COMMENTS and MEASUREMENTS on the PHYSICAL LAYER

Bruce Tuch
NCR Systems Engineering
Utrecht the Netherlands

I. COVERAGE DISTANCE ESTIMATION

In order to predict coverage area performance of any radio link, a Power Budget is needed. Before any statement can be made about system performance a criteria must be defined:

Outage := Pr[BER<10E-8]

For a fixed coverage area the above Outage gives the probability that a required instantaneous BER of 10E-8 is not met. It is noted that the 10E-8 BER does not necessarily have to be the physical layer raw data error ratio, but is the data error ratio at the MAC interface.

From a set modulation/demodulation scheme, the required SNRo needed to achieve the instantaneous BER of 10E-8 (including any FEC or ACK implementations) is known.

Outage = Pr[SNR<SNRo]

Using the definition in the PAR; acheiveing link performance within 99.9% a conformant coverage area.

Conformant Coverage Distance := [TX/RX distance|Outage < .1%]

The transceiver parameters that effect the performance criteria are put into a Power Budget:

Example Power Budget

Thermal Noise (10 MHz BW)	-104 dBm	
Receiver NF	8 dBm	
Receiver Thermal Noise	- 96 dBm	(a)
Man-Made Noise (10 dB above Thermal)	- 94 dBm	(b)
Receiver Input Noise Level	- 92 dBm	Power sum (a) + (b)
Required SNR (Instantaneous BER 10E-8)	18 dB	
Required Instantaneous Receive Level	- 74 dBm	(c)
Isotropic Antenna Path Gain (@ 1 meter) @ f= 2.4 GHz	- 40 dB	(d)
Antenna Gain (TX+RX)	4 dB	(e)
Transmit Power	24 dBm	(f)
Power @ one meter	- 12 dBm	(g) = (d) + (e) + (f)
Allowed instantaneous Signal Attenuation (AIA) at receiver Noise Limit wrt one meter.	62 dB	(h) = (g) - (c)
Fading Margin[1] needed to achieve .1% Outage.	18 dB	(i)
Allowed average Attenuation (AAA) at receiver Noise limit wrt one meter.	47 dB	(j) = (h) - (i)

[1]The advantage of this approach is that the internal modulation/demodulation structure and techniques used to achieve this margin are not explicit, therefore systems comparisons are more readily made.
In this example calculation two switched antenna diversity is assumed, in a Rayleigh Fading channel, with a log-normal mean distribution (sigma 4 dB). This gives a "fading Margin" of 18 dB. It is noted that without any sort of diversity in this type of channel 31 dB would be required.

With the AAA parameter, from the Power Budget, and a mean attenuation vs distance curve of the conformant coverage area in question, a distance estimation can be obtained.

Using an indoor model of the average attenuation of a semi-open office: (This has been measured)

Attenuation Exponent n = -3.6
2nd order cross over point = 8.5 meters

The average attenuation wrt one meter is then:

$$\text{Attenuation} = 36 \cdot \text{Log}(d) - 14 \text{ dB}$$

The AAA from the Power Budget is 47 dB giving:

$$d = 10E(61/36) = 50 \text{ meters}$$

In doing all the above calculations various channel assumptions have been made. The following section will give measurements which substantiate these assumptions.

II. THE CHANNEL MODEL

The power budget calculation does not take channel echo or selective fading into account. The modulation structure of the radio communication link must be so dimensioned such that the irreducible error ratio is sufficiently low (<.1% Outage). Therefore the above is just a total power budget assuming flat fading. If the fading is actually selective (which is the case in wide spread-spectrum bandwidths or high data rate systems) then the fading margins will differ accordingly taking this into account.
(It is noted that in most indoor environments a coherence bandwidth of more than 15 MHz is not uncommon).

