Methodology and Preliminary Findings towards the Characterization and Evaluation of Non-Line-of-Sight (NLOS) Paths for Fixed Broadband Wireless Communications for Emergency and Disaster Response

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Abstract – Fixed broadband microwave communications are usually considered line-of-sight (LOS) technologies. Conventional wisdom holds that non-line-of-sight (NLOS) paths are of insufficient quality for broadband commercial deployments. However, it is possible that the only links available in an emergency deployment are NLOS paths. Since little work has been published regarding the usefulness of these channels, the proposed measurement campaign will be focused on characterizing these channels and evaluating their potential to carry digital data with a desired fidelity. Field measurements are expected to begin in April, 2003 and will include channel impulse response measurements as well as bit error rate (BER) tests. Preliminary simulations have been run that demonstrate the dependence of BER on the complex channel impulse response rather than on certain statistics of the power delay profile. Early indications are that BER degradations due to the amplitude variation of the channel frequency response can be related to the variance of the amplitudes across the frequency band of interest.

1. Introduction

As part of the project "Testbed for High-Speed End-to-End Communications in Support of Comprehensive Emergency Management" funded by the National Science Foundation's Digital Government Program (award EIA- 9983463), Virginia Tech researchers are developing a prototype system to provide a high-speed backbone network for emergency and disaster response. The radios were designed to operate in the Local Multipoint Distribution Services (LMDS) band (28 GHz), but the core value of the research is frequency independent and can be applied to any number of other radio technologies.

The system is intended to utilize a geographic information system (GIS) tool developed at Virginia Tech for rapid site planning and incorporate adaptive data link protocols based on a low-cost channel sounder, also developed at Virginia Tech, that will assess channel quality. Figure 1 displays a system concept for the given GIS map.

An early version of the system was demonstrated for federal, state, and local emergency personnel in 2001 and 2002. In this paper, we discuss system issues related to the operation of the communications system, including the estimation of system performance before deployment, in-field identification of the optimum channel, and the adaptation of the network configuration based on the channel response. Section 2 evaluates conventional wireless channel metrics and their applicability to fixed broadband wireless communications. Section 3 describes the methodology to be employed during the measurement process. Section 4 highlights preliminary results and Section 5 is an evaluation of those results and provides some insight into the future direction of the research.

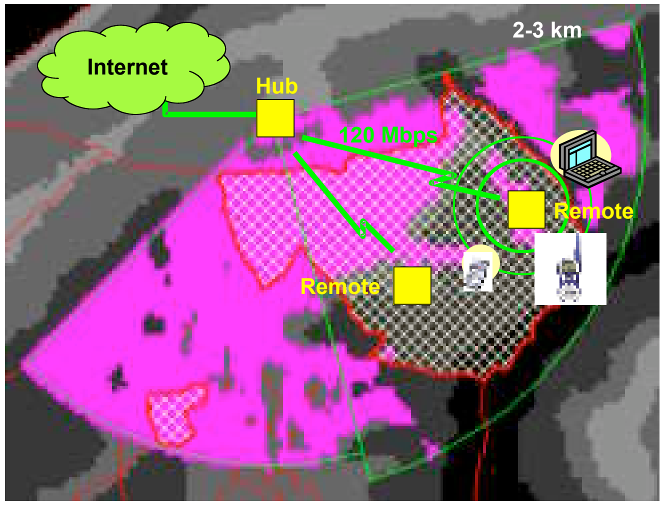

Figure 1: System concept for rapidly deployable fixed wirless broadband communication system for emergency and disaster response.

2. Assumptions

Much of the literature about microwave communications is devoted to mobile systems. Analysis of these systems relies on assumptions about the channel that may not be valid for fixed wireless systems. These assumptions include a bit error performance that is independent of the shape of the channel response and multipath interference that consists of discrete reflections. Two studies call into question the validity of these assumptions for fixed wireless communication systems.

