Air5^{TM} In-Home Field-Testing Results

December 2002 Tests

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Report No. 1[1]

1. Introduction

Extensive in-home and in-office field testing of the Air5 system is an on-going ingredient of Magis' engineering philosophy. The difficulties presented by the indoor wireless channel, specifically multipath, make it necessary to evaluate any real-world solution in a truly representative environment.

The results presented here made use of the Core Module (CM) hardware demonstration platform, version 1.1 based upon the MSG61XX[2] chipset. The high-level details of the testing performed were:

- CM version 1.1 demonstration hardware was used for both the AP and RT stations based upon the MSG61XX chipset.
- MAC framing set to deliver a maximum possible throughput of 34 Mbps whereas the MSG62XX chipset[3] will deliver upwards to approximately 43 Mbps
- Effective AP transmit power was set to +14 dBm
- Maximum allowable data-packet time jitter set to 3 msec.
- Access Point (AP) antennas used were Skycross 222-0875 Rev. A used in a pentagon arrangement, 2 inch spacing, with the transmit antenna element positioned in the center
- Remote Terminal (RT) antennas used were also Skycross 222-0875 Rev. A, but arranged in a linear array with 2 inch spacing.
- Cable and connector losses resulted in a receiver noise figure of approximately 10 dB.

The home which is the subject of this field testing report had the following characteristics:

- Approximately 3,500 square feet
- Two-story, stucco construction
- AP purposely positioned in a non-advantaged corner on the first floor

[1] Data collected December 6-7, 2002
[2] First-generation Magis chipset
[3] Second-generation Magis chipset

2. Test Methodology

Even though the data rates used during the field testing ranged from approximately 2 Mbps to greater than 30 Mbps, the time-variability of the 5 GHz communication channel makes it necessary to conduct measurements over a time span of minutes at each data collection point in order to obtain reliable results. The AP was left unchanged in a fixed location within the home whereas the RT was mobile on a small equipment cart and moved throughout the home to the different collection points. The antenna heights for both the AP and RT were slightly above waist level.

In order to get reliable results, it is also important to conduct the field testing cognizant of the differences between video and data-only distribution. The quality-of-service (QoS) aspects needed for video transmission are considerably more demanding than those required for data-only communications. This was accomplished in part by using actual trans-coded video MPEG2 streams ranging from 2 Mbps up to 29 Mbps[4] working with all of the appropriate IEEE802.11a physical layer (PHY) signaling rates and accumulating a wide range of link statistics from which video and data-only performance could be computed. Furthermore, testing of each trans-coded video rate at each appropriate PHY signaling rate was completely automated using a custom test instrumentation program working in conjunction with our MagisTest software operating on the host laptop computers used at the AP and RT ends of the link.

2.1 Performance Criteria

As alluded to already, the field testing focused simultaneously on data-only and video operational modes by collecting a wide range of link statistics. The following criteria were adopted:

Data-Only Mode: Disregard the number of required data packet re-transmissions for any given data packet (unbounded QoS) and report the maximum average throughput rate observed from all possible PHY modes. The average for each PHY mode was computed by averaging the RT data throughput for a specific PHY mode starting with the highest trans-

[4] Actual trans-coded video rates used were 2,4, 8, 12, 15, 19, 22, 25, 29 Mbps

coded video rate possible for the given PHY mode down through the lower trans-coded video rates until zero errors were observed over a 2 minute time period.

Video Mode: Recognizing that different MPEG2 decoders will conceal errors differently and perform differently in general over a wireless link, adopt the criteria that the link must be ***perfect*** over a 2 minute time interval and report the maximum trans-coded video rate supported independent of the PHY mode used.

