High-Speed Internet Access via HVAC Ducts: A New Approach

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Abstract—**In this paper, we report a novel technique for inexpensive high-speed internet access in buildings. Our work shows that, one can use heating, ventilation, and air conditioning (HVAC) ducts for indoor wireless transmission systems and networks. Measurements and system calculations show that coverage distances in excess of 100 meters from the base station and data rates of up to 100 Mbps should be possible, when HVAC system is used in conjunction with OFDM technology.**

Keywords—Internet access; indoor propagation; Heating, Ventilation, and Air Conditioning Systems for wireless transmission.

I. Introduction

WIRELESS transmission of electromagnetic radiation (communication signals) has become a popular method of transmitting RF signals such as cordless, wireless, and cellular telephone signals, pager signals, two-way radio signals, video conferencing signals, and local area network (LAN) signals indoors. Perhaps among these different applications, the driving force behind much current research is the desire to enable the end-users in buildings (residential, office, and commercial) to have high-speed internet access. Indoor wireless transmissions have the advantage that the building in which transmission is taking place does not have to be filled with wires and cables that are equipped to carry a multitude of signals. Wires and cables (for example, fiber and coax) are costly to install and may require expensive upgrades when their capacity is exceeded or when new technology requires different types of wires and cables than those already installed.

Traditional indoor wireless communications systems transmit and receive signals through the use of a network of transmitters, receivers, and antennas that are placed throughout the interior of the building. These devices must be located in the interior structure such that the signals are not lost or the signal strength does not diminish to the point that the data transmitted is unreliable. The placement of the devices becomes more complex when portable receivers, such as laptop computers, are integrated into the communication systems.

Due to the variations in architecture and types of building materials used in different structures, the placement of transmitters, receivers, and antennas is very difficult. Wall board, steel studs, metallic air ducts, electrical conduit, plumbing, etc. all have an effect on wave propagation in a structure. Methods for predicting indoor radio coverage include ray tracing, which uses geometrical optics and diffraction to model the propagation of waves through a structure, and statistical channel modeling, which attempts to characterize the general indoor channel by determining the most appropriate distributions for a set of channel parameters [1], [2], [3]. Despite these methods, the placement of transmitters, receivers, and antennas (communication systems) in an indoor environment is still largely a process of trial and error [4], [5].

Many communication systems are thus implemented inefficiently. High power or redundant transmitters are often positioned to ensure full coverage of the structure. Furthermore, a change in position of objects such as metal desks, metal filing cabinets, etc. that are placed in a room can affect the transmission or reception in that room.

Hence, there is a need for a method and a system for efficiently transmitting RF and microwave signals indoors without having to install an extensive system of wires and cables in the building. In fact, it is estimated that about 1% of the cost of any modern large building currently being constructed is the cable (fiber, coax, or twisted pair) installation cost for communication purposes [6], [7]. Also, there is a need for a method and a system for efficiently transmitting electromagnetic signals indoors without having to design and elaborate a system of transmitters, receivers, and antennas that may not have optimal placement.

This paper describes a new method that uses heating, ventilation, and air conditioning (HVAC) ductwork for transmitting RF signals (electromagnetic radiation) to the users inside buildings. The system includes a device (typically a coupler) for introducing electromagnetic radiation into the ductwork such that the ductwork acts as a waveguide for electromagnetic radiation. The system also includes devices (simple antennas) for enabling the electromagnetic radiation to propagate beyond the ductwork. The HVAC channel, like all other waveguides, is a linear channel and therefore can be completely characterized by its impulse response (or transfer function).

The experimental measurements carried out in the laboratory for HVAC ducts at Carnegie Mellon University (CMU) indicate a coherence bandwidth of 1.7 MHz. Using OFDM technology in conjunction with the HVAC channel, our preliminary calculations show that a coverage distance (from the base station) of 100 meters and data rates of up to 100 Mbps for internet-access can be supported with this technique.

The remainder of this paper is organized as follows. In Section II we describe the underlying concept behind the HVAC system. Section III contains some of the measured channel characteristics of HVAC. In Section IV we provide simple system calculations and a brief discussion of some system level issues. Finally, Section V concludes the paper.

II. CONCEPT

The underlying concept behind the HVAC system is extremely simple and relies on the key observation [7], [8], [9] that in most parts of the USA and Europe almost every building is equipped with HVAC ducts (for the purpose of heating, ventilation, and air conditioning), which are essentially waveguides. Therefore, all forms of wireless transmission (for internet access and other applications) can, in principle, be done via these waveguides.

Since most of the offices and other places in buildings where people work, sit, or reside are reached by these HVAC ductwork, it is also possible to provide communications between building occupants and the rest of the world (i.e., Internet).

