Is a Fiber-Fed Antenna Network Optimal for In-Building Wireless Signal Distribution?

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ABSTRACT

In-building radio propagation measurements at 900MHz are used to analyze the dynamic range requirements and optimal architecture for a distributed antenna network. The ideal performance/cost ratio for the network is found to be achieved with a low-cost hybrid fiber-coax architecture. A system design procedure and field-trial results are presented.

INTRODUCTION

As the consumer demand for ubiquitous wireless coverage continues to grow, service providers are quickly developing and deploying networks with greater utility than ever before. It is clear that to meet the new demands of wireless customers, cellular and PCS service providers must upgrade their networks to provide complete radio coverage. This evolution has motivated the need for low-cost systems that transport radio signals to and from areas of poor signal coverage such as: office buildings, shopping malls, hotels, hospitals, and tunnels. The most important area where this problem must be solved is inside of buildings, since this is where people spend most of their time. Unfortunately, the in-building environment is also the most challenging area to provide radio coverage due to severe attenuation and multi-path effects. Wireless providers seek solutions to this problem that optimize the performance/ cost ratio of the network.

In-building radio coverage can be provided by deploying a network of distributed antennas, thus providing high-quality uniform wireless service. The use of analog fiber-optics as a connecting infrastructure for such a distributed antenna network has been proposed [1-2]. Optical fiber may be ideal in some applications due to its low loss, light weight, high bandwidth, and immunity to electromagnetic interference. In the design of a distributed antenna system, there are two major performance/cost design issues: (1) Where (if at all) should fiber-optic links be used?, and (2) What dynamic range is required for each antenna in the network? This paper presents a design approach to answer these questions in the context of a real in-building environment illustrated in Figure 1 below.

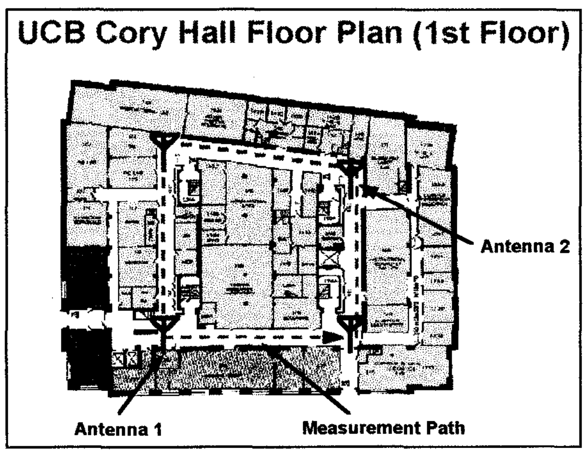

FIGURE 1. Floor plan of the radio environment under study. Initial radio measurements were made in the main corridor with four distributed antennas.

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It is found that by proper antenna placement, the dynamic range requirement of the antenna sites can be relatively low (~90dB-$Hz^{2/3}$). Given that fiber-optic links with this performance typically have a high noise figure (~30dB), the fiber link can be used to feed multiple antennas through ~50 meters of coaxial cable with no performance degradation. By feeding multiple antenna sites per fiber link, this hybrid fiber-coax architecture achieves a performance equivalent to a completely fiber-fed antenna system at a much lower cost.

RADIO MEASUREMENTS

An in-building wireless field-trial is currently in progress at the electrical engineering building at the University of California at Berkeley. The floor plan of the first floor of this building is shown in Figure 1. To perform an initial system design, radio measurements were taken along the main hallway as illustrated by the dotted line in the figure. Dipole antennas were positioned at the four corners of the hallway (as shown), and used to measure the received signal power from a mobile dipole antenna driven with a +15dBm oscillator at 900MHz. The mobile antenna and remote antennas were positioned 1 and 3 meters above the ground respectively. The entire length around the square corridor is approximately 140 meters. The signal strength at each of the 4 antennas was measured independently. Figure 2 below shows the measurement results for two of the antennas. On the left, the received radio signal strength is plotted as a function of the mobile distance along the hallway. On the right, the distributions of the received signal powers are shown.

Note the wide range (~70dB) of received powers as the mobile travels around the corridor. If one were to use only one fiber-fed antenna to cover the entire floor, the link dynamic range would need to be ~115dB-$Hz^{2/3}$ to maintain adequate voice quality (C/N = 18dB) and spur-free operation. Given the high cost of such fiber-optic links, a more optimal architecture is needed.

