Unlicensed Wireless Multipoint System in Sacramento Metro

Motorola Canopy

The Problem

- No broadband communication available to four cameras in the Sacramento Metro Area.
- Date Line June 2004

The Options

- POTS line
- Microwave Wireless link
- GPRS Wireless link

Feasibility Requirements

- Permission to mount radios on DGS Tower
- Permission to mount radios on TMC Tower
- Time time to receive tower permissions
- Line of Sight
- RF Environment analysis
- Costs

The Choice

- Multi-Point Microwave link to central communication tower and a separate backhaul link to D3 RTMC
- Motorola Canopy 5.7 GHz U-NII Band, 6 channels at 20MHz
- Deployed World Wide
- Proven reliability with ISP and Carriers

Canopy Part Number	5701SM
Description	5.7 GHz SM AES
Market Availability	North America, Europe, South America, Asia
Signaling Rate	10 Mbps, 20 Mbps with Advantage AP
Typical LOS Range	2 mi (3.2 km), 10 mi (16 km) with reflector
Typical Aggregate Useful Throughput	7 Mbps
Frequency range of band	ISM 5725-5850 MHz
Non-overlapping Channels	6
Channel Width	20 MHz
Modulation Type	High Index 2-level and 4-level Frequency Shift Keying (FSK) optimized for interference rejection
Channel Spacing	configurable on 5 MHz increments
Encryption	AES capable
Latency	6 msec with Advantage AP, 15 msec with Canopy AP
Carrier to Interference ratio (C/I)	~3dB @ 10 Mbps, ~10dB @ 20 Mbps at -65dBm
Nominal Receiver Sensitivity (dbm typical)	-86 dBm
Antenna Gain (dB)	7 dBi
EIRP (dB)	30 dBm (48 dBm with reflector)
Equivalent Isotropic Radiated Power (EIRP)	1 W (63 W with reflector)
DC Power (typical)	0.3 A @ 24 VDC = 7.2 W
Antenna Beam Width	3 dB antenna beam width 60 degrees, Azimuth and Elevation
Mean Time Between Failure (MTBF)	40 yr
Temperature	-40° C to +55° C (-40° F to +131° F)
Wind Survival	190 km/hr (118 miles/hr)
Dimensions	11.75 in H x 3.4 in W x 3.4 in D (29.9 cm H x 8.6 cm W x 8.6 cm D)
Weight	.45 kg (1 lb)
Access Method	Time Division Duplexing/Time Division Multiple Access (TDD/TDMA)
Interface	10/100 Base T, half/full duplex. Rate auto negotiated (802.3 compliant)
Protocols Used	IPV4, UDP, TCP, ICMP, Telnet, HTTP, FTP, SNMP
Network Management	HTTP, TELNET, FTP, SNMP Version 2c
FCC ID	ABZ89FC5804
Industry Canada Certification Number	109W-5700
NYCE	0202CE08128
FIPS	AES product is FIPS 197 certified

HD23444
Stinger™ Passive Gain Antenna for 5.7 GHz SMs

Slip on an extra 10 dB @ 5.7 GHz.

- Extend your range to 5 miles without using a large reflector.
- Boost signal levels for marginal customers.
- Speed up your installs
- Narrows the pattern to 12 degrees
- Lowers Jitter

Typical gain increase from 12 to 14 dB.

Controlling Interference: The Canopy Approach

Interference in a PMP BWA network,either self-induced or external, is generally an issue more for the Access Point (AP) than for Subscriber Modules (SM).

At the AP, typically antennas with much wider angles are used so that they may communicate with many SMs spread over a given geography..

Beam widths for these devices can range from 45 to 360 degrees. The wider the angle, the more potential there exists for either self-interference or external interference.

Because a single AP supports dozens, if not hundreds, of end users or customers, interference at this stage in the network deployment can have a large impact.

Controlling Interference Continued

The issue in BWA networks designed to support data or IP-based traffic can be even more insidious.

In this instance, a very small amount of RF interference can have a huge performance impact on the network throughput: in some instances three to four percent RF interference can result in a 40 percent reduction actual end-to-end data rates.

The problem of interference in PTP networks operating in the license exempt bands, while not as severe as that encountered in PMP networks(due to the use of highly directional antennas at both ends),must still be addressed.

Modulation and the C/I ratio

At the most fundamental level, an interfering RF source disrupts the digital transmission by making it too difficult for the receiving station to "decode" the signal.

How much noise or interference a digital RF transmission can tolerate depends on the modulation used.

Fundamentally, modulation is the method whereby zeros and ones are communicated by varying one of three aspects of a radio signal.

The three portions of an RF signal that can be changed or modulated are phase, frequency, and amplitude. Shifting the properties of any of these parameters can be used to communicate different "states." These states, in turn, are translated to zeros and ones for binary communications.

Binary Frequency Shift Keying BFSK

For example, with frequency modulation, if the sine wave is at frequency one, it is decoded as a zero. If the sine wave is shifted slightly to frequency two, this is decoded as a one.

This type of modulation is referred to as Binary FSK (BFSK), or Frequency Shift Keying. In this example, a system must only be able to tell the difference between one of two states or phases.

More complex modulations, such as 16QAM (quadrature amplitude modulation), attempt to differentiate among 16 different possible states of an incoming signal.

Advantage of BFSK

The ability of a receiving station to decode an incoming signal at the most basic physical layer is dependent on a factor called the "carrier to interference ratio," or C/I.

This fancy-sounding term means exactly what it says: how strong the desired signal (the carrier) is relative to the unwanted signals (the interference).

C/I ratios are based primarily on the modulation used, with more complex modulations requiring higher C/I numbers than more robust modulations, such as BFSK.

More BFSK

The Canopy product employs BFSK for modulation. With this modulation the C/I ratio necessary to operate properly with an error rate of 1x 10-4 bits per second is only 3dB;

i.e. the wanted signal need be only 3dB higher in power than the unwanted interferers.

A system operating with 16 QAM at these levels would require a C/I ratio ofroughly 12 to 14dB.

Putting this into perspective, with every 3dB of additional signal strength, the power of a signal is doubled.