The basic principle of operation of the herein proposed HVAC communication system is again quite simple: for the down link, RF signals sent from a base station propagate through the HVAC ductwork (i.e., channel) and a small portion of the electromagnetic energy is radiated by a simple antenna inserted into the HVAC duct passing from each room. In the uplink, the RF signal of the end-user transmitted by the laptop, handset, etc. reaches the passive antenna located in each office and propagates toward the base station. This is depicted in Figure 1.

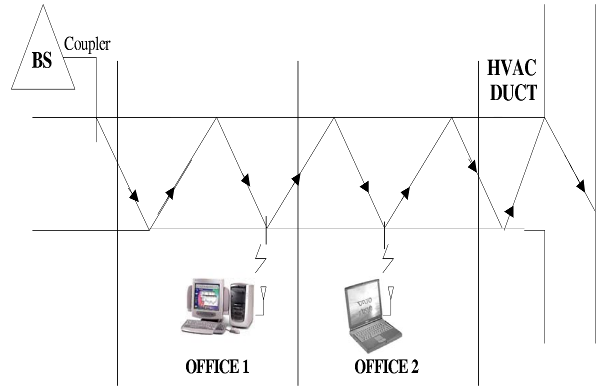

Fig. 1. Basic principle of operation of HVAC system.

III. CHARACTERISTICS OF HVAC CHANNELS

It is well-known that one of the most challenging aspects of most wireless communication systems is the wireless channel [10], [11], and HVAC system is no exception. For wireless transmission systems and networks the ultimate capability of the HVAC system depends on the channel characteristic of the HVAC waveguide. To determine this, several measurements of HVAC ducts in the Dept. of Electrical and Computer Engineering of Carnegie Mellon University have been made. Below, we summarize some of these measurements.

Measurements were made using a 16 meter long ductwork path on the second floor of Roberts Hall on Carnegie Mellon University's campus. The ductwork plan in the area in which the tests were made is shown in Figure 2. Swept frequency measurements were made between points A and B using a vector network analyzer. The frequency was swept between 2.1 GHz and 2.8 GHz and was inverse Fourier transformed to obtain the impulse response shown in Figure 3. The rms delay spread of the impulse response is 120 ns, implying a coherence bandwidth of 1.7 MHz.

Assuming that the extended time response is caused by multiple reflections in the duct, the decay rate of the response is a measure of the intrinsic waveguide loss. As shown by the imposed line in Figure 3, the decay rate indicates a loss of about 3.67 dB/100 ft or 0.12 dB/m.

IV. DISCUSSION

To put these results into perspective, below we provide some simple system calculations which show the capabilities of the HVAC system for broadband internet access.

As an example, consider a base station using an RF

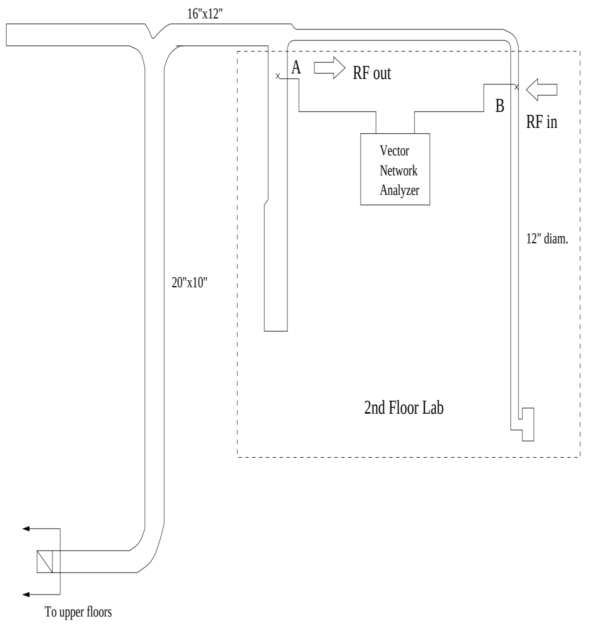

Fig. 2. The experimental setup used for measuring impulse response of HVAC ducts.

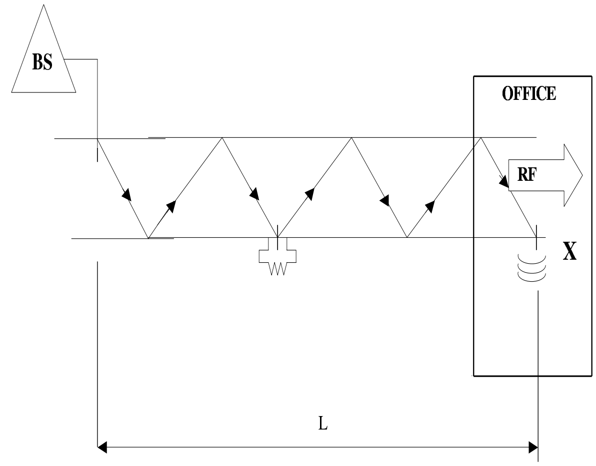

Fig. 4. System illustration.