An example should clarify the relationship between the data-mode and video-mode criteria:

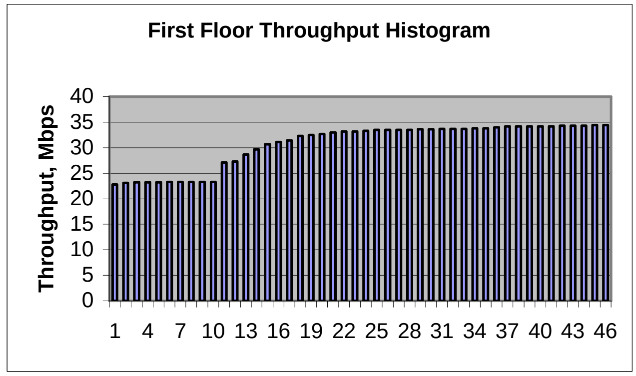
Example: 64-QAM R= ¾ has a maximum achievable throughput rate of 34 Mbps. Due to a non-zero packet-error-rate (PER) for the link in question, the delivered throughput at the RT may be only 23 Mbps whereas in video mode the supportable trans-coded video rate may only be 15 Mbps since data packets are dropped if they are not delivered without error within the 3 msec time-jitter QoS requirement.

2.2 Data-Mode Results

2.2.1 First-Floor

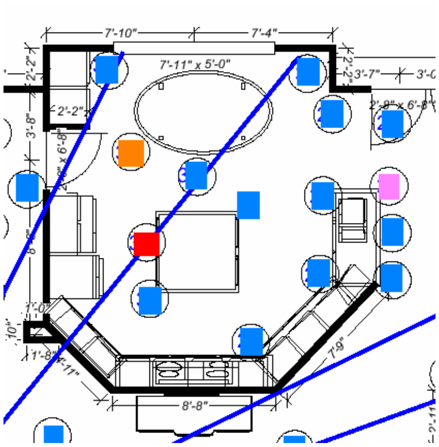
The data-mode field test results are shown relative to the home floor-plans in Figure 8 and Figure 9 in Section 5. As shown there and collectively shown in Figure 1, all of the collection points aside from some points in the garage delivered greater than approximately 22 Mbps throughput.

Figure 1 Data-Mode Throughput for All Data Collection Points on First-Floor



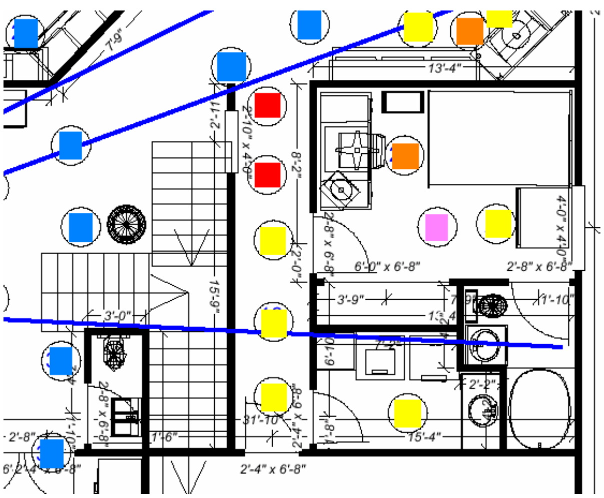
It is worthwhile discussing some of the collection points within the first floor where the data throughput rate was less than other nearby points. Take for instance the red and orange collection points within the kitchen area where the throughput dropped below the maximum 34 Mbps rate (see Figure 2). The blue lines in Figure 2 are meant to convey line-of-sight propagation paths possible from the AP. The reason that the data-mode throughput rate is below the full-rate in these kitchen areas is that a side-by-side double-oven and double-wide refrigerator impose substantial shadowing of the direct line-of-sight signal from the AP until the RT collection point is either pulled further away from these objects and signal diffraction is allowed to fill-in the shadowed area, or the collection point is moved to one side or other of the main signal shadow. A number of collection points were purposely taken in order to investigate signal shadowing and diffraction points like these in the kitchen and these are self-evident in Figure 8.

