Factors Causing Uncertainties in Outdoor Wireless Wearable Communications

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Wearable computers are becoming increasingly popular as new features emerge and device portability improves—making them suitable for accessing multimedia services on the move. Wireless networks offer many advantages over traditional wireline local area networks in areas such as scalability, mobility in a locality, and elimination of wiring reconfiguration. Wireless LANs are compatible with Ethernet and asynchronous-transfer-mode-based fiber-optic networks,^{1,2} providing high mobility to user nodes while integrated and connected to high-speed networks wired with broadband. With a range covering several kilometers, WLANs are advantageous for providing multimedia services to wearable computers.

Providing reliable services to wearable computers using radio waves is challenging mainly because maintaining radio links under various operating environments is difficult. In an indoor environment, radio signals encounter physical obstacles that cause reflection, diffraction, and shadow fading. Outdoors, however, rain is the most significant and uncontrollable variable, leading to signal attenuation, service disruption, and uncertainties in system operations. Various factors influence the operation of wirelessly connected wearable computers, but we emphasize rain-fall's influence.

SYSTEM OVERVIEW

Figure 1 shows a typical system layout providing network access services

to users outdoors with a point-to-multipoint (PMP) configuration. Such a system lets wearable computers maintain a network connection both inside and outside the building. Users can take wearable computers virtually anywhere in the locality without disconnecting from the network. The wireless link must therefore be extremely reliable to sustain the connection even when uncontrollable parameters such as rain-fall and physical objects blocking the base station constantly change the operating environment.

Users widely employ wearable computers with low power consumption to access multimedia services while on the move. Primarily, physical size and the ability to receive radio frequency signals under different environments determine a wearable computer's mobility. The complexity of most modern networks generates numerous factors that in turn increase uncertainty in system operations. An efficient framework that B.R. Badrinath and his colleagues proposed reduces the uncertainties associated with network complexity.³ Factors such as multipath and shadow fading are common problems with broadband wireless access systems using radio frequencies of several gigahertz.

Expecting 100 percent link availability is unrealistic, particularly with outdoor deployment, mainly because rain statistics are uncontrollable and nonuniform. Where rain attenuation is not too severe, most systems operate at fre-

quencies between 2.4 and 5 GHz. The proposed WLAN operating standard is 17 GHz because this offers numerous advantages, including a less congested spectrum and wider bandwidth. This frequency is particularly suitable for wearable computers because you can use much smaller integral antennas. However, rain attenuation's effects become more severe as operating frequency increases.

As rain becomes heavier, the radio link's range decreases owing to more severe attenuation. Normally, a link is available when it can perform at a bit error rate of 10^{-6} or better, and a system should provide a minimum availability of 99.99 percent—that is, link outage should total no more than 52 minutes per year. Link outage due to heavy rain is the most important factor at carrier frequencies higher than approximately 10 GHz. So, we must minimize rain attenuation's effects to provide a sustainable network connection to wearable computers that operate outdoors.

THE OUTDOOR OPERATING ENVIRONMENT

Radio links are subject to both man-made and natural noise, including interference from other equipment operating on the same premises. Path loss primarily occurs because stationary objects such as surrounding buildings and trees cause scattering, as do moving objects such as people, animals, and

vehicles. Other physical obstacles, such as vegetation, also cause signal loss (see Figure 2). These physical obstacles cause reflection, diffraction, and shadow fading in the radio wave. The partitioning materials in surrounding areas therefore affect the extent to which radio waves are absorbed and reflected.

Multipath fading occurs when the signal takes multiple paths that reach the receiver with slightly different time delays, which is generally insignificant at frequencies higher than 10 GHz because paths are short. As Figure 3a shows, reflection along a short path does not cause significant signal degradation. Also, narrow-beam-width antennas are used for systems operating at higher frequencies, and this combination minimizes multipath fading's effects. In Figure 3b, a 180-degree phase shift results from reflection to the transmitted signal because the signal path is longer. This generates a signal attenuation inversely proportional to a factor of d^4 (where d is the distance traveled), instead of complying with the inverse-square law. This is not generally an issue at higher frequencies, partly because the range is more limited.

EFFECTS OF RAIN

Climate phenomena such as rain, snow, and gas absorption attenuate and distort radio waves outdoors. The extent of signal degradation depends largely on the carrier frequency. Also,

Figure 1. Block diagram of system configuration.

Figure 2. Possible causes of radio wave signal loss to wearable computers operating in an outdoor environment influenced by stationary and moving physical objects.

the rain's effects are the main cause of attenuation at frequencies above several GHz commonly used in mobile computing applications. Rain affects

wearable computing operations, but various ways exist that reduce its impact on system performance.

Rain attenuates, scatters, and depo-

Figure 3. Radio wave reflection with (a) a short path length with high frequency and (b) a long path length with low frequency.

Figure 4. Fade margin relative to a quadrature-phase-shift-keying modulation scheme (measured using quadrature amplitude modulation [QAM]).

larizes the carrier signal. To maintain the radio link's availability, you must set an appropriate *fade margin*.⁴ Figure 4 shows a system's necessary fade margin for 16- and 64-QAM (quadrature amplitude modulation) with reference to a quadrature phase shift keying, which is a more robust modulation scheme. The fade margin, also called the *system operating margin*, measures the difference between the received signal strength and the minimum signal level necessary to maintain link availability. The margin is usually maximized to support maximum reliability without excessive transmission power. The fade margin requirement increases when you use a higher-order modulation, which provides a higher-spectrum efficiency. Cross-polarization is important when frequency reuse is necessary to ensure optimal use of available bandwidth. Orthogonally polarized signals often help increase bandwidth use with higher-frequency reuse. Heavy rainfall's effects on the radio propagation path reduce system availability because rain causes cross-polarization interference. This interference subsequently decreases the cross-polarization isolation between signals of vertical and horizontal polarizations as they propagate through rain. We measure the extent of radio link per-

formance degradation by cross-polarization diversity (XPD), determined by the degree of coupling between signals of orthogonal polarization. XPD typically results in approximately 10 percent reduction in coverage due to cell-to-cell interference.