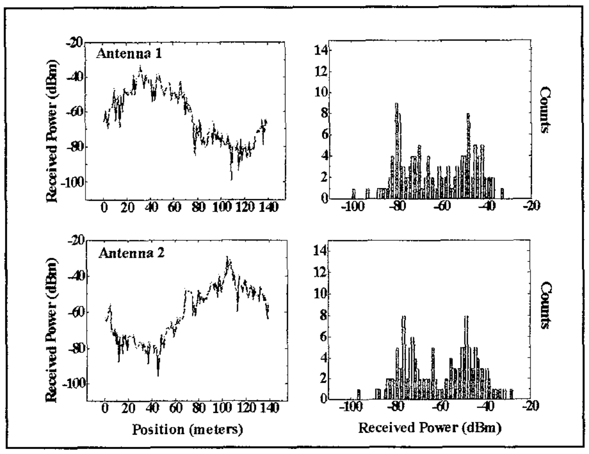

FIGURE 2. Measured received RF power at antennas 1 and 2 as a function of the mobile position along the corridor. The distributions of the received powers are also shown.

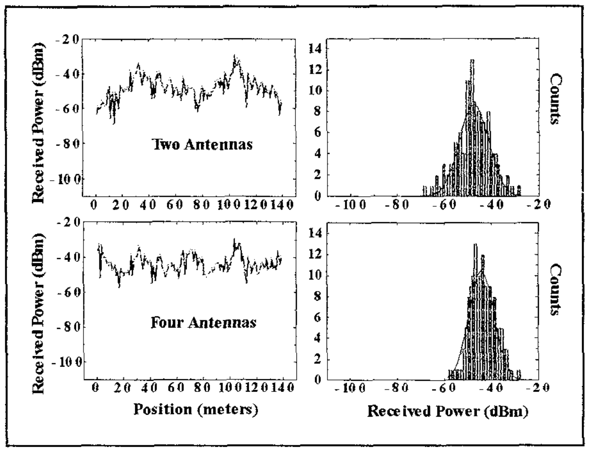

FIGURE 3. Measurement based prediction of the system radio performance with 2 and 4 antennas used with a diversity selection technique.

By noting the complementary nature of the signals received at antennas 1 and 2, we observe that an architecture that implements *both* antennas, and selects the stronger of the two signals would provide better radio coverage and a reduced range of powers at each remote antenna site. Figure 3 shows the calculated consequence of such a diversity combination method using antennas 1 and 2 (two antennas) and by using all of the antennas (4 antennas). Note that by using two (four) antennas, the range of received powers is reduced to ~35 (25) dB, resulting in an antenna dynamic range requirement of ~85 (70) dB-Hz$^{2/3}$. Given that very low-cost fiber-optic transmitters can have an analog dynamic range performance of ~90dB-Hz$^{2/3}$ [3], the use of two antennas for this particular environment is ideal. A comparison of the required antenna dynamic range as function of the number of antennas is shown in Table 1 below.

Number of Antennas	1	2	4
Range of Selected Powers (dB)	68.0	35.7	23.0
Required SFDR (dB-Hz$^{2/3}$)	115.8	83.5	70.8
Percent of Hallway 'Over-Covered' (%)	0	2.8	39.5

TABLE 1. Comparison of the antenna dynamic range requirements and radio coverage characteristics of the hallway under study.

The fact that two antennas are ideal for this system is further emphasized by calculating the fraction of the hallway that is 'over-covered' which we define to be a region where the signals received by any two active antennas are within 3dB of each other. Table 1 shows that the use of four antennas over-covers the hallway by ~40%, as compared to ~3% if only two antennas are used. Also, this overlap between antenna coverage areas leads to severe fading if simple power combination is used to connect the antennas. In this simple environment, the use of two antennas provides the optimum tradeoff between radio coverage, antenna dynamic range requirements, and antenna isolation.