Figure 2 Close-Up of Kitchen Area on First-Floor Where Red, Orange and Lavender Squares Indicate Less than Full Throughput Rate



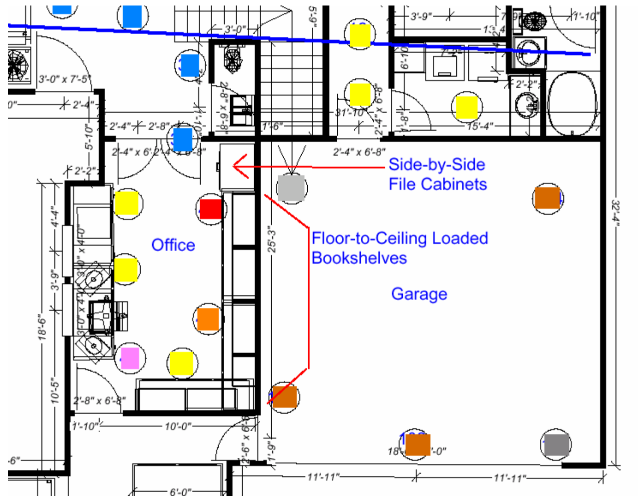
The collection points within the bedroom at "3 o'clock" in Figure 8 are shown separately here in Figure 3. A wooden double-stairway is to the left of the bedroom as shown and the signal must pass through two interior walls in order to reach the interior of this bedroom. Owing in large part to the moisture content in the wood, the signal undergoes a fair amount of attenuation when it is forced to pass through the staircase. Even so, the worst-case throughput in this bedroom is still 23 Mbps.

Figure 3 Close-Up of Collection Points in First-Floor Bedroom at "3 O'Clock" in Figure 8



Throughput into the garage was hampered by a number of factors as discussed using Figure 4. First of all, the interior of the garage is fairly distant from the AP. More importantly however, the direct line-of-sight path is heavily attenuated by multiple walls, including the firewalls that are a standard construction practice for garages.

Figure 4 Close-Up of Garage Area on First-Floor



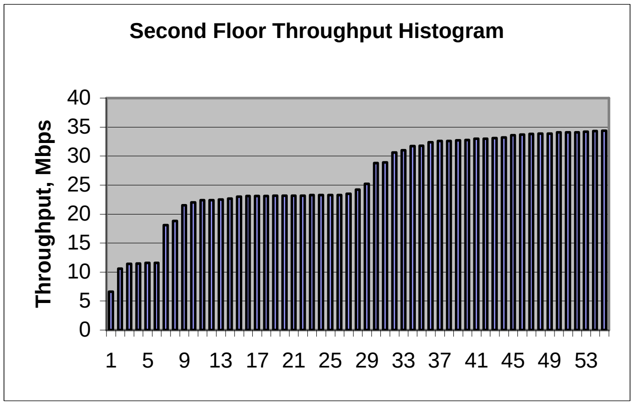
As shown in Figure 4, Side-by-side large file cabinets fall in line with floor-to-ceiling custom shelving in the office area to highly attenuate signals that are coming from the AP direction. The light-gray spot immediately to the right of the file cabinets (within the garage region) is evidence of the signal shadowing due to the collection point being so near to the large metal cabinets. Although not shown in Figure 4, the upper garage wall has a large up-right freezer, up-right metal utility cabinet and other loaded wall-mounted shelving that serves to attenuate signal energy that could enter the garage region from that direction. Given all of these factors, connectivity into the garage is still achieved however.

2.2.2 Second-Floor

The second-floor results show more throughput variability than the first-floor results primarily due to the heavily lossy paths from the AP to the front two bedrooms of the house. With the position of the AP adopted, the line-of-sight signal paths to the front bedrooms encounters multiple interior walls as well as the exterior walls of the home that contain a metal mesh for the stucco exterior. The signal radiation that reaches the front two upstairs bedrooms does so primarily through multiple reflections from within the home's interior.