Unlike in indoor environments, where most parameters are controllable, signal degradation in an outdoor environment induces a much higher degree of uncertainty because many factors are virtually uncontrollable.

Alternately polarized signals often increase available bandwidth use. Rain's depolarization effect makes using orthogonally polarized signals particularly challenging in heavy rainfall regions. This is because horizontally polarized signals undergo more attenuation than vertically polarized signals as they propagate through the wireless channel under the rain's influence. Generally, cross-polarization and signal attenuation more severely affect higher frequencies. A difference of 3 decibels per kilometer with horizontal and vertical polarizations results when a 20-GHz carrier propagates through persistent rain (120 millimeters per hour).⁵ Figure 5 illustrates rainfall's impact on attenuation. The attenuation is insignificant when rainfall is low, and minimal

difference exists between Figures 5a and 5b, which show the difference for vertically and horizontally polarized signals at 10 and 20 GHz, respectively. Rain affects vertical polarization less severely, so vertical polarization offers a longer range than horizontal polarization under identical operating environments. Figure 5b shows that horizontally polarized signals suffer from a high degree of attenuation under the same environment. The red (bottom) curve representing a 20-GHz carrier suffers a much greater signal attenuation as the rainfall increases with a difference of 3 dB from 10 to 20 GHz experienced at a rate of 40 mm per hour. Rain causes a degree of attenuation that depends largely on polarization.

Multipath fading is generally an issue with signals below 10 GHz, whereas the attenuation rain causes is the most important consideration at frequencies above 10 GHz. Lower frequencies are therefore preferred in tropical regions where heavy and persistent rainfall is expected, while systems at higher frequencies operate in a less congested part of the spectrum with more available bandwidth. Most cellular telephone systems allow international roaming with a single, handheld phone that operates in the frequency range of approximately 1 to 2 GHz. Providing similar services to wearable computers operating in different climate regions might be more challenging owing to bandwidth requirements. Refining small, integrated high-gain antennas will certainly improve the reception properties of devices operating at high data rates using orthogonally polarized signals. Also, uncertainties related to network availability at these operation frequencies are primarily determined by rainfall and demand an adequate fade margin to compensate for the rain's effects and give wearable computers a reliable network connection.

Figure 5. Signal attenuation caused by rainfall per kilometer range: (a) a 10-GHz carrier and (b) a 20-GHz carrier.

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New Products

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EDITORS' INTRODUCTION

It's no surprise that companies are integrating PDAs and cellular telephones; each device offers functions that complement the other and many people carry and use both. This integration, although desirable, pits the small, lightweight phone's appeal against the desirability of a PDA with a large screen and qwerty keyboard. Today's integrated devices address this tension much better than earlier devices such as the Qualcomm (now Kyocera) pdQ 1900 Smartphone, which was $9.6 \times 2.6 \times 1.4$ in. and weighed 9.8 oz. when it was introduced in 1999. In this month's column, we review four of the newest devices.

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—Keith Farkas and Guernsey Hunt

T-MOBILE POCKET PC PHONE EDITION

The T-Mobile Pocket PC Phone Edition (www.t-mobile.com), shown in Figure 1, is part of a new generation of integrated phones and PDAs. It's partly worth noting because it is based on Microsoft's Pocket PC operating system, which is a flexible platform on which developers can deploy their own applications and which integrates easily with many other Microsoft products. The device includes a suite of integrated applications, including an address book, a calendar, Microsoft Pocket Word and Excel, and a phone application. Reflecting T-Mobile's PDA roots, the phone application renders a phone keypad on the display. T-Mobile offers additional services including two-way text messaging; an Internet browser (with VPN support); international roaming (via changeable

band settings) with one phone number; and "T-Mobile Alerts," a service through which users can have information sent to their phones via SMS (short message service) messages. It also offers internal flash memory and an SD/MMC memory slot where you can store any of the growing number of applications available for download, as well as data and music files. It weighs 7 oz. and is $5.1 \times 2.9 \times 0.7$ inches. Read more about the hardware platform in the 2 September 2002 "Under the Hood" column in *EE Times* (www.eetimes.com/sys/uth).

Figure 1. Along with standard PDA functions, T-Mobile's Pocket PC Phone

Edition supports calls, two-way text messaging, Web browsing, and SMS (short message service).

BLACKBERRY 6210

Another recent PDA-phone combination is the phone-enabled BlackBerry 6210 (see Figure 2) from Research in Motion (www.blackberry.com). BlackBerry handhelds' robust, secure integration with Microsoft Exchange and IBM Lotus Domino might be noteworthy to pervasive systems developers. The BlackBerry 6210 provides wireless extension to these and other systems, using a desktop-based email pull/push application for the latter. This lets users compose, forward, and delete emails; keep the handheld's mail folders and calendar synchronized with those on the corporate server; accept or decline meeting requests; and more. The BlackBerry can deploy custom Java-based applications and leverage

Figure 2. The BlackBerry 6210 is securely integrated with Microsoft Exchange and Lotus Domino.