Still More BFSK

This means that the Canopy system, with its C/I ratio of 3dB, can tolerate an interfering signal that is many times more powerful than a 16QAM system and still operate at the specified error rate.

Canopy system employing BFSK modulation will tolerate substantially higher levels of interference before the communication stream becomes impacted. All other PHY layer techniques are designed to improve this most fundamental measurement of network robustness and operational effectiveness by sustaining the necessary C/I level.

Antenna Front-To-Back Ratio

The front-to-back ratio of an AP antenna indicates how much of an incoming signal will be absorbed coming into the front of the antenna as compared to how much of a signal arriving at the back of the antenna is absorbed.

When deploying networks in a cellular topology, the performance of the antenna in rejecting unwanted signals from behind is an important feature.

The Canopy system, with its integrated antennas at the AP, has a front-to-back ratio of 20dB.

Coupled with the excellent C/I ratio, this means a Canopy AP receiving a signal at threshold (the weakest signal it can still detect) can be hit with an interfering signal from behind, either internal or external, on the order of -60dBm and still support connections at an acceptable error rate.

Time Division Duplexing Synchronization

BWA networks that use Time Division Duplexing for separating upstream and downstream communications are ideally suited for asymmetric traffic, such as data.

The ability to adjust the amount of bandwidth dedicated for upstream and downstream communications without changing hardware is a powerful feature.

TDD systems operate by transmitting downstream (from the AP to the SM) for a period of time -- 1ms for example. Following a short guard time, the SMs then transmit on the same frequency in the upstream.

TDD Continued

For a cell site with more than one radio operating in TDD mode, it is important that all the sectors of the cell transmit and receive at precisely the same time.

Otherwise, if sector 1 is transmitting when sector 2 is receiving, sector 2's incoming transmission can be interfered with even if they are on different frequency channels because the sector 1 signal is so close it is strong enough to "flood" or overwhelm the electronics in sector 2.

More TDD

When deploying a TDD system in a cellular topology, it is desirable to be able to use the same frequency in each cell site even though those cell sites are possibly several miles away.

This means sector 1 from AP A may interfere with sector 1 of AP B. To avoid this inter-cellular synchronization is required, making sure that all the sectors in all the cell sites are properly timed and synchronized in terms of downstream and upstream communications.

With the Canopy system, designed for large scale, dense network deployments, TDD synchronization is a critical requirement. This has been solved with the use of a GPS signal. These precise satellite signals are used for timing and, ultimately, transmit/receive synchronization, thus tying all sectors in a Canopy network to the same "clock."

Dealing W/Interference- The MAC Layer

MAC - Medium Access Control

MAC Layer- That layer of a distributed communication system concerned with the control access to a medium that is shared between two or more entities

The original data, an IP packet datagram, for example, is segmented into packets that fit into a radio data packet (RDP).

Despite all the best deployment design and use of the extremely robust Canopy system, there will be instances where interference will overcome these measures and corrupt a MAC frame or a portion of a MAC frame.

When this happens, the corrupted data must be sent again. If the MAC frame is designed for large RDPs on the order of several hundred bytes, the entire slot must be re-transmitted even if only a small amount of this packet is damaged

The MAC Layer Continued

The impact on network throughput as a result can be large, with a few bytes in error causing hundreds of bytes to be re-sent.

Canopy solves this problem by using RDPs sized at 64 bytes. With this smaller RDP size, the re-transmission can be contained to only those bytes that were damaged, thus avoiding the re-send of large chunks of valid data.

The 64-byte slot could have been made even smaller, but as RDP size decreases, the slot header which is fixed becomes a more significant portion of the packet data, hence increasing the MAC layer overhead.

In addition the 64-byte slot is ideally sized for handling the TCP acknowledgements sent for most IP packets.

The Problem With TCP

TCP/IP networks were designed to operate in the wired world where interference was assumed to be negligible.

The protocol design calls for a positive acknowledgement sent from the receiving station to the sending station for every IP packet sent out.

If the sending station does not receive the TCP ACK in a certain amount of time, it is assumed that the cause was congestion of the network - not an error resulting from transmission impediments.

When encountering congestion, TCP responds by dramatically slowing down the transmission and then increasing transmission speed slowly.

Automatic Retransmission Request

The Canopy system solves the problem with a feature called Automatic Retransmission reQuest or ARQ.

ARQ actually inspects the RDPs that come into the receiving SM and looks for errors. If an error is detected, the SM (or AP) will send a request to the sending entity to re-send the RDP.

All of this is accomplished two layers below TCP in the protocol stack. The net effect is that as far as TCP is concerned, it never receives a packet of data with an error as a result of the wireless portion of the network.

This prevents TCP from invoking the slow start algorithm, keeping the end-to-end data rates at the peak or just slightly below peak operational rates.

IEEE 802.11 Transmit Contention

The IEEE 802.11 standard operates in what is referred to as a distributed control manner. This means that each SM has the ability to send a packet at its own discretion.

Typically in this scenario the SM will "listen," and if it does not hear any transmissions, it will assume the channel is clear and send its data.

The problem arises if the sending SM cannot hear other SMs.

In this instance, two or more SMs may send a packet at the same time, corrupting both and causing a retransmission. Interference is also a culprit in blocking SMs from hearing each other with the same effect

Centralized Transmission Control

Canopy solves this contention problem by implementing a demand contention access scheme where the AP controls all transmissions in the sector, both upstream and downstream.

An SM will only send its data when allowed.

If an SM's request to send data is interfered with, it will wait and try again, but at no point will it ever transmit into the uplink data channel until it is permitted by the AP.

Expectations

- To stream video at a bandwidth of 150K bps.
- High Reliability 99.9999% ?

Reliability

- The simplest definition of **reliability** is quality over time. Since time is involved in reliability, it is often measured by a rate. Just as quality is usually measured in terms of rejects (or un-quality), reliability is measured in terms of failures (or un-reliability). (from NASA website)
- **Reliability** is a network's ability to perform a designated set of functions under certain conditions at specified operational times.
- **Availability** is a network's ability to perform its functions at any given instant under certain conditions. Average availability is a function of how often something fails and how long it takes to recover from failure.

