Better Wireless LAN Coverage Through Ventilation Duct Antenna Systems
Benjamin E. Henty and Daniel D. Stancil
Electrical and Computer Engineering Department, Carnegie Mellon University, Pittsburgh, PA, USA
Email: henty+icc08@eirp.org and stancil@cmu.edu

Abstract—This work presents fair comparisons of a ventilation duct based antenna system to a conventional wireless LAN access point installation, both inside and in areas around the outside of a building. We present comparisons of 3 different access point locations using signal strength measurements at nearly 100 different locations in the building for each location. We also present signal strength measurement comparisons as a user gets further and further away from the building outdoors. Lastly, we use this data to show that ventilation duct antenna systems can provide better signal strength inside a building resulting in improved user experience and in reduced system installation and life-cycle cost.

I. INTRODUCTION

Winding their way through every corner of modern buildings are a series of tubes designed to deliver ventilation air to the users of the building. Ventilation ducts can also be used to provide inexpensive cellular and wireless data coverage inside a building. This idea is to use a building’s ventilation ducts as an antenna system for distributing radio frequency (RF) signals. Ventilation Duct Antenna Systems (VDAS) avoid the dead spots and mysterious variations in signal strength that plague wireless communications indoors. Instead, the closed metal ducts act as waveguides with low loss to evenly disburse wireless signals throughout buildings.

The use of ventilation ducts to distribute RF has been extensively studied (see for example [1]–[3]). However, in this work we present the first side-by-side comparison of wireless LAN (Local Area Network) coverage in an actual building. Others have looked at such a concept but for cellular installations, and less extensively in [4]. The results presented here also present a different propagation result than those presented in [4]. We also note that some portions of this work were presented in [5], but this is the first publication in a refereed setting.

Our measurements compared the coverage of a VDAS to a conventional IEEE 802.11g access point (AP) inside of and outdoors nearby to an open office building located in Stavanger, Norway and owned by the YIT corporation. We limited our measurement to the two ventilation duct networks present on the second floor of the building. The duct system is a specialized duct system called ClimaCeil, manufactured by YIT Building Systems. These two duct networks mainly consist of spiral cylindrical ducts of 400 mm and 315 mm diameters, though there are some rectangular ducts and junctions present in the network. The duct networks are run along the ceiling of the office and are located behind sheet metal ceiling panels of the sort shown in Fig. 1. These metal panels may provide an impediment to the performance of a ventilation duct network located behind a drop ceiling, so these results may be slightly pessimistic for the potential of a VDAS.

Fig. 1. Picture of the metal panels used to conceal the ventilation ducts used in our testbed network. These panels are used with the ClimaCeil commercial ventilation duct system available from the Building Systems division of the YIT Corporation.

We present our indoor propagation measurements in Section II. In Section III, we go on to present propagation measurements in the immediate surroundings outside of the building. We go on to analyze the potential improvements to wireless LAN coverage from using a ventilation duct antenna system (VDAS) over a conventional system in Section IV.

II. COVERAGE MEASUREMENTS

Using a Berkeley Varitronics YellowJacket scanning receiver, we simultaneously measured the signal strength from an AP connected to a ventilation duct and an AP of the same manufacturer and model setup conventionally at the same location directly below the duct connected AP. We compared the measured received signal strength indication (RSSI) for 3 different AP locations, totaling 290 measurement locations and covering 1400 m² of floor space. The scanning receiver recorded the signal strength of both APs over a 15 second or greater period and averaged the result for each measurement point. Since the beacon interval of the APs was set to 0.1024
seconds, this results in about 150 measurements at each measurement point. Both APs were Linksys WRT54G APs configured to transmit the same power and use the same channel frequency, but different SSIDs (Service Set IDentifiers). In this manner we could be sure we measured the RSSI of both APs at exactly the same location over the same period of time. The measurements were made in the late evening when the building was unoccupied to minimize the effects of fading, in addition to the use of the time averaging. The conventional AP was located at about 1.8 meters above the ground and the scanning receiver was placed on a rolling wooden cart at desk height of about 0.6 meters. Both the conventional AP and scanning receiver antennas were vertically polarized. The conventional AP used the standard rubber duck monopole antennas provided by the manufacturer. The ventilation duct AP was placed inside an RF shielded metal box to prevent any non-duct propagation. A cable was then run from an antenna connector jack on the AP out of the metal box to a quarter-wave monopole antenna inserted inside the ventilation duct. Both the conventional and ventilation duct APs had the transmit and receive diversity disabled on the device so that only a single antenna was used.

