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A STATISTICAL MODEL FOR THE SQUARED ENVELOPE OF RADIO CHANNEL IMPULSE RESPONSE FUNCTIONS

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1. Introduction

Measured wideband characteristics of static and time varying radio channels are currently reported in a number of different ways, including: (1) the plotting of individual impulse response estimates; (2) the plotting of impulse response estimate averages, and (3) the reporting of