Preliminary Planning

The next step should be to decide on the degree of reliability or availability which the system is required to yield.

Most non-technical people posed with such a question would probably respond with answers like: "The best possible, " "It must always be available when needed," or possibly "Communications are vital to be my business and no service interruptions can be tolerated."

Unfortunately, these answers are of little value or help to the microwave system designer who requires a specific numeric value upon which to base the design.

The appropriate selection of this value is of paramount importance, since it will affect many subsequent design decisions and the over-all cost of the system.

RF Design Criteria

- Operating frequency band
- Maximum path length
- The need for diversity
- Equipment failure protection
- Antenna size
- Transmitter output power
- Equipment selection
- The required traffic capacity
- The length of the path
- Frequency congestion in the area
- Weather conditions

Reliability Table

Reliability %	Outage time %	Outage time per year
0	100	8760 hours
90	10	876 hours
98	2	175.2 hours
99	1	87.6 hours
99.9	0.1	8.8 hours
99.95	0.05	4.4 hours
99.99	0.01	53 minutes
99.995	0.005	26 minutes
99.999	0.001	5 minutes
99.9999	0.0001	32 seconds

Reliability Continued

The reliability Table shows the relationship between reliability and outage time, but it is almost impossible to predict the duration and frequency of each individual outage, which will contribute to this total value.

Further, the outage time will be composed of two different reliability figures.

Equipment malfunctions can be expected to be relatively rare, particularly if standby assemblies are furnished, but may be of long duration. If the microwave station is remotely located, it may take an hour or more to dispatch a technician and remedy the fault.

Service interruptions due to propagation conditions will be more frequent but of short duration—typically a few seconds. The permissible outage time will affect such factors as:

Reliability Calculations (Norwood)

Unreliability= Outage Probability =

$$Undp = a \times b \times 2.5 \times 10^{-6} \times f \times D^{3} \times 10^{\frac{-F}{10}}$$

a = Terrain Factor = 1 (for average terrain, with some roughness)
b = Climate Factor = 0.25 (for nomal interior temperate or northern areas)
f = frequency in GHz
D = Path length in miles
F = Fade Margin in dB

$$Undp_{Norwood} = 1 \times 0.25 \times 2.5 \times 10^{-6} \times 5.7 \times 5.4^{3} \times 10^{\frac{-7}{10}} = 111.9126 \times 10^{-6}$$

The percent reliability is computed from the outage probability = $\%R = 100 \times (1 - Undp)$

$$\%R = 100 \times \left(1 - 111.9126 \times 10^{-6}\right) = 99.9888\%$$

$$\frac{\text{Outage}}{\text{Year}} = 365.25 \times 24 \times 60 \times 111.9126 \times 10^{-6} = 58.86\,\text{min}$$

Reciprocity In Antenna Design

One important point to note here is that the antenna gain is reciprocal, i.e., the antenna gain can be added to the wireless device at either end to increase the overall link budget.

For example, a wireless system with a 10 dBi antenna on the transmitter and a 2 dBi antenna on the receiver will have the same range as a system with a 4 dBi antenna the transmitter and an 8 dBi antenna on the receiver, everything else being equal.

Therefore, adding a high gain antenna allows a device not only to transmit signals farther, but also to receive weaker signals.

Calculating Rx Signal Level

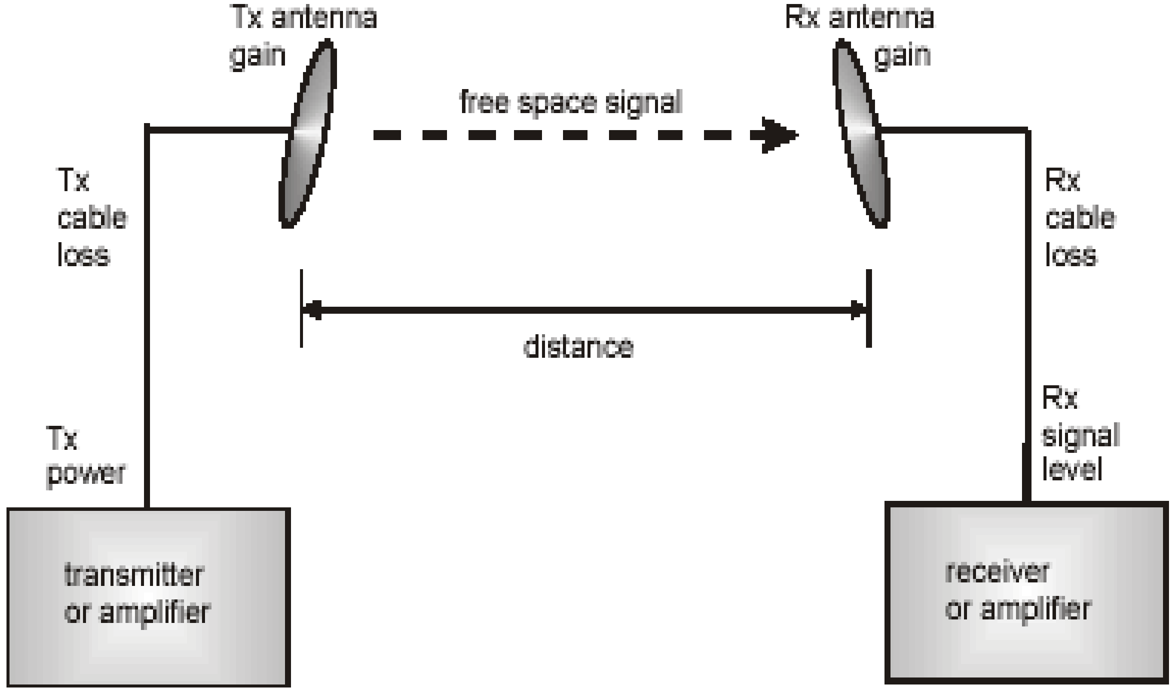


Figure 37: Determinants in Rx signal level

Rx signal level is calculated as follows:

