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Indoor Channel Characterisation Measurements with Directional Antennas for Future High Frequency ATM Wireless Access Systems

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ABSTRACT

This paper presents a selection of wideband channel sounding measurements performed as part of the ACTS AWACS (ATM Wireless Access Communications System) project. The results were obtained for two different indoor operating environments (mainly in line-of-sight conditions) at a carrier frequency of 19.37 GHz.

The paper discusses the configuration of the wideband channel sounder and its connection to the prototype ATM transmission system. Measurements concentrate on average power, rms delay spread and K-factor for a number of different antenna configurations and beamwidths. Mixed antenna configurations are also analysed with a directive antenna at the base station and an omni antenna at the mobile station. In particular, the results demonstrate the improvement in K-factor and the reduction in rms delay spread that can be achieved with correctly oriented high gain antennas.

I - INTRODUCTION

The ACTS AWACS project is addressing the feasibility of low cost, high data rate radio LAN systems (be operated in both indoor and outdoor environment). These systems will operate predominantly in line of sight environments with the aim of operating without the need for costly equalisation or multicarrier architectures. To allow the receiver to overcome the harmful effects of multipath and intersymbol interference, the project is investigating the use of high gain directional antennas. The AWACS project differs from most ACTS projects in that a working hardware pre-prototype system has been made available by NTT research Labs (Tokyo) at the start of the project. This hardware is being used to evaluate the channel characteristics at 19 GHz and to determine its impact on real high bit rate wireless ATM transmissions.

The market demand for wireless communications has grown rapidly and is expected to continue into the future. Over the next 10 years, optical fibre networks are expected to be extensively introduced as an infrastructure for a broadband integrated service digital network (B-ISDN). Throughout Europe, North America and Japan, there is a great deal of research focusing on the development of future broadband wireless access systems. The recently completed ETSI Hiperlan standard represents Europe's first attempt to produce a next generation high speed wireless LAN standard. The system supports transmissions up to 24 Mb/s over distances up to 100 m. The ETSI RES10 group are now focusing their attention on broadening the Hiperlan standard into a family of communication sub-systems with a total of four standards being proposed. These future standards will focus on the support of wireless ATM [1].

The Hiperlan type 1 standard [2] is firmly aimed at non-ATM indoor use and supports both Line-Of-Sight (LOS) and Non-LOS locations with the aid of adaptive equalisation techniques [3]. Hiperlan has dedicated access to two frequency bands throughout Europe. At present, Hiperlan type-1 products operate in the 5.1 to 5.25 GHz band. However, a further 200 MHz of spectrum has been allocated for future Hiperlan products in the 17.1 to 17.3 GHz band. At present, the ETSI RES10 group are drafting a wireless ATM version of the Hiperlan standard for use in the 5 GHz band (type 2). The results from AWACS will be used to help develop and influence the design of a new 17 GHz Hiperlan standard currently under discussion at ETSI (type 4).

ATM has become popular due to its flexibility in supporting a wide range of services from voice and short text messages to full motion video. Flexible connection support includes asymmetric bandwidth assignments and services based on constant bit rate (CBR), variable bit rate (VBR), available bit rate (ABR) and unspecified bit rate (UBR). However, ATM is currently only a standard for wired information transfer and at present there are no wireless ATM multimedia terminals in the marketplace.

AWACS is concerned with the development of low mobility, mainly line-of-sight, wireless ATM terminals operating in the 19 GHz radio band. The AWACS pre-prototype supports on-air data rates in excess of 70 Mb/s with user bit-rates of up to 34 Mbits/s (including head, coding, spare bits inserted, etc.). The project began in September 1996 and throughout October, NTT's existing wireless ATM equipment was modified to support wideband channel measurements. This paper discusses a number of the measurements taken to date and concentrates on the use of different antenna configurations to improve the channel's K-factor and reduce its rms delay spread. Based on these measurements, channel models and simulations will be performed in AWACS to redesign and optimise the system performance. The main goal of AWACS is to support and influence emerging ATM wireless standards, in particular the new Hiperlan type 4 system.

The channel sounder structure and the measurement environments are described in sections II and III respectively. Section IV presents the measurement results and discusses their impact for future wireless LAN designs.

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II - SETUP OF CHANNEL MEASUREMENT SYSTEM

The are three main radio equipment sub-sections that must be configured before performing channel measurements, these are the antenna, the ATM transceiver and the channel sounder.