After setting up both APs at one of three locations, we used the scanning receiver to record signal strength at about 100 different locations in the building. For each AP location, we have generated a coverage plot of the conventional and duct coverage, as shown in Figs. 2, 3 and 4. These figures allow a fair, side-by-side comparison of a conventional wireless LAN AP and a ventilation duct AP. Note that in all figures, a numbered grid is used to refer to locations in the figures. Each square of the grid is 4.8 meters on a side.

In Figs. 2, 3 and 4, the AP is indicated by a star shape and labeled as an AP. In the VDAS cases, the ventilation duct network that the AP is connected to is highlighted in white. The received signal strength then is plotted as an interpolated and thresholded color map. That is, a triangular mesh grid is created of all of the measured points in each case. At every pixel inside every triangle, the RSSI is linearly interpolated between the three measured values used as the vertexes of each triangle. Each pixel then is colored according to one of eight colors indicated in the color bar legend in each graph based on the interpolated signal strength calculated for that pixel location. The signal strength range represented by each color is held fixed over all 3 figures for ease of comparison.

On first glance, the plots in Figs. 2, 3 and 4 may seem to show conventional systems are better than a VDAS system. However, from both individual performance and system level points of view, this is not the case. Firstly, we have seen in our own experimentation that at around -55 or -60 dBm of measured power the AP can achieve the maximum possible transmission bandwidth of 54 Mbps. The “hot spot” of power around the conventional APs therefore represents effectively wasted power because signal levels that high do not improve the throughput of the system.

Secondly, we note that while the signal from an AP in a conventional system decreases rapidly with distance, in a VDAS the signal distribution follows the ducts. This allows the coverage provided by the VDAS to be much more even than that provided by the conventional AP. Further, there is little variation in signal strength to areas within about 5 meters of a ventilation duct connected to an AP, while significant variations owing to the structure of the building occur in the conventional system.

We have also plotted comparisons of the duct based coverage versus the conventional coverage based on the same three AP locations. Figs. 5, 6, and 7 show the VDAS signal strength minus the conventional duct signal strength for each measurement point and once again interpolated and thresholded for plotting. Thus, the lighter colors are areas where the VDAS
provides better signal strength than a conventional AP.

Fig. 5. Plot of the difference in signal strength between conventional and duct based propagation using the data presented in Fig. 2.

Fig. 6. Plot of the difference in signal strength between conventional and duct based propagation using the data presented in Fig. 3.

Fig. 7. Plot of the difference in signal strength between conventional and duct based propagation using the data presented in Fig. 4.

Figs. 5, 6, and 7 further illustrate the benefits of VDAS based coverage. All three figures show that as we get further from an AP in a conventional system, we can have unexpected holes in coverage. Particular locations in a building will happen to perform worse than others based on the vagaries of the building structure. In contrast, the duct based coverage can consistently deliver power to the extremities of the building using the ventilation ducts. The comparison plots indicate that the duct based coverage can provide better coverage at distances as short as 10 meters in the building we measured. It should also be noted that the structure of the building we considered is a very open office environment. It has very few internal walls and those that exist are primarily glass or low cubicle walls. This sort of indoor environment should allow conventional signals to propagate more easily than an office environment with more internal walls. The duct based system, however, appears to be far less affected by the makeup of the building walls, and perform well regardless of the internal structures.

III. MEASUREMENTS OUTSIDE BUILDING

We were also interested in the coverage provided by a VDAS system to areas outside of, but near to a building. To explore this aspect, we performed a similar measurement to those presented in Section II. We compared the power leakage outside of a building from the same two APs, one connected to a duct as before, and one to a location just below the duct location. The location of the APs is indicated by a star in Fig. 8. Also shown are the 16 measurement locations outside the building. It should also be noted that the APs were near ceiling level on the second floor of the building and measurements outside were made at ground (i.e. first floor) level. The signal strength was measured using the YellowJacket so that both APs could be measured simultaneously. Both APs were set to the same channel, but had different SSIDs so that beacons could be distinguished and so that power measurements could be made simultaneously. Each signal strength measurement was averaged over 15 or more seconds of data.