Rx signal level dB = *Tx power* − *Tx cable loss* + *Tx antenna gain* − *free space path loss* + *Rx antenna gain* − *Rx cable loss*

Signal Level Calculations

Link Budget =TXpwr +TXgain + Rxgain + Rxgain - (-Rxsensitivity) - FM
= 23dBm + 7dBi + 10dBi(stinger) + 7dBi - (-86dB) -3dB= 130dB

Rx Bryte Bend = 23dBm + 7dBi - 0 + 10dBi(stinger) - 119dB(2.4miles) + 7dBi - 0 = -72dB

Rx Northgate = 23dBm + 7dBi - 0 + 10dBi(stinger) - 122dB(2.4miles) + 7dBi - 0 = -75dB

Rx Norwood = 23dBm + 7dBi - 0 + 10dBi(stinger) - 126dB(2.4miles) + 7dBi - 0 = -79dB

Rx Raley = 23dBm + 7dBi - 0 + 10dBi(stinger) - 126dB(2.4miles) + 7dBi - 0 = -79dB

Fade Margin Calculations

Calculating Fade Margin

Free space path loss is a major determinant in Rx (received) signal level. Rx signal level, in turn, is a major factor in the system operating margin (fade margin), which is calculated as follows:

system operating margin (fade margin) dB = *Rx signal level* dB − *Rx sensitivity* dB

Thus, fade margin is the difference between strength of the received signal and the strength that the receiver requires for maintaining a reliable link. A higher fade margin is characteristic of a more reliable link.

Typically, broadband wireless systems recommend a fade margin of 10dB. The Canopy system is unique in being more tolerant of lower fade margin that other systems, and can operate reliably with a 3dB fade margin.

FM Bryte Bend = -72dB - (-86dB) = 14dB

FM Northgate = -75dB - (-86dB) = 11dB

FM Norwood = -79dB - (-86dB) = 7dB

FM Norwood = -79dB - (-86dB) = 7dB

Norwood Fresnel Zone Calculation

F1 = The first Fresnel zone radius in feet
D = the total path length in miles
d1 = the distance from one end-point to the point being considered in miles
d2 = D - d1 in miles
f = Frequency in GHz

$$F_1 = 72\sqrt{\frac{(d1 \times d2)}{f \times D}}$$

$$F_1 = 72\sqrt{\frac{(0.3mi \times 5.1mi)}{5.7GHz \times 5.4mi}} = 16\,ft$$

Jitter

USING JITTER TO CHECK RECEIVED SIGNAL QUALITY

The General Status tab in the Home page of the Canopy SM and BHS displays current values for **Jitter**. This is an index of overall received signal quality. Interpret the jitter value as indicated in Table 32.

Table 32: Signal quality levels indicated by jitter

Signal Modulation	Correlation of Highest Seen Jitter to Signal Quality		
	High Quality	Questionable Quality	Poor Quality
1X operation (2-level FSK)	0 to 4	5 to 14	15
2X operation (4-level FSK)	0 to 9	10 to 14	15

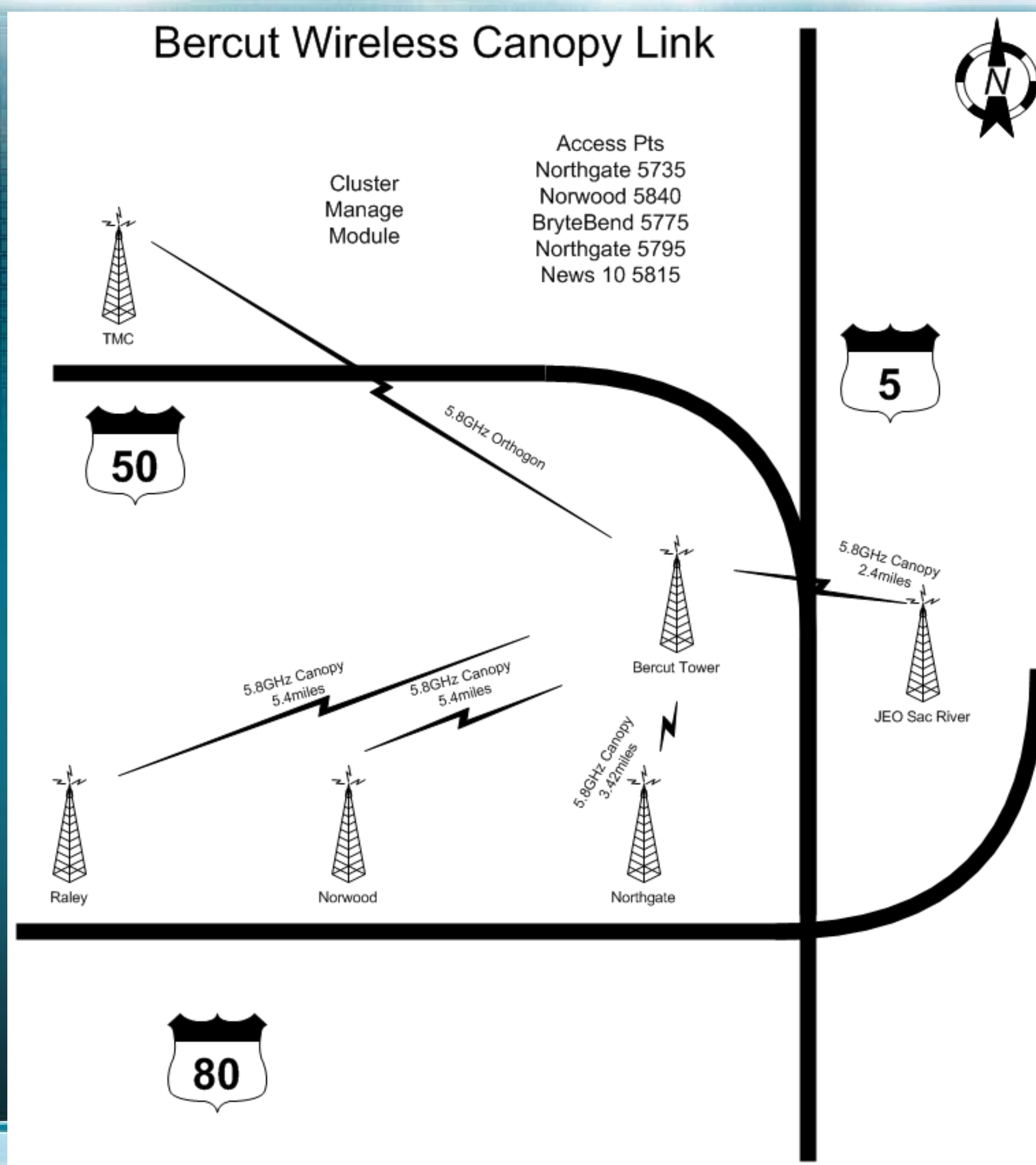
In your lab, an SM whose jitter value is constant at 14 may have an incoming packet efficiency of 100%. However, a deployed SM whose jitter value is 14 is likely to have even higher jitter values as interfering signals fluctuate in strength over time. So, *do not* consider 14 to be acceptable. Avoiding a jitter value of 15 should be the highest priority in establishing a link. At 15, jitter causes fragments to be dropped and link efficiency to suffer.