A. The Rayleigh Fading Model

Various researches have shown that for indoor radio propagation a Rayleigh fading path model is valid [35], [19]. The question has been asked how does this model fit as a function of distance from the source. Assuming Line of Sight propagation one does have better fading statistics (Rican) which leads to lower fading margins. From actual building measurements and topologies one cannot assume a Line of Sight path exists. Also if we demand LOS on the radio system (Antenna must always see each other) one could probably design a better system using light technology. The major advantage of radio is in its in building penetration capabilities.

In figure 1 a layout of a typical office structure is shown. Each cubicle is made of paper partitions 1.6 meters high. Each cubicle is labeled with a three digit number (corresponding with the telephone extension of the cubicle).

1. The Measurement

At (483) a vertical dipole transmitter was positioned 2 meters above the ground. At different cubicle locations a vertical dipole receiving antenna was located on a rotating mast either one or two meters above the ground. There is a distance of one quarter wave length between measurement points of the receive antenna in each measurement run. In each cubicle, 150 measurements where taken in area within one meter of the receivers coordinates. From this data the cumulative distribution function of the received power, with respect to the average power was calculated.

2. Some Results

The following measurements were performed with the receive antenna one meter above the ground (shadowed by the paper partitions).

In Figure 3 the cumulative distribution of the receive power is shown at (461) which is the last measured cubicle of the floor, 38 meters from the transmitter. The solid line is the theoretical curve from a Rayleigh distribution. It is noted how the measurements closely agree with the theory.

Comments: At distances of 40 meters and the receive antenna below a paper partition the Rayleigh Model is valid. This is expected.

In figure 2 the cumulative distribution is shown at (432) which is 13 meters from the transmitter.

Comments: Even a close distance to the TX antenna Rayleigh Fading seems to occur even with soft partitions in a indoor environment. Unless strict LOS demands are place on the TX/RX combination, including polarization orientation, a Rayleigh fading model seems to be an accurate method in predicting power loss of the channel.

The above measurements were repeated with the receive antenna two meters above the ground (Line of Sight with TX Antenna) as shown in figures 4 and 5.

Comments: Notice that even with a "good" line of sight path excellent Rayleigh Fading characteristics are seen, even up to a 13 meter TX RX separation! This can be explained by the strong reflections, due to the surrounding building structure (ceiling and metal supports of the paper partitions) which have significant power with respect to the LOS path. Even at close distances it would be overly optimistic to assume "free space" propagation. (The average value does follow the free space exponent at distances around 10 meters).

To gain more insight into LOS propagation statistics a "close in" measurement, the receiver at 8 meters, at both one and two meters.

Comments: As expected the "shadowed" path, figure 7, shows excellent Rayleigh Fading. The LOS path, figure 6, at this close range has better fading statistics. Even at extremely close ranges the antenna link must be almost "perfect" to get out of a Rayleigh Fading Model.

III. CONCLUSION

A good model for the fading characteristics of an indoor channel, using dipole antennas, even at RX/TX close distances of 15 meters, is the Rayleigh distribution. With indoor LOS links, a free space assumption leads to an overly optimistic Power Link Budget.