The purpose of the antenna configuration setup is to characterise the indoor propagation channel as a function of the gain and the aperture of the transmit and receive antennas. In the following measurements, the antennas ranged from being omni directional at one extreme to having a 15 degree 3dB beamwidth at the other. The antenna configurations for these measurements are summarised in Table 1.

Omni-Omni	Omni- 60^o
60^o - 60^o	Omni- 30^o
15^o - 15^o	Omni- 15^o

Table 1: Antenna Configurations employed during the channel measurement

The channel sounder was originally used to determine the wideband characteristics of the 5.2 GHz Hiperlan system. In the AWACS project, the channel sounder has been interfaced to the ATM transmission equipment via an intermediate frequency (IF) of 850 MHz. The signal is then up converted to the final 19.37 GHz radio frequency (RF). The ATM transmission equipment is currently configured as a uni-directional system, i.e. from the BS (Base Station) to the MS (Mobile Station) with a single RF transmission filter. The data transmission system has a 3dB bandwidth of approximately 133 MHz.

The details of the channel measurement setup is shown in Figure 1 where the sounder uses a transmitter based on the use of an 11-tape PN sequence to bi-phase modulate an 850 MHz carrier.

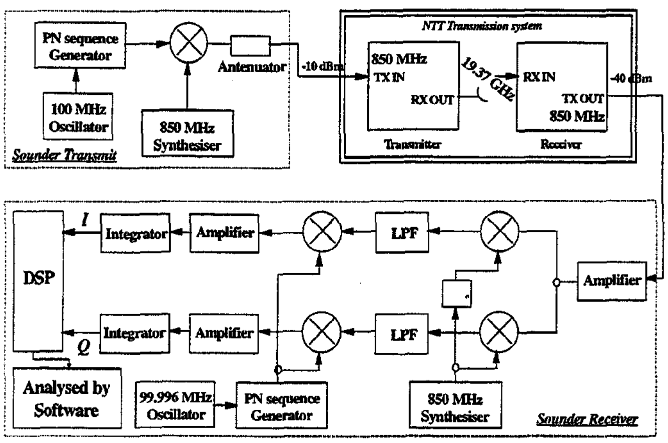


Figure 1: Block diagram of measurement system

As shown in the above figure, the PN generator is clocked at 100 MHz, giving the system a repetition period of 20.47 micro seconds. The output from the transmitter can be represented mathematically as [4],

$$T_x(t) = s(t)\cos(2\pi f_c t) \qquad (1)$$

where $s(t)$ represents the PN sequence and f_c is the frequency of the carrier.

The propagation channel can be mathematically represented by the vector summation of the multiple rays, each arriving with their own amplitude A_k, delay τ_k and associated phase θ_k as,

$$h(t) = \sum_{k=1}^{N} A_k e^{-j\theta_k}\delta(t-\tau_k) \qquad (2)$$

Thus, the signal arriving at the receiver can be denoted as,

$$R(t) = \sum_{k=1}^{N} A_k s(t-\tau_k)\cos(2\pi f_c t + \theta_k) \qquad (3)$$

This bandpass signal is then linearly translated back to baseband to derive its inphase and quadrature baseband components. This allows a two-channel correlation to be performed with a replica PRBS code running 4 kHz slower. Following the integration process, the output of the sounder yields,

$$I(t) = \sum_{k=1}^{N} A_k R_k(c\cdot t-\tau_k)\cos\theta_k \qquad (4)$$

$$Q(t) = \sum_{k=1}^{N} A_k R_k(c\cdot t-\tau_k)\sin\theta_k \qquad (5)$$

where c is a constant value and can be defined as,

$$c = \frac{f_{chip}}{\Delta f_{chip}} \qquad (6)$$

which represents the time factor arising from the difference in the chipping rate of the two PN sequences. The $I(t)$ and $Q(t)$ signals are then collected by the DSP and stored for further processing.

III - DESCRIPTION OF THE MEASUREMENT ENVIRONMENTS

In our measurement programme, six environments have been chosen to represent various indoor locations. The following sites have been used: (i) an open plan office; (ii) an entrance foyer in a modern building; (iii) a meeting room; (iv) a hardware laboratory; (v) a corridor in an old building; (vi) a corridor and the neighbouring offices in a modern building. The first two sites are now presented in detail.