Canopy modules calculate jitter based on both interference and the modulation scheme. For this reason, values on the low end of the jitter range that are significantly higher in 2X operation can still be indications of a high quality signal. For example, where the amount of interference remains constant, an SM with a jitter value of 3 in 1X operation can display a jitter value of 7 when enabled for 2X operation.

However, on the high end of the jitter range, *do not* consider the higher values in 2X operation to be acceptable. This is because 2X operation is much more susceptible to problems from interference than is 1X. For example, where the amount of interference remains constant, an SM with a jitter value of 6 in 1X operation can display a jitter value of 14 when enabled for 2X operation. As indicated in Table 32, these values are unacceptable.

Assumptions

- Bercut tower radio mounting height 220ft
- Spectral Density
- Line of Sight was “good enough”


Bercut Wireless Canopy Link
Cluster
Manage
Module
Access Pts
Northgate 5735
Norwood 5840
BryteBend 5775
Northgate 5795
News 10 5815
N
TMC
5.8GHz Orthogon
5
50
5.8GHz Canopy
2.4miles
Bercut Tower
JEO Sac River
5.8GHz Canopy
5.4miles
5.8GHz Canopy
5.4miles
5.8GHz Canopy
3.42miles
Raley
Norwood
Northgate
80

Motorola’s Analysis

Bob Simmons (Senior Account Manager) wrote the following:

The two Access Points (AP) located at the Bercut site will facilitate the connections to all four of the camera sites, with on one AP providing connections for the Northgate, Norwood, and Raley sites (as these sites appear to be within a 60 degree sector), and the other AP facilitating the connection to the Bryte Bend Bridge.

The Cluster Management Module (CMM) will provide the clocking for all the radios in this application.

I have also included 2 Ethernet surge suppressors at each remote location with the assumption that there will be a high level of radio activity in the area.

If you feel that there is a minimal amount of RF interference at these locations, you may choose to install a single surge suppression unit at the bottom of the Ethernet cable run on the tower.

Motorola Caveats

With regards to the path analysis:

I wanted to mention that the path analysis information noted does not make allowances for any man-made or vegetative obstacles which may be in the transmission path.

I also want to note that as the antenna heights at each of the remote camera sites are relatively low, any man-made or vegetative obstacles which may be in close proximity to the remote camera sites may cause the link to be unreliable.

Please be advised that the Canopy units require a line of sight transmission path (which includes a minimum requirement for an 80% Fresnel Zone clearance for the same transmission path).