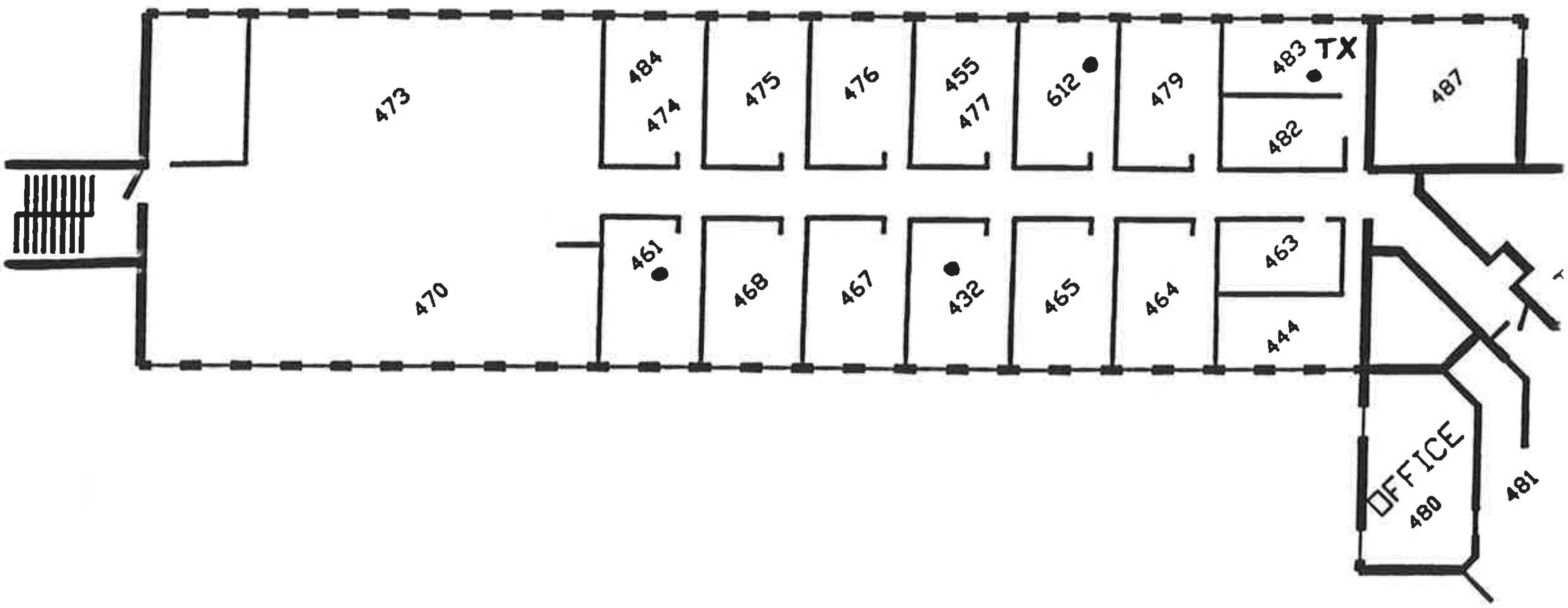

Figure 1 Topology of Indoor Measured Environment

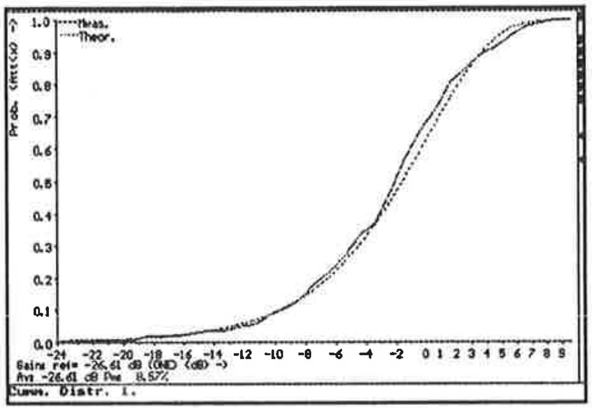

Figure 2 (432)
TX/RX 13 m (RX Height @ 1 m)

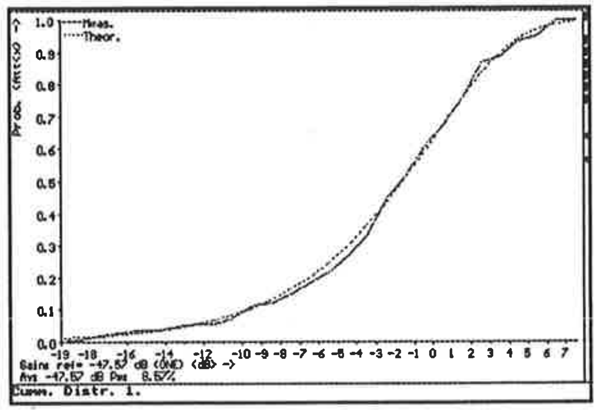

Figure 3 (461)
TX/RX 38 m (RX Height @ 1m)