An analytical model for bit error rate in a stationary frequency selective channel employing bi-phase shift keying (BPSK) system was developed by Janssen [1] that suggests a dependence on the shape of the channel response. This result follows intuition. Discrete multipath signals may add constructively or destructively depending on their phase relationships. In mobile channels where the impulse response of the channel can change rapidly over time, stochastic models are employed to describe the channel. In fixed wireless communication systems where the channel is relatively stable, a new description of the channel incorporating the phase of the impulse response must be employed. One of the goals of this work is to develop just such a model.

Work recently completed at Virginia Tech [2] suggests the presence of diffuse scattering from certain materials and asymmetry with regard to the channel response of the forward and reverse links in a system. A certain amount of diffuse scattering was expected as the wavelength of the carrier was on the order of the surface irregularities. Energy is scattered from these surfaces making it impossible to discern particular bounce paths. Traditional mobile communications occur at much lower frequencies (longer wavelengths). Since the wavelengths are much longer, diffuse scattering is less likely and multipath can reliably be treated as discrete bounces. The presence of diffuse scattering in some scenarios makes it necessary to account for this phenomenon in whatever channel model is developed.

3. Methodology

Three deployment and operation issues will be addressed by the proposed work: estimation of the channel before actual deployment, identification of optimum channels (pre- and post-deployment), and adaptation of relevant radio and network parameters.

To estimate the channel impulse response before deployment, it is necessary to obtain reasonable approximations of the channel based on the physical configuration of the environment. Channel impulse response measurements will be collected in a variety of environments to begin the process of understanding the effects of the environment on the channel. At each location, multiple channel impulse responses will be collected to determine the time-varying nature of the channel.

Optimum channel selection requires a ranking of channels based on received signal strength and the channel impulse response. To do this, it is necessary to develop a relationship between the impulse response and an appropriate performance statistic, such as bit error rate (BER). BER tests will be conducted over the same links being characterized by their impulse responses. These in-field tests will then be used to develop and validate those relationships. Once a relationship is obtained between BER and the impulse response, estimations can be made on the quality of the channel both before and after deployment occurs.

This leads directly to adaptation of the radio and network parameters. If a map can be drawn from the channel impulse response to the error statistics, intelligent decisions can be made on the configuration of the system. Parameters such as modulation, symbol rate, forward error correction (FEC), frame length, and automatic repeat request (ARQ) schemes can be adjusted to obtain optimum performance for a given channel. Realistically, it may not be possible to test the effects different combinations of these parameters have on real hardware. However, given reasonable knowledge about the relationship between the channel impulse response and the corresponding error statistics, this portion of the work may be investigated using simulations.

In summary, the test plan will include channel impulse response measurements over time and BER measurements. The analysis will include studying the time-varying nature of the channel response, determining the correlation between the channel impulse response and the error statistics, developing an algorithm for ranking potential performance of the communication link based on the channel impulse response, and determining the appropriate network settings for a given channel impulse response.

4. Preliminary Results

Toward the investigation into the relationship between the channel impulse response and BER, simulations have been run using a two-ray multipath channel. The first path has an amplitude of one and the second path has an amplitude of 0.5 and occurs at a time delay of $0.5T_s$, where T_s is the symbol period. The data is quadrature phase-shift key (QPSK) modulated and the phase of the second path is shifted with respect to the first path by 0, p/4, p/2, and p radians. Figure 2 clearly shows the dependence of BER on the relative phase of the second path.