OPTIMAL ARCHITECTURE

Given the results of the previous section, the next step in the system design is to determine the optimal architecture for connecting the distributed antennas to the RF distribution point. This distribution point is typically located either on the roof or in the basement of the building. It is well known that the use of optical fiber is ideal for the transport of RF signals over a relatively long distance; however, its use is not justified for short distance connections since coaxial cable links are significantly lower in cost than analog fiber-optic links. With this consideration, the most cost-effective scheme for connecting distributed antennas is to use a hybrid fiber-coax (HFC) network as illustrated in Figure 4 below.

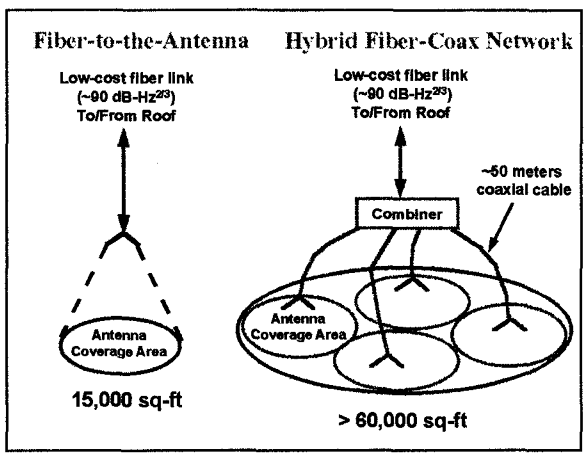

FIGURE 4. A comparison of fiber-to-the-antenna and hybrid fiber-coax architectures for providing cost effective in-building radio coverage.

This conclusion is based on the fact that 90dB-Hz$^{2/3}$ analog fiber-optic links typically have a high RF noise figure (~30dB) [4]. In this case, one can add up to ~30dB of coaxial cable loss before the fiber link with no degradation in system performance. For typical coaxial repeater specifications, this corresponds to a distance of approximately 50 meters. In this way, the advantages of both low-cost fiber links and coaxial cable are both exploited to achieve optimal network performance at the lowest cost. This point is clearly illustrated in Figure 4 since the HFC system covers a much larger area than the fiber-fed antenna at a comparable cost.

For the radio environment under study, the two antennas on the first floor are separated from each other by only ~50 meters, and hence are a perfect candidate for hybrid fiber-coax interconnect. The optimal design in this case is to feed the two first floor antennas with coaxial cables, and to trunk the combined signals from both antennas to/from the roof of the building using a low-cost, 90dB-$Hz^{2/3}$ analog fiber-optic link. This design has been implemented and tested in the field-trial at U.C. Berkeley, and is illustrated in Figure 5 below. The network provides superior radio coverage on the first floor of the building under multi-user test conditions.

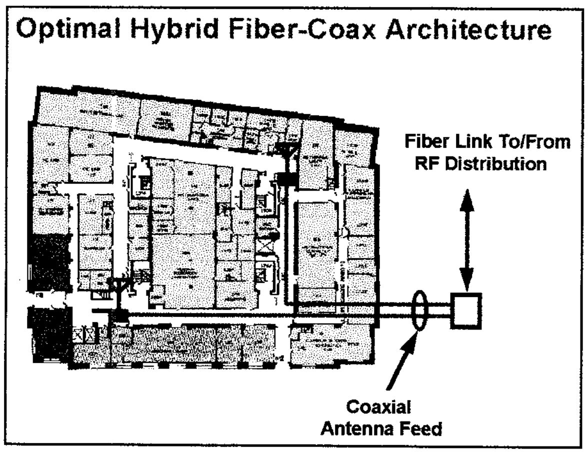

FIGURE 5. Illustration of the optimal hybrid fiber-coax architecture implemented in the wireless field-trial at the University of California at Berkeley.

CONCLUSIONS

In summary, a real in-building radio environment is currently under study to evaluate the architecture and dynamic range requirements of distributed antenna networks. It is found that two antennas implemented in a hybrid fiber-coax architecture will provide good radio coverage of the first floor at the lowest cost. By proper antenna placement, a modest (~90dB-$Hz^{2/3}$) dynamic range analog fiber-optic link can be used for transmitting the radio signals to and from the roof of the building. Further investigation of the optimal coverage solution for the *entire* building is currently underway. David Cutrer is supported by an AT&T Bell Laboratories Ph.D. fellowship. This research is supported by ARPA and Rome Laboratories.

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