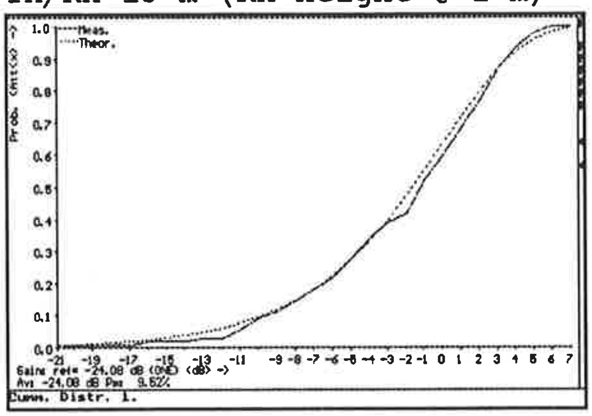

Figure 4 (432)
TX/RX 13 m (RX Height @ 2 m)
LOS

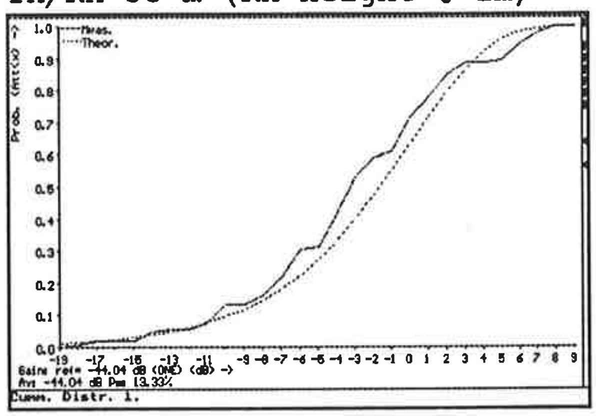

Figure 5 (461)
TX/RX 38 m (RX Height @2m)
LOS

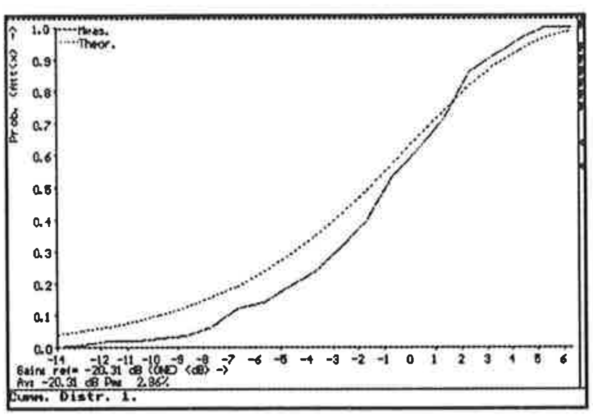

Figure 6 (612)
TX/RX 8 m (RX Height @ 2 m)
LOS

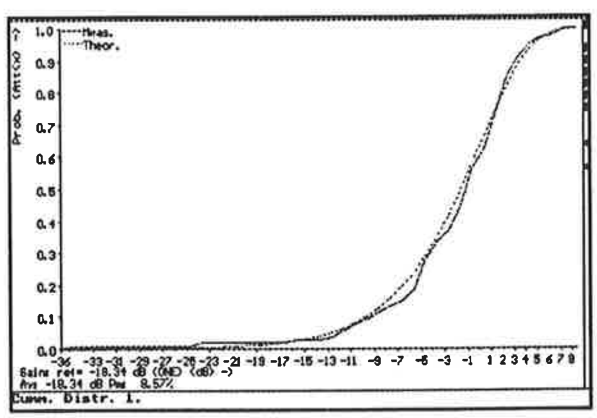

Figure 7 (612)
TX/RX 8 m (RX Height @ 1 m)