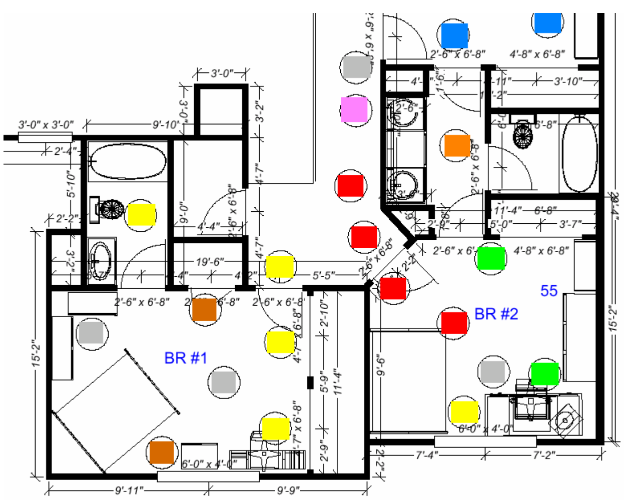
A histogram of all of the second-floor collection points along with the garage collection points is shown in Figure 5. As shown there, most of the collection points still exhibited a data-mode throughput rate in excess of 20 Mbps nonetheless.

Figure 5 Data-Mode Throughput for All Data Collection Points on Second-Floor Plus Garage



A close-up portion of the front bedrooms on the second-floor is shown in Figure 6. In the bedroom labeled "BR #1", the minimum throughput rate is > 10 Mbps for the two brown regions but otherwise > 20 Mbps even though the signal paths involved are unquestionably non-line-of-sight. These are impressive results given that multiple signal reflections within the home's interior are responsible for illuminating this bedroom with sufficient signal power for good link quality.

Figure 6 Front Bedrooms on Second-Floor



Signal coverage in the second bedroom labeled "BR #2" in Figure 6 is even better than the "BR #1" bedroom because although more distant from the AP, this bedroom is further away from the massive super-structure that goes up through bedroom "BR #1" and signal diffraction is more effective in illuminating this region of the home.

2.2.3 Data-Mode Conclusions

A number of conclusions can be drawn from the measurement results presented:

- The direct line-of-sight propagation path is normally preferred by the signal unless that path is highly attenuated;
- The data-mode throughput rate was > 20 Mbps throughout most of the house;
- Excellent non-line-of-sight performance was clearly exhibited;
- Even in the garage, network connectivity at a non-zero throughput rate was achieved throughout the entire home.
- The CM 1.1 hardware is a ***demonstration*** platform rather than a reference design. Substantial improvement beyond these reported results can be delivered in the forthcoming MGS61XX- and MGS62XX-based products.

2.3 Video Mode Results

Operation in the MPEG2 video mode is considerably more demanding than the data-only mode primarily due to QoS requirements. Unlike many other 802.11x based products, Air5 does not use large data buffers to try to smooth out large bursts of errors. Consequently, the link reliability must be much greater to support video but this also means that time latency is extremely small, on the order of a few msec.

As described earlier, in order to avoid any double-standard in comparing overall video performance with one MPEG2 decoder versus another, a very stringent link requirement was used as the criteria for the maximum supported video rate at any given data collection point. The criteria was zero errors over a minimum of 2 minutes with a QoS time-jitter limit of 3 msec. In actual practice, lesser requirements are sufficient as described in the summary section of this memorandum, Section 4. In field trials that have been subsequently done, this parameter has been relaxed to more like 10-15 msec with no impact on the video quality delivered but a substantial improvement in link performance. Nonetheless, the data with the more stringent jitter specification is reported on here, and the other results will be reported in subsequent memoranda.