Site 1: Entrance foyer of a modern building. This site was chosen since it represents a large open indoor environment where LOS and NLOS scenarios can be easily studied. Figure 2 shows the plan of the location as well as the dimensions of the surrounding area.

It is worth noting that there is a large metal surfaced column in the foyer as shown in figure 2. The MS route along *A-B-C* is free from any obstacles. However, along the path *C-D-E-B*, the LOS will be blocked by the column.

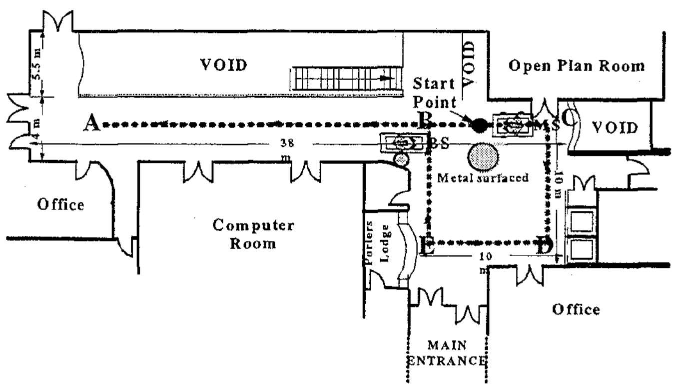


Figure 2: Entrance foyer of the Engineering building (Site 1)

Site 2: Open plan office. The office represents an area of 18x12m^2. The room is divided into work areas separated by partitions of height 1.6m. Figure 3 shows the plan of the room together with the dimensions, the positioning of the BS and the route for the MS. The walls of the room are made of reinforced concrete covered by paint and the wall and door losses have been measured and are tabulated in Table 2.

Material	Thickness (cm)	Attenuation (dB)
Concrete Wall	15	41.8
Plasterboard Wall	8	1.5
Standard Wooden Door	5	9.0
Wooden Fire Door	5	34.5

Table 2 - Material loss measurement results

The large fire door attenuation appears to arise due to a metal sheet within its structure. The floor is made of hard floorboard with a metal sheet top which is fitted with carpet.

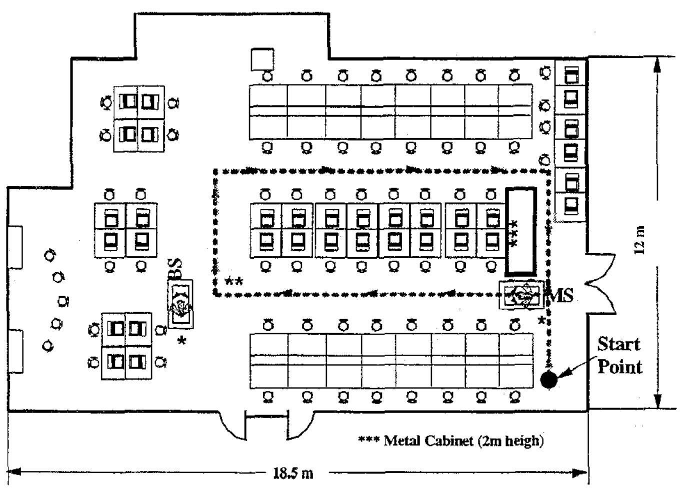
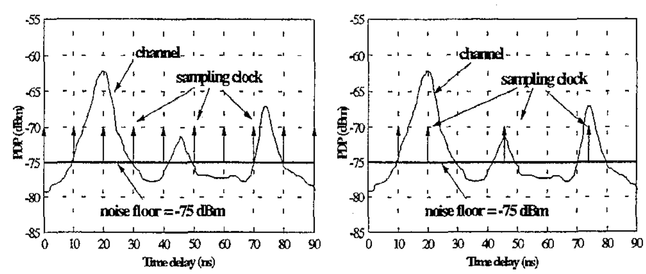


Figure 3: Schematic diagram of the open-plan office (Site 3)

IV - MEASUREMENT RESULTS AND DISCUSSION

The measurements were analysed to obtain average power (averaged over three points), rms delay spread and K-factor.