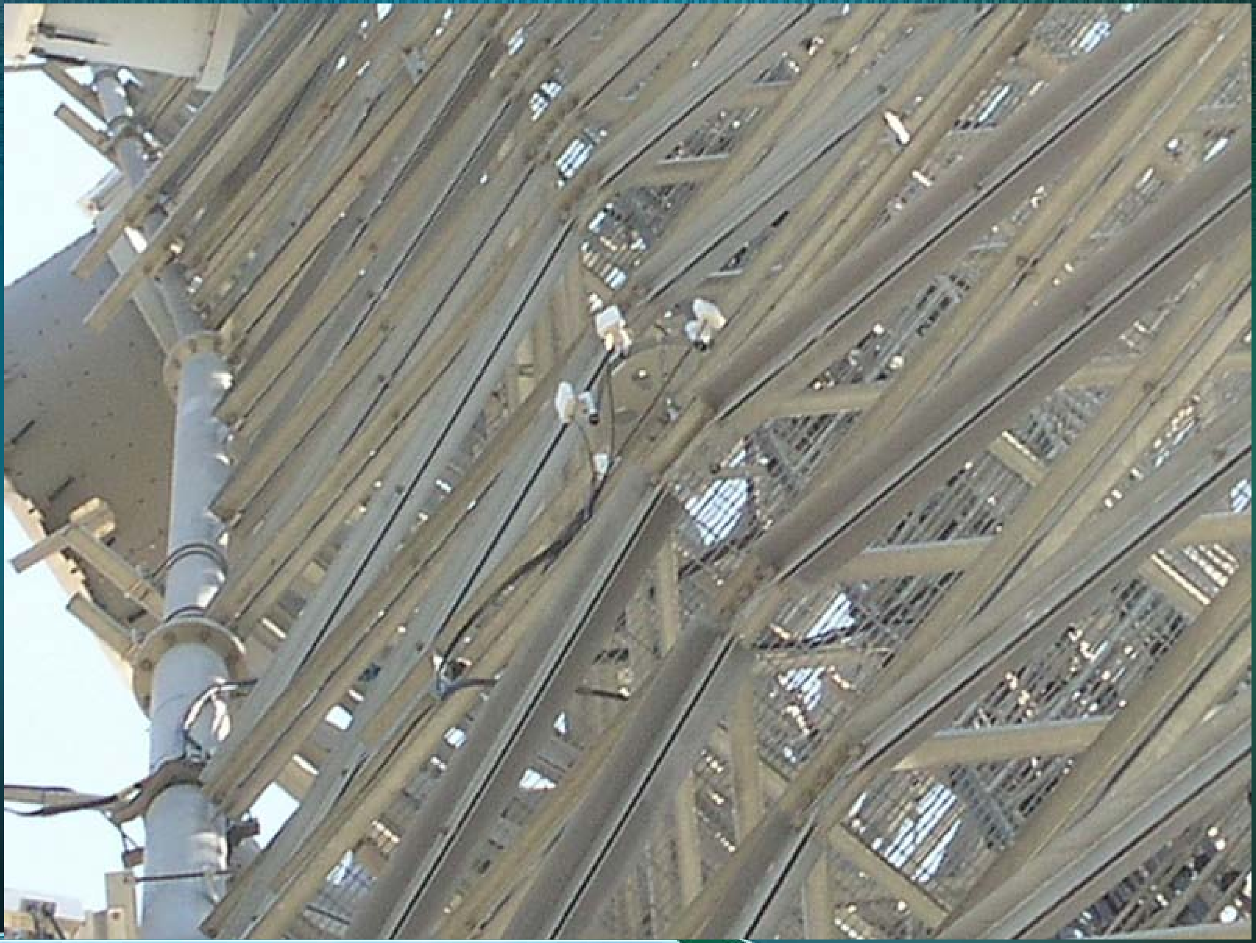
Actual Conditions August 2006

The DGS permit was restricted to the 135 ft level, not the 220ft as requested.

It was decided to populate the CMM with five radios. One per SM in case we needed to try a point-to-point approach. And One extra for future use.

The 10dBi Stinger antenna was used over the 18dBi Dish to avoid potential conflict with Structures.

Bercut Tower Array



Bercut Tower Array 2

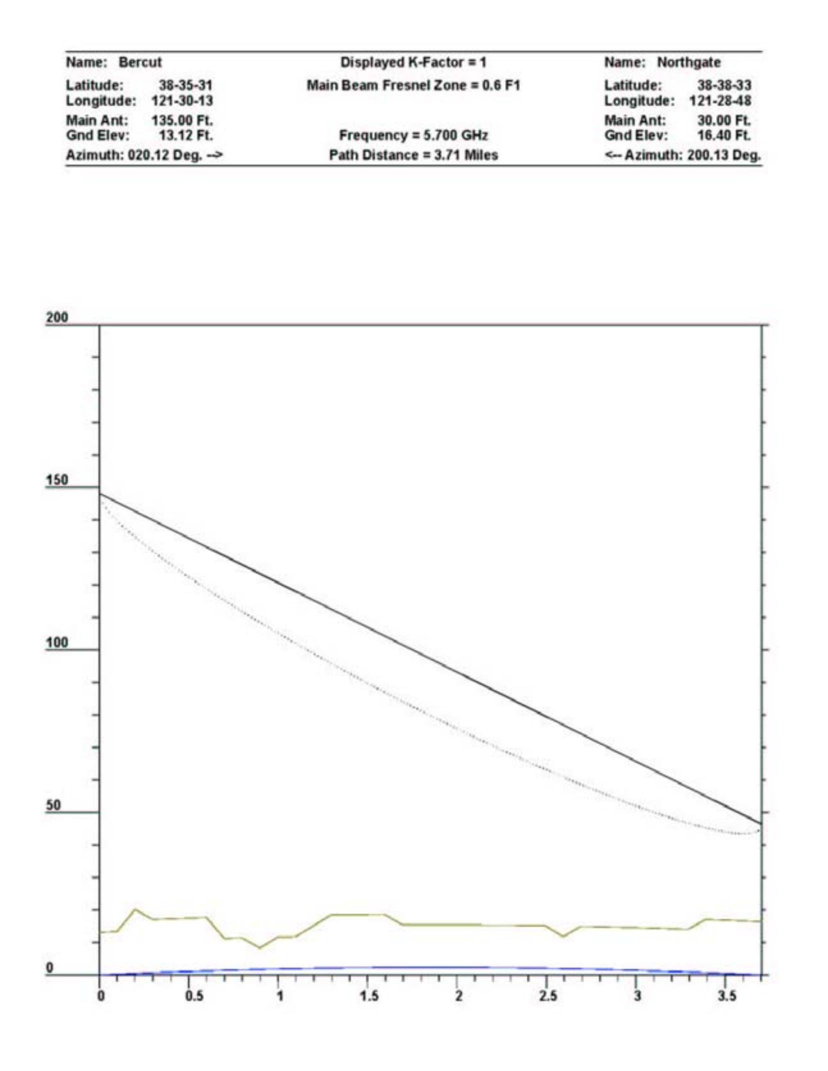
Northgate Results

The site at Northgate came up without issue and the received signal strength at the SM is -75dB

This yields an actual fade margin of 86dB - 75 dB = 11dB

The calculated fade margin was -75dB

Northgate Path



Northgate View From Cam to Bercut

Northgate SM

Bryte Bend Results

The site at Bryte Bend came up with issues and the received signal strength at the SM was -91dB