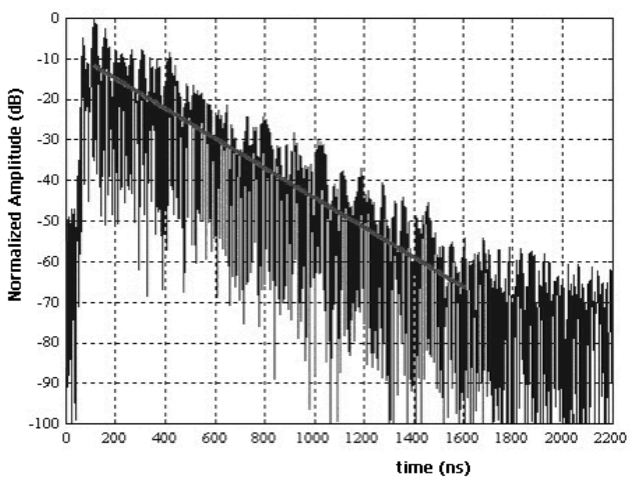

Fig. 3. The impulse response measured for a 16 m long HVAC duct.

power of 30 dBm (1 Watt) communicating with a user in an office connected by a 100 m path in the duct. We assume the input coupler is bidirectional, and therefore introduces 3 dB into the loss budget. As a conservative estimate, we further assume that there are 5 branches in the duct along this path which introduce an additional 3 dB of loss each. Our measurements indicate that a simple monopole antenna reradiates 1/100-th of the power into the office, and we desire a 5 dB fade margin. The receiver sensitivity is taken to be -78 dBm. The tolerable additional propagation loss is then obtained from the loss budget analysis depicted in Table I.

TABLE I

THE LOSS BUDGET ANALYSIS TABLE.

Transmitted power	30 dBm
Bidirectionality loss	-3 dB
Duct attenuation loss	-12 dB
Power loss at branches	-15 dB
Monopole coupling loss	-20 dB
Fade margin	-5 dB
Receiver sensitivity	-78 dBm
Tolerable additional path loss	53 dB

The additional path loss between the monopole and the mobile user is obtained using the FRIIS formula [10], [11]

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 G_r G_t, \qquad (1)$$

where P_r is the received power, P_t is the transmitted power, λ is the wavelength of interest, d is the separation between transmitter and receiver, and G_r and G_t are the gains of the receiving and transmitting antennas, respectively. Assuming an ISM band operation at 2.4 GHz, λ=12.5 cm. Using worst-case scenario of $G_r = G_t$=1

$$20log_{10}\left(\frac{0.125}{4\pi d}\right) = -53\,dB \tag{2}$$

Solving eqn.(3) for d, one finds d ≈4.4 m, which for most offices appears quite sufficient. However, for larger offices it is straightforward to obtain a larger d (coverage) by simply using a receiving antenna gain $G_r > 1$. The simple calculation outlined above indicates that the herein proposed HVAC system can cover offices 100 m away from a base station radiating 1 Watt of power into the HVAC duct.

We believe that OFDM would be an effective transmission technique for the duct channel [12]. As an example, consider the performance of Hiperlan-2 at 36 Mbps (nominal bit rate). The modulation is 16-QAM with rate 3/4 coding. There are 48 data subcarriers and 4 pilot subcarriers spaced at intervals of 0.3125 MHz. This gives

$$\frac{4\,bits}{carrier} \times \frac{48\,carriers}{symbols} \times \frac{3}{4} = 144\,data\ bits/symbol. \tag{3}$$

With a symbol interval of 4 μs, this represents a data rate of 36 Mbps, while the symbol rate is 0.25 Msps. This symbol rate should be quite satisfactory over a channel with a coherence bandwidth of 1.7 MHz. The spacing between the two outermost subcarriers is $52 \times 0.3125\ MHz = 16.25\ MHz$, consistent with 20 MHz channel spacing. Thus three such channels in the 2.4 GHz ISM band will provide in excess of 100 Mbps. This is a promising speed for broadband internet access.

V. Conclusions

We have reported a new technique for indoor broadband internet access which seems to be a viable inexpensive alternative to other existing "last mile" technologies. The coverage of HVAC system is more than 100 m from the base station and data rates of up to 100 Mbps can be supported in the 2.4 GHz ISM band. With simple modifications, the HVAC system seems to be a viable and attractive option for broadband internet access in legacy systems having HVAC ducts. Likewise, initial design considerations show that, for future buildings one can design "RF-friendly" HVAC systems for inexpensive high-speed internet access.

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