Efficient Data handling: For the measurement system, the time resolution of the sounder is 10 ns and the DSP performs analogue-to-digital conversion at a frequency of 48 kHz producing 15,000 samples. The effective sampling frequency is 1.2 GHz and this corresponds to a time resolution of 0.83 ns. To process 15,000 samples for each channel is time consuming and unnecessary. For an ideal infinite bandwidth channel sounder, a single impulse is expected for each multipath. However, due to the finite bandwidth, the channel sounder produces a pulse with a span of approximately 20 ns. There are two methods that can be used to reduce the number of samples stored. The first is to use uniformly spaced samples while the second is based on non-uniform sample spacing. As an example, Figure 4 shows an extreme occasion where the left-hand figure uses uniform spacing and the right-hand plot uses non-uniform synchronised to the peak of each pulse group. Within each pulse group, uniform sampling is used.



(i) Uniform-spacing (ii) Non-uniform spacing

Figure 4: Extreme occasion for sampling

Average Receiver Power Measurements (Site 1): The average received power measurements were taken along the path of *C-B-A* as shown in Figure 2. The BS was placed at location C. The height of both antennas was 1.6m. Three channel measurements were taken every 1m along the route. The theoretical received power can be calculated using Equation 7 assuming a transmit power of 20 dBm and the antenna gains measured in annachoic chamber listed in Table 3.

$$P_R(dBm) = G_T + G_r - 20\log d - 38.17 \qquad (7)$$

where d is the distance between the BS and MS.

3 dB beamwidth (degrees)	Gain (dBi)
16	21
30	14.1
58	10.9

Table 3: Gain of antenna

Figure 5 shows the average received power measurements for identical antennas at the BS and MS. The theoretical power levels (assuming a power exponent of 2) for each antenna configuration is also shown.

For very directive antennas (15^o - 15^o beamwidths), the results are very close to the LOS free-space predictions. Results were also obtained for mixed antenna arrangements where it was found that the performance of the omni-15^o combination is very similar to that of the 60^o - 60^o result. This implies that it is the total value of the directive gain ($G_T + G_R$) that is important when determining the average received power level (since the omni-15^o and the 60^o - 60^o arrangements both have approximately 22 dBi of total antenna gain). In addition to average received power, it is also important to consider both the rms delay spread and the overall K-factor.

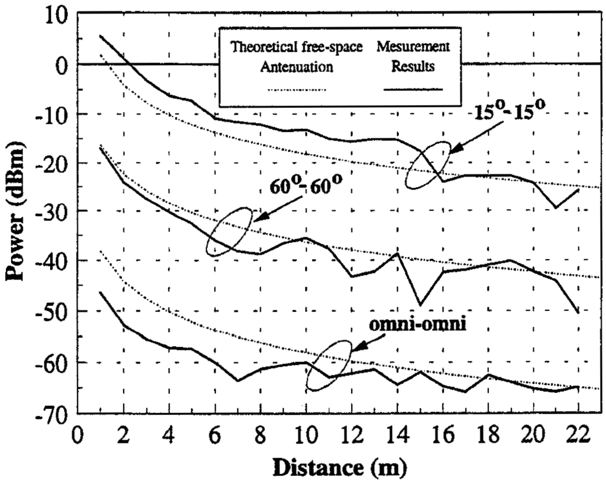


Figure 5: Path-loss measurement results

RMS delay spread and K-factor (Site 1): The rms delay spread measurements for site 1 are shown in Figure 6. A total of six antenna configuration are considered. It can be seen that the performance of the $60^o - 60^o$ arrangement is better than the omni-15^o approach, and the omni-30^o is much better than the omni-60^o. The results indicate that low rms delay spreads can be achieved with correctly orientated narrow beamwidth antennas. Assuming rms delay spreads less than 20 ns are required, the $15^o - 15^o$ configuration achieves 100% coverage whereas the $60^o - 60^o$ setup allows 90% coverage.