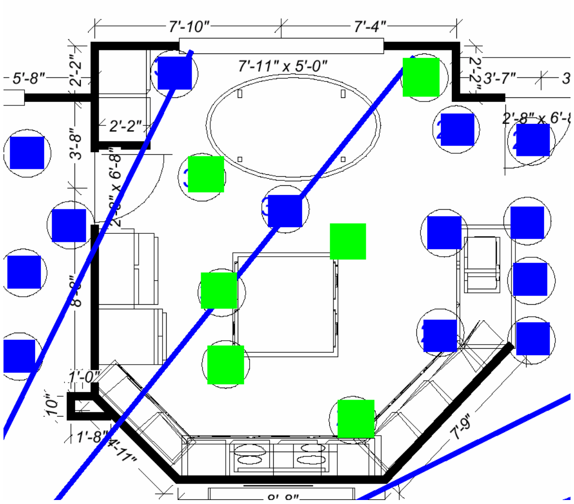
The trans-coded video source rates used in the testing were {2,4, 8, 12, 15, 19, 22, 25, 29} Mbps. In order to simplify presentation of the video performance results visually, all supported video rates 19 Mbps (corresponding to HDTV in the United States) and higher at a specific data collection point are denoted by the single color blue. Individual color legends are used for the remaining video rates that are less than 19 Mbps.

The color-coded video-mode performance results are shown in Section 5.2 in Figure 10 and Figure 11. Full 19 Mbps HDTV is supportable in the vast majority of data collection points within the entire home as shown.

2.3.1 First-Floor

Aside from two points within the garage area, DVD-quality video is supportable in the entire first-floor. HDTV at 19 Mbps is supportable as shown in the vast majority of the first-floor area with the exceptions due to heavy signal shadowing like that described in Section 2.2. The shadowing posed a significant impact on the collection points within the kitchen area where the combination of major appliances, metal piping and flashing along with waist-high antenna height were factors as shown in the close-up of this region in Figure 7.

Figure 7 Video-Mode Close-Up of Kitchen Area on First-Floor



2.3.2 Second-Floor

HDTV at 19 Mbps was fully supported in the majority of the second-floor as shown in Figure 11. Regions where the data-mode reception were challenging understandably showed up with lower video-mode capabilities as expected. DVD-quality video was supported throughout the second-floor with only one collection point exception.

3. Summary

Originally designed as a demonstration platform rather than a full-performance reference design, the CM 1.1 hardware displayed very good data-mode and video-mode performance in this sizeable home. The performance data clearly shows that the system performs very well in non-line-of-sight scenarios and the back-ground data showed that loss of performance was due to the absence of received signal strength rather than multipath. This point is very key in extrapolating what performance improvements are possible with the Air5 technology as discussed in Section 4.

The video-mode criteria of zero errors while limiting the time-jitter to a 3 msec maximum was overly conservative as mentioned earlier. At most collection points under this criteria, the supported video rate was only 66% to 50% of the supported data-mode throughput! Later tests have shown that relaxing the time-jitter requirement from 3 msec to 10-15 msec substantially increases the supportable video rate without any degradation in video performance (i.e., still maintaining the zero-error over 2 minutes video-mode criteria).

Other factors that can be improved by extending the CM 1.1 design into more of a reference design type platform include the following:

- The maximum transmit power level used in the field testing was 14 dBm whereas the (a) the 5.15 – 5.25 GHz frequency band permits +17 dBm to be used and the 5.25 – 5.35 GHz permits +23 dBm to be used;

- Cable and cable connector losses easily added 1-2 dB of additional loss at each end of the link because no effort was made to eliminate these;

- All of the antennas that were used were omni-directional, but in the second-floor locations their gain was often compromised due to shadowing of the equipment cart or CM1.1 circuit-board hardware. Compared to what is feasible, antenna losses between the transmit and receive ends of the link easily amounted to 5-15 dB depending upon the look-angle of each antenna. Subsequent measurements of the antenna performance in the array configurations have shown that the Skycross antenna elements perform very poorly when in proximity with other antenna elements even when spaced 2 inches apart making the 5-15 dB quantity mentioned here still quite conservative.

