings contain a mixture of single pane and double pane style glass. The single pane glass was concentrated within the entrances. All of the entrances showed signs of leakage, as the doors were not completely sealed. As testing moved through Building "Z" in an eastward direction engineering was unable to obtain any registrations within the building.

***Table C- 3. Results of Testing with College Campus***

| Rate | Power Level | Aggregate Throughput | Description |
|---|---|---|---|
| 2x | -50 | 4.3Mbps | Reading taken from East end of Campus. |
| 2x | -58 | 4.3Mbps | Reading taken from West External Reading.1 ft outside building. |
| 2x | -60 | 4.14Mbps | 1 ft inside Building |
| 2x | -62 | 3.8Mbps | 16 ft inside Building |
| 2x | -67 | 2.4Mbps | 20 ft inside Building |
| 1x | -70- to -78 | 1.6Mbps | 40 ft inside Building |

The single point in which a registration was again achieved at an entrance composed of double pane glass, but again there was some signal leakage around the door. Within Building "Y" in an elevated location closest to the corporate tower and was unable to attain stable registration.

The final College Campus test point was between Building "Y" and Building "J" (East External Reading). Here registration was attained at the entrances, but on either side of the entrance registration was not achieved. Once the SM was relocated outside of the building, registration was attained at a -50 dBm signal level, a difference of 8 dBm from Building “R”’ outside reading.

Motorola, Inc. www.motorola.com