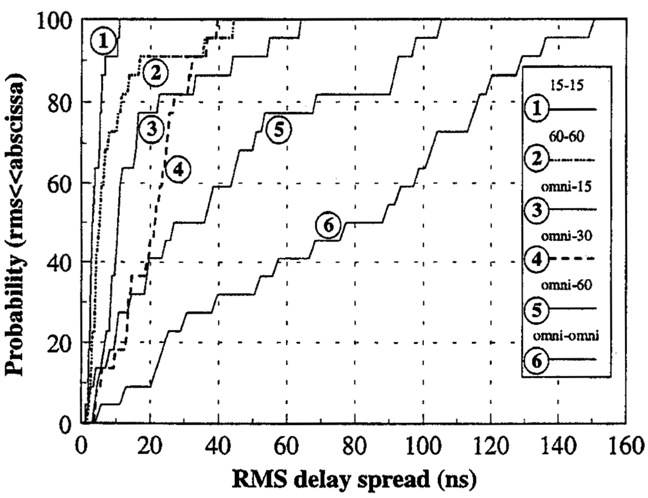
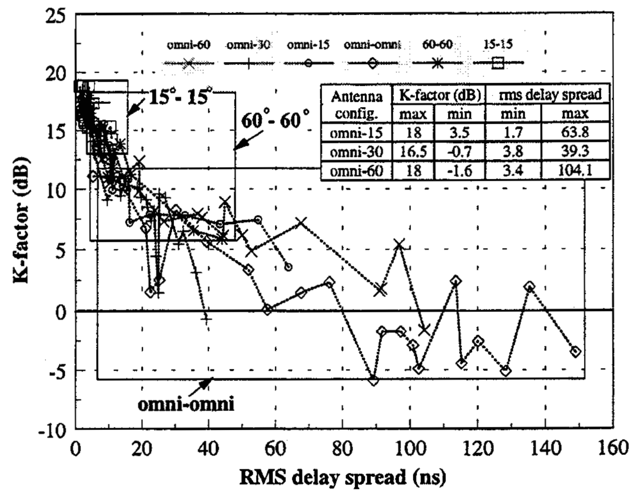


Figure 6: RMS delay spread CDF

With an omni-antenna at the mobile, a 15 degree antenna was necessary at the basestation to achieve 75% coverage. For 30 and 60 degree antennas at the basestation, coverage drops to around 40% of locations. It should be noted that all these measurements were taken within 25 m of the BS.

Assuming no equalisation is used, high speed wireless LANs can tolerate higher values of rms delay spread when a strong line of sight path is present at thre receiver to prevent multipath fading. Hence, the relationship between K-factor and rms delay spread is important and is shown in Figure 7 for each antenna configuration. The graph shows that the K-factor remains high (>7 dB) for values of rms delay spread less than 20 ns. As the rms delay spread increases, there is a greater possibility of encountering low K-factors, and hence severe fading. For a given modem, it is possible to determine the required K-factor, power and rms delay spread thresholds necessary to achieve acceptable performance. Using these values, the appropriate antenna configuration can be chosen. For example, with 15 degree beamwidth antennas, the lowest measured K-factor was 12 dB and the highest rms delay spread was 10ns. However, for an omni-omni configuration, the K-factor can be as low as -6 dB (Rayleigh) and the rms delay spread as high as 150ns. The table in figure 7 shows the extreme K-factors and rms delay spreads for mixed antenna solutions.



Antenna config.	K-factor (dB)		rms delay spread	
	max	min	min	max
omni-15	18	3.5	1.7	63.8
omni-30	16.5	-0.7	3.8	39.3
omni-60	18	-1.6	3.4	104.1

Figure 7: Performance of K-factor against rms delay spread

Figure 8 shows the K-factor plotted against average received power for various antenna arrangements. As expected, highly directive antennas result in large powers and K-factors. As the directivity is reduced, the average power falls and lower values of K-factor were measured.

For digital transmission through such channels, it now appears that the K-factor is a more important parameter than the rms delay spread. For example, when the K-factor is high then the received 'eye diagram' will remain open at the sampling points irrespective of the time delay spread. For K-factors greater than 8-10 dB, even if the random multipaths add up coherently (which is unlikely), the LOS component will remain greater and hence the 'eye diagram' will remain open. Using this argument, at high K-factors the rms delay spread is not important and the supported bit rate will be determined by the signal to noise ratio. This implies that with sufficient antenna gain and transmit power, for K-factors greater than 8-10dB, very high bit rates (in the region of 155 Mb/s) could be supported.

Based on the results shown in figure 7, the $15^o - 15^o$ antenna configuration would meet this K-factor criteria over the 25 meter route considered. However, the omni-15^o antenna resulted in a worst case K-factor of 3.5 dB. This implies that for some locations (approximately 30% assuming a worst case Rayleigh distribution), the phasor summation of the random components would result in eye-closure and hence, bit errors. To improve the probability of a favourable channel, simple spaced antenna diversity can be used at the mobile. Assuming two uncorrelated paths, the probability of failure would be statistically reduced to 9%. This implies that very high speed data links can be achieved over our test route with two spaced omni antennas at the mobile and a 15 degree directional antenna at the BS.