These are very attractive dB-budget quantities to capture in a new hardware demonstration platform since only 3-6 dB was needed in all but a very few data collection points to provide full HDTV video throughput.

4. Performance Expectation Using the MSG62XX Chipset

A complete reference design based upon the MSG62XX chipset will extend the level of performance substantially compared to the field test data reported in this memorandum. As stated earlier, loss of signal throughput was primarily due to inadequate signal strength rather than multipath. Any improvements in the basic link margin thereby improve the system throughput and robustness dB for dB since the multipath factor has already been accounted for.

Regarding the MSG62XX MAC, the following enhancements will be present as compared to the MGS61XX-based demonstration platform that was used in this field test effort:

- Maximum throughput rate increased from 34 Mbps for the MGS61XX-based field-test platform to > 43 Mbps representing an increase efficiency from 63% to >80%. A correspondingly higher PER can be tolerated over the channel while delivering the same video quality which translates into greater link robustness and or range.

- Relaxation of the time-jitter limit as discussed in Section 2.3 can be done for both the MSG61XX as well as the MGS62XX-based platforms resulting in substantially higher supported video-mode rates in difficult channel conditions.

The hardware demonstration platform performance can be improved substantially as described earlier in Section 3. In addition, the MSG62XX chipset offers significantly better performance in (i) receiver noise figure, (ii) local oscillator phase noise, (iii) linearity and (iv) baseband processing that all translate to additional improvements in link range and robustness. These items along with the expected improvements in each area are delineated in Table 1. As shown there, the potential to claim substantial improvement in link margin is sizeable and thereby very attractive since not all of the improvements need to be achieved in order to deliver truly outstanding performance. With this much performance improvement possible (26 dB for the first floor, 36 dB for the second floor), customers are free to make trade-offs in their hardware implementations in favor of different product criteria that they may have particularly high interest in. Some customers may not be able to position their product to transmit at +23 dBm for instance either due to power consumption or regulatory issues, but even without increasing the transmit power level above that used in the field-testing, the performance improvements possible from Table 1 would still amount to 17 dB for the first floor and 27 dB for the second floor which is outstanding.

Table 1 Estimated MSG62XX Reference Design PHY Improvements Compared to the CM 1.1 Demonstration Platform Performance in Field Testing

Link Budget: CM1.1 (MGS61XX) Vs Reference Design with MGS62XX						
Item	CM Test First Floor (MGS61XX)	CM Test Second Floor (MGS61XX)	First Floor with MGS62XX	Second Floor with MGS62XX	Δ, dB Improvement First Floor	Δ, dB Improvement Second Floor
AP						
Transmit Power	14	14	23	23	9	9
Transmit Antenna Cable Loss	1.5	1.5	0.5	0.5	1	1
Transmit Antenna Gain	1	-3	2	2	1	5
Improved Phase Noise**	0	0	2	2	2	2
Improved Linearity**	0	0	1	1	1	1
RT						
Receive Antenna Gain	1	-5	5	5	4	10
Receive Antenna Cable Loss	1.5	1.5	0.5	0.5	1	1
Receiver Noise Figure	9	9	4	4	5	5
Improved Phase Noise**	0	0	1	1		
Improved Rx Processing	0	0	2	2	2	2
					26	36