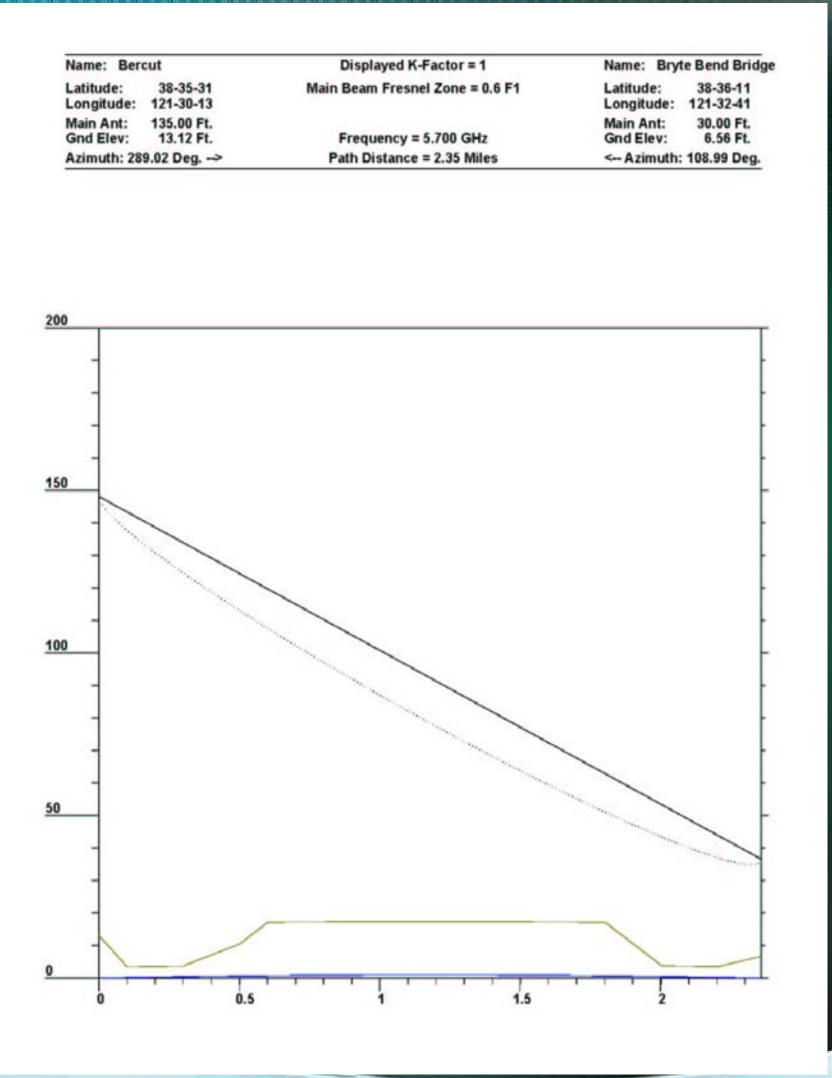
This yields an actual fade margin of 86dB - 91 dB = -5dB

It was determined that there was tree inclusion in the Fresnel Zone.

The SM was elevated 10 ft with a pole-to-pole extension and the Rx signal strength is now a measured 72dB.

This yields an actual fade margin of 86dB - 72 dB = 14dB
The calculated fade margin was -72dB

Bryte Bend Path



Bryte Bend Cam to Bercut

Bryte Bend SM

Norwood Results

The site at Norwood did not come up due to low -90dBm Rx signal

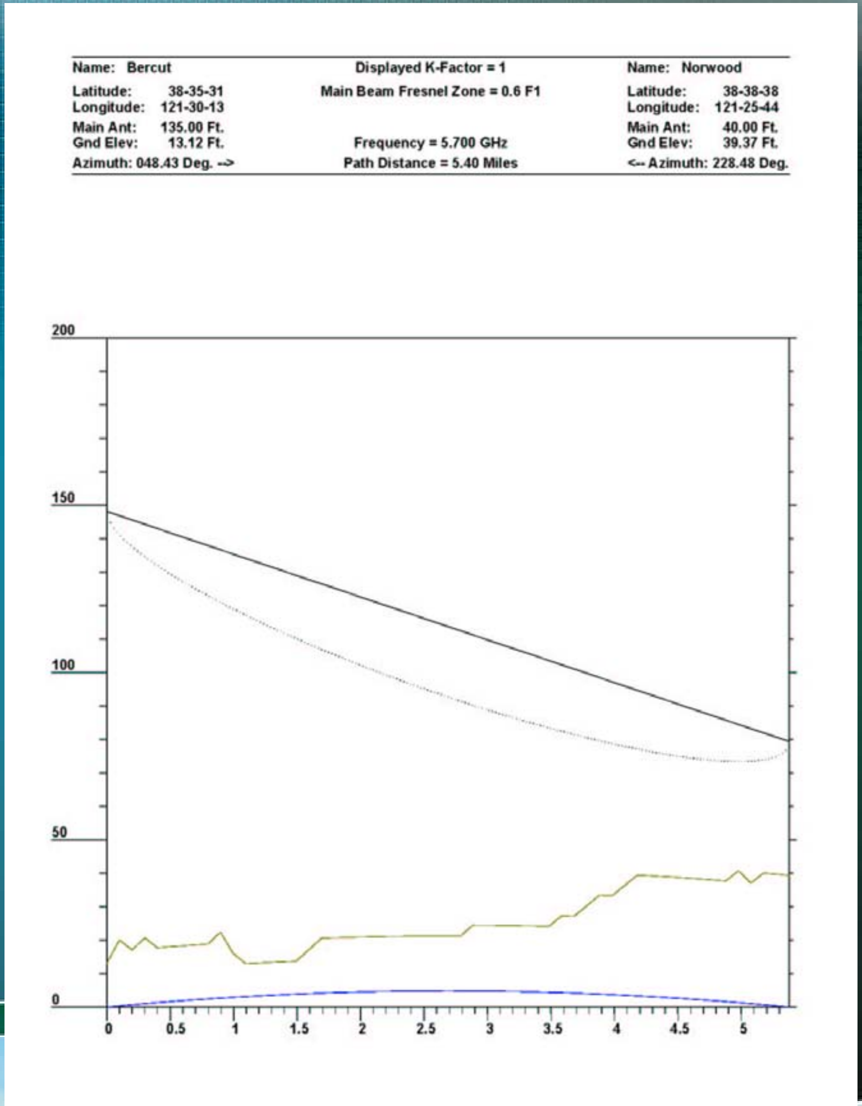
This yields an actual fade margin of 86dB - 90 dB = -4dB

Then came Fall/Winter 2006 and the link came up!
The Rx signal is now -80dBm

This yields an actual fade margin of 86dB - 80 dB = 6dB

Then came spring 2007, Rx back down to 90dBm
The calculated fade margin was -70dB