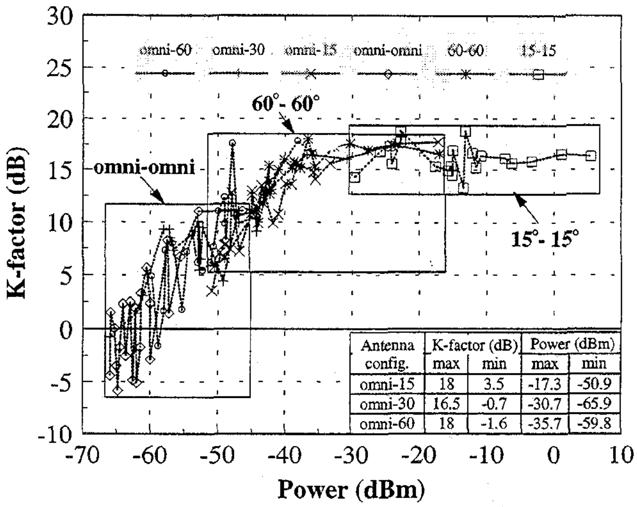


Figure 8: Performance of K-factor against power

Example results for open plan office (Site 2): The rms delay spread statistics for site 2 are shown in Figure 9 (see Figure 3). Part of this route is blocked by a metal filing cabinet and in this location rms delay spreads in excess of 100ns were measured.

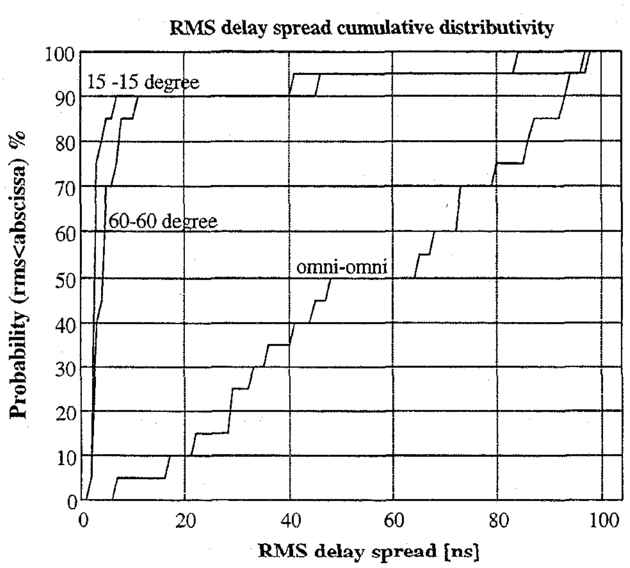


Figure 9: RMS Delay Spread Statistics
(open plan office)

Once again, the rms delay spread measurements confirm that omni-omni antennas can result in very high rms delay spreads (values around 100ns were measured). For this value of delay spread, it would be difficult to achieve data rates in excess of 1 Mb/s without the use of adaptive equalisation or multicarrier transmission. However, with the directive antennas, around 90% of locations were found to have rms delay spreads less than 10 ns. Given that these locations will also have high values of K-factor, it should be possible to support very high unequalised data rates. The next phase of the AWACS project will see BER and Cell Loss Rate (CLR) measurements being taken along these routes for an on-air data rate of approximately 74 Mb/s. These data measurements will help to confirm the conclusions drawn from this channel sounding exercise.

V - CONCLUSIONS

In this paper, measurements at 19.37 GHz have been presented for two typical wireless LAN operating environments. The results give a good indication of the propagation characteristics that can be expected in this emerging frequency band. Generally, rms delay spreads varied between 5ns and 150ns (with the lower values being achieved with at least one end making use of a correctly orientated high gain antenna). Values of K-factor have also been measured and it is suggested that for values greater than 8-10dB, the bit rate becomes limited by Signal to Noise rather than rms delay spread.

The results indicate that for radio LAN systems such as the 17 GHz Hiperlan type 4 standard, the use of fairly narrow antenna beamwidths can be used in line-of-sight (and some non-line-of-sight) locations as an alternative to adaptive equalisation or multicarrier transmission. The results show good perform can be expected when highly directive antennas are used at the basestation and omni-directional antennas are used at the mobile. The problem of achieving good omni-directional coverage still needs to be addressed. The AWACS project aims to investigate the feasibility of switched beam antenna solutions at the basestation.

VI - ACKNOWLEDGEMENTS

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VII - REFERENCES

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