** Full Benefit Only Realized for 64-QAM Modes

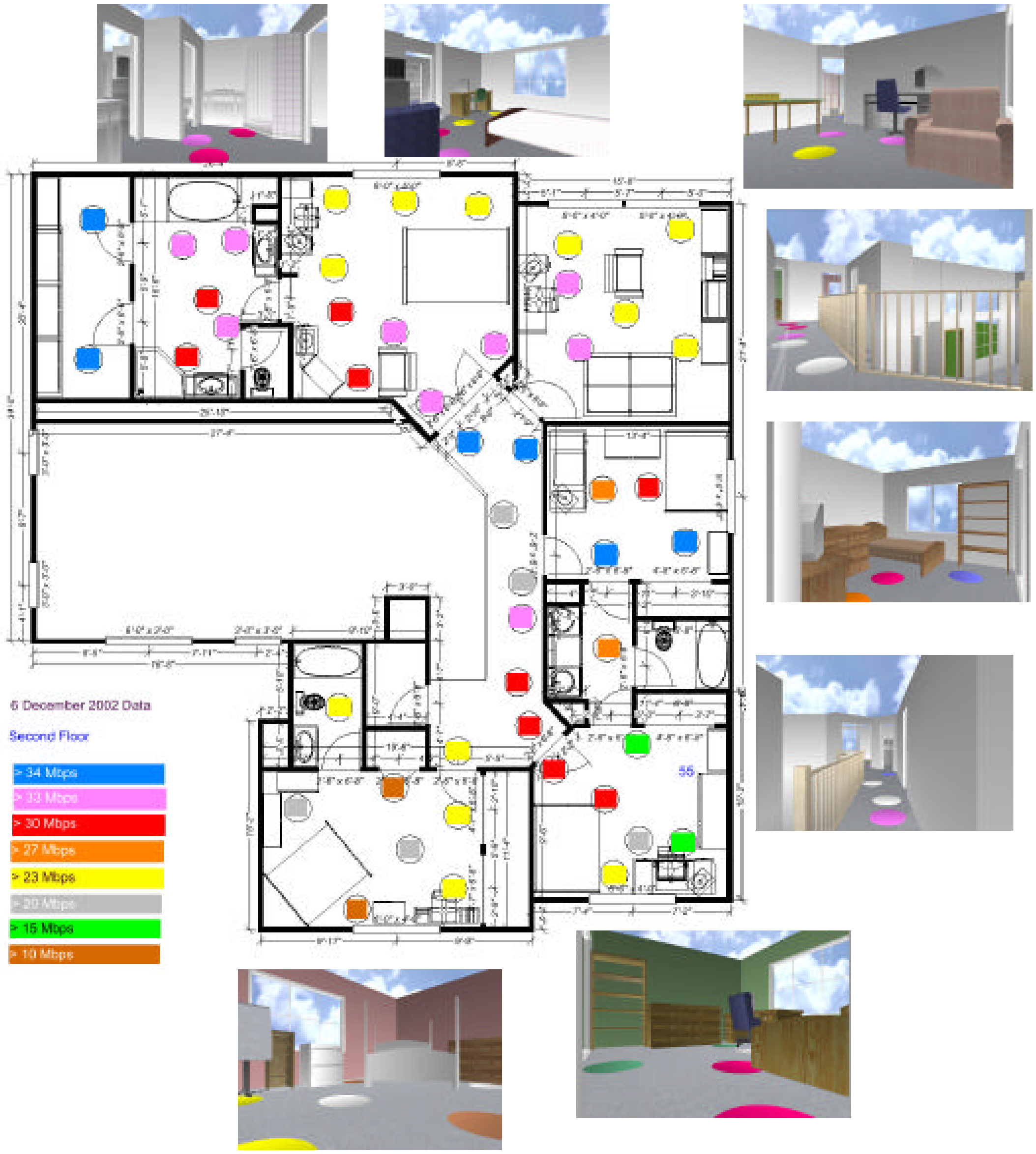
5. Appendix

5.1 *Data-Mode Testing Results*

Figure 8 Data-Mode Collection Results for First-Floor (Maximum diagonal distance shown in main living area is approximately 60 feet.)

Figure 9 Data-Mode Collection Results for Second-Floor

Home Testing
6-7 December 2002
Transmit Power: +14 dBm
Skycross Discrete Antennas



5.2 Video-Mode Testing Results

Figure 10 Maximum Supportable Video Mode for First-Floor

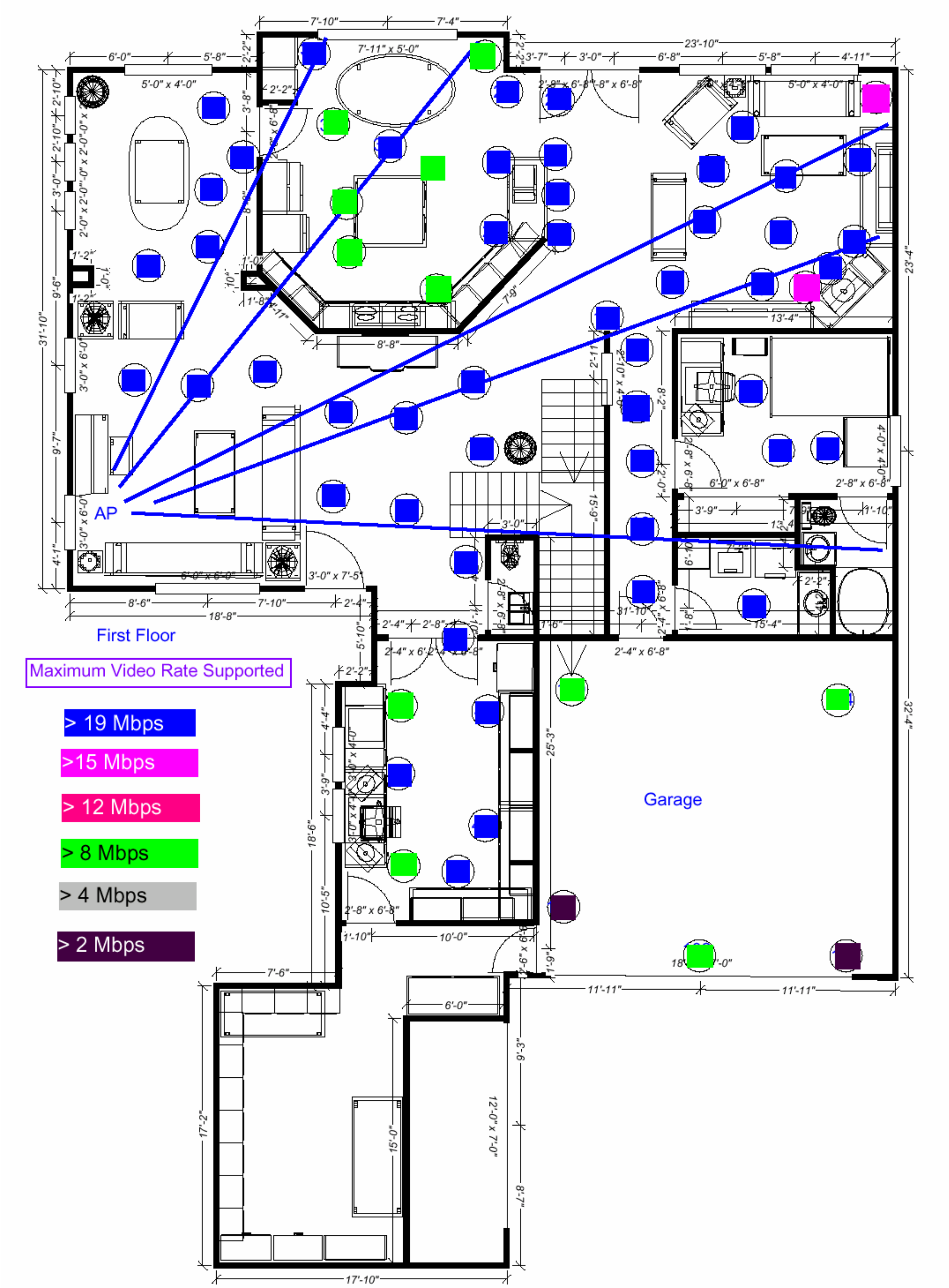


Figure 11 Maximum Supportable Video Mode for Second-Floor