Norwood Path



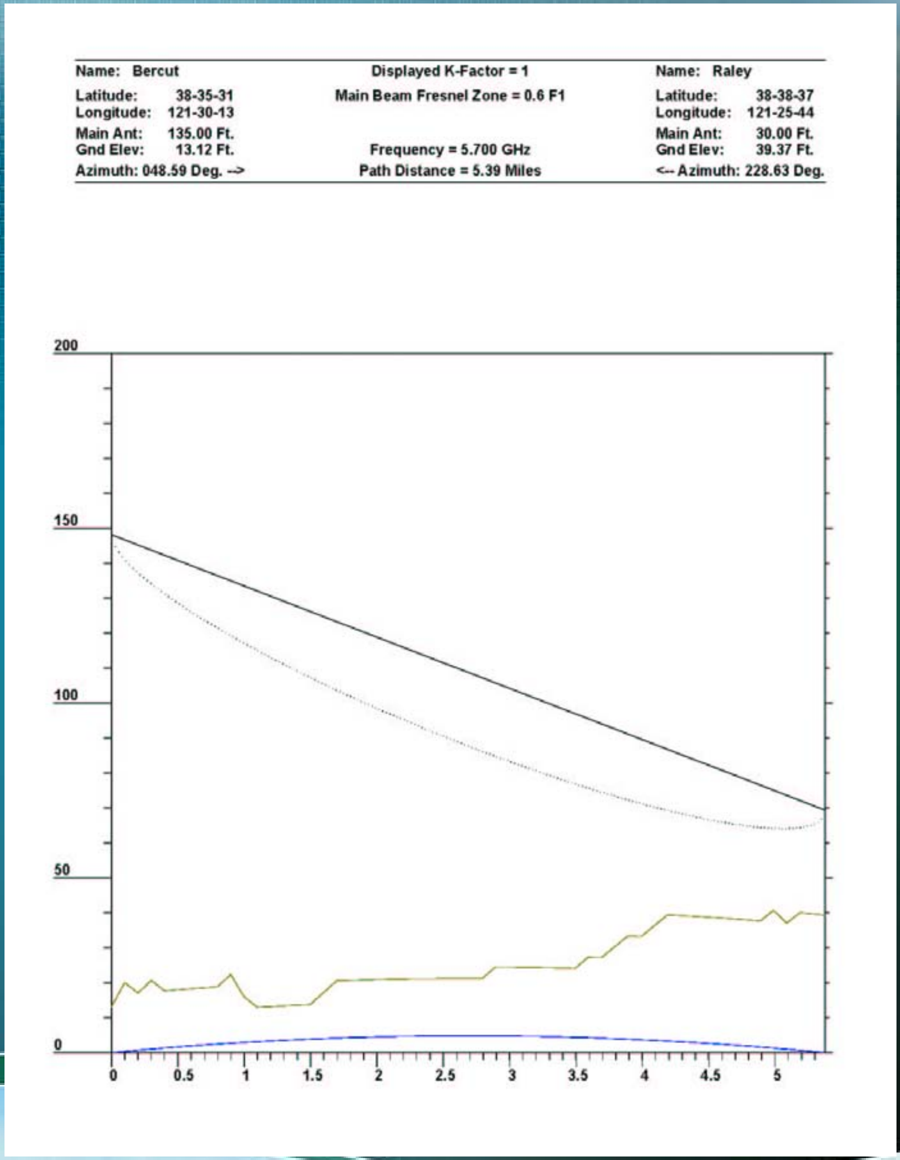
Norwood Cam to Bercut

Norwood SM

Raley Results

The site at Raley did not come up due to low Rx signal

Raley Path


Name: Bercut
Latitude: 38-35-31
Longitude: 121-30-13
Main Ant: 135.00 Ft.
Gnd Elev: 13.12 Ft.
Azimuth: 048.59 Deg. -->
Displayed K-Factor = 1
Main Beam Fresnel Zone = 0.6 F1
Frequency = 5.700 GHz
Path Distance = 5.39 Miles
Name: Raley
Latitude: 38-38-37
Longitude: 121-25-44
Main Ant: 30.00 Ft.
Gnd Elev: 39.37 Ft.
<-- Azimuth: 228.63 Deg.
200
150
100
50
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Raley SM

Wi-Fi Connective is providing the following prices for the products and services as listed in the tables below:

Note: Quotation valid for 30 days

Table 1: Product Description Canopy Multi-Point Links

PRODUCT DESCRIPTION	QTY.	LIST	PRICE	TOTAL
Motorola Canopy 5.7GHz Access Point w/AES (#5701AP)	5	1,595.00	1,454.65	7,273.25
Motorola Canopy 5.7GHz Subscriber w/AES (#5701SM)	5	845.00	770.65	3,853.25
Canopy Reflector Kit (#27RD)	5	100.00	91.20	456.00
Lightning Suppression (#NX4-60)	10	108.20	90.45	904.50
Canopy Power Supply (#ACPS110-03)	10	10.00	9.15	91.50
Cluster Management Module (#1070CK)	1	1,395.00	1,272.25	1,272.25
Estimated Product Sub-Total				13,850.75
CA Sales Tax	7.75%			1,073.43
Estimated Product Total				14,924.18
SERVICES DESCRIPTION				
Site Survey & Spectrum Analysis	16 hrs		187.50	3,000.00
Installation and configuration – Bercut	8 hrs		187.50	1,500.00
Installation and configuration – Northgate	8 hrs		187.50	1,500.00
Installation and configuration – Norwood	8 hrs		187.50	1,500.00
Installation and configuration – Bryte Bend Bridge	8 hrs		187.50	1,500.00
Documentation & Turnover Included				
Estimated Services Total	48 hrs			9,000.00
Estimated Project Total				**$23,924.18**

1. *All products are covered by the manufacturer's warranty and conditions*

Lessons Learned

- Nail down design variables prior to design (ie: Tower height availability)
- Perform site survey(spectral analysis of RF frequencies and line-of-sight determination) prior to project design.
- The more directional the antenna the better
- Choose licensed or licensed public safety band frequencies

Fixing Norwood & Raley

- Add a Stinger antenna to the AP
- Replace Stinger with a Dish at SM
- Raise the SM height
- Prune a tree