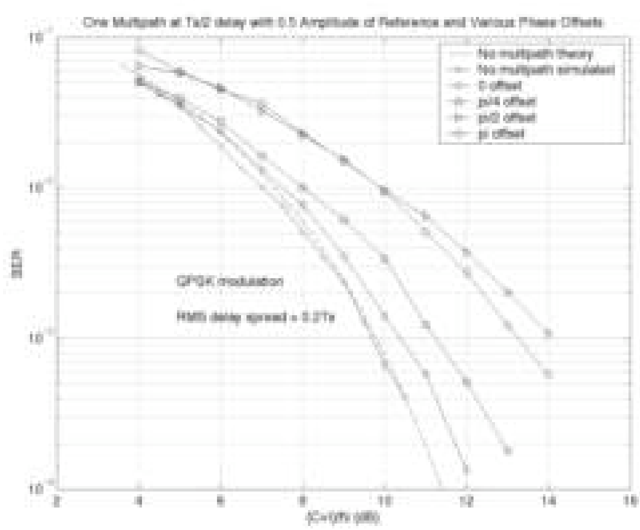

Figure 2: Bit error rates for various phases of the second multipath signal in a two-ray channel.

An empirical relationship between the impulse response and BER has been found that is based on the variation, σ^2, and mean, μ, of the channel frequency response, where the frequency response is the Fourier transform of the impulse response. For a specified BER, the required signal plus interference to noise ratio, $((C+I)/N)_{req}$, can be estimated by Equation 1.

$$\left(\frac{C+I}{N}\right)_{req} = \left(\frac{C}{N}\right)_{TH} + 10\ \log_{10}\left(\frac{N + \sigma^2 / \mu^2}{N}\right) \qquad (1)$$

where $(C/N)_{TH}$ is the theoretical signal to noise ratio required for that BER (in dB). This approximation fits very well over the range of signal-to-noise ratios tested for this two-ray channel when the phase of the frequency response is nearly linear as in the cases shown in Figure 3.

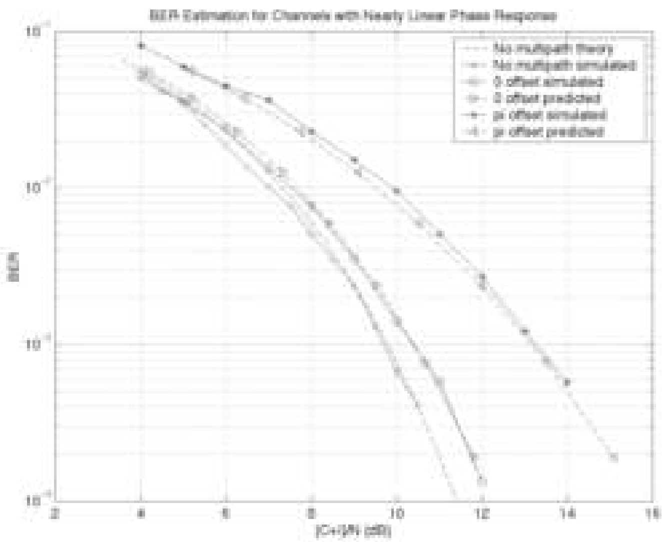

Figure 3: BER estimation for channels with amplitude variation and nearly linear phase responses.

For non-linear phase, the approximation underestimates the BER suggesting the approximation must be amended to also include the effect of the non-linear phase.

5. Conclusions

It is clear that in the stationary channel investigated that performance depends not only on the magnitude of the channel impulse response, but also on the phase. Preliminary results suggest that a reasonable relationship between the channel impulse response and BER may be determined either analytically or with some empirical fit based on certain parameters of the channel impulse response. More work needs to be done to both include the effects of non-linear phase and to ensure that the particular channel model chosen is not a special case.

References

[1] G.J.M. Janssen, P.A. Stigter, and R. Prasad, “Wideband indoor channel measurements and BER analysis of frequency selective multipath channels at 2.4, 4.75, and 11.5 GHz,” IEEE Transactions on Communications, Vol. 44, pp. 1272-1288, October 1996.

[2] C. L. Dillard, T. M. Gallagher, C. W. Bostian, and D. G. Sweeney, “28 GHz scattering by brick and limestone walls,” IEEE AP-S International Symposium and USNC/CNC/URSI National Radio Science Meeting, June 2003, to appear.