The power level measured at each location is plotted in Fig. 9. Both the conventional and the duct connected AP power levels are shown. As can be seen from the figure, there is little difference in the signal strength between the two systems. This implies that there is no increased leakage around the building for those concerned with outdoor eavesdropping. It also implies that the VDAS system does as good a job as conventional installations at providing coverage to areas near a building for users who want some nearby coverage outside the building for areas like outdoor cafeterias.
IV. ADVANTAGES OF VDAS COVERAGE

Below we discuss some of the implications of the measurements presented above in terms of improvements to indoor coverage that can be made available by a VDAS technique. As we see it, the primary advantages of a VDAS are:

1) Coverage with fewer dead spots
2) Coverage in more ideal locations
3) A more fair allocation of coverage
4) Easier to predict coverage
5) Flexible AP locations
6) Reduced installation and life-cycle costs

The propagation measurements for the duct based coverage shown in Figs. 2(b), 3(b) and 4(b) clearly illustrate the first point. In all 3 cases, there is simply a low variation, even coverage area surrounding the ventilation ducts, especially within about 5 meters of a duct. However, unexpected holes in signal strength such as at the (7.3, 5.1) location in Fig. 2(a) are present in conventional coverage, sometimes within as few as 10 meters of an AP.

The second point we mentioned is less obvious from the plots presented, but is important to consider nonetheless. The second point is based on the location of ventilation ducts compared to the location of APs. Ventilation ducts are designed to provide air to the very locations where people are present in buildings. Thus, by their very nature, a VDAS routes its signals directly to the user location. However, for a conventional system, an AP can not be located near all the users it needs to serve. A system designer must decide in a sense which users are “more important,” use more APs than necessary, or simply locate APs as the building structure and propagation dictate.

The third point above is a combined result of the other two. Since the ventilation duct based coverage provides similar signal strength values to all locations near a ventilation duct and the areas covered are those where there are users, then a VDAS provides a more uniform user experience and should provide better overall fairness to the users of each AP. The reasoning behind this idea is that a VDAS may give up some high signal strength values near the AP, but in return, the VDAS provides very similar RSSI over the entire area covered. As a result, the network will be free of poor coverage areas. This in turn should prevent a user in a poor coverage area from consuming more network resources than other users due to a necessary lower transmission rate. For example, a user in a low signal strength location in a conventional coverage system may be forced to use a lower bandwidth transmission rate. Assuming all users want to access the same amount of data, the lower bandwidth will result in the disadvantaged user consuming more of an APs time and reducing the system capacity available to all users. By reducing or eliminating the weak locations, a VDAS prevents such a circumstance and also provides a more uniform user experience. By providing users with the same signal strength everywhere, there is less confusion on a user’s part over why their network performs better in some areas of a building than others.

The fourth point above refers to the fact that coverage seems to evenly and directly follow the area around a ventilation duct. While trying to predict the signal strength around a conventional AP, one either needs to accept reduced accuracy or carefully model the structures of a building. However, we observe that the areas covered by a VDAS do not seem to be affected by the specific structure of the building, only by the locations of the ducts. This allows us to more easily predict the covered areas in a building for the VDAS system.

Our fifth point is based on the argument that we seem to be afforded a great deal of flexibility in choosing where along the duct that we can connect an AP. For different duct connection locations, we still cover the area around the duct. Thus, we can select a duct connection location based on other factors such as easy to access locations or locations with shorter power or data cable run requirements. This flexibility can also contribute
to a reduced life-cycle cost, which is our sixth point.

Our last point is that a VDAS based system can help an installation have a lower total cost over the life-time of the system. If APs are located in easier to access locations, service and replacement costs are reduced. However, it is also not unusual for building renovations to add or remove walls to an office space. Such renovations may require a costly redesign or change to the wireless system. However, the VDAS is much more tolerant to the rearrangement of indoor building partitions (assuming the ventilation ducts are not too significantly rerouted in the renovation) because the propagation is dependent mostly on the duct locations, not the location of building structures.

V. CONCLUSION

In this work we have presented side-by-side comparisons of the signal strength coverage using a conventional AP and a VDAS AP. We performed nearly 100 measurements in each of 3 different AP locations to demonstrate the improved coverage provided by a VDAS. We also showed that the signal levels outside of the building using a VDAS AP are very similar to a conventional AP. Lastly, we used these measurements to discuss the potential improvements to wireless LANs using a VDAS, both in terms of better coverage and fairness and in terms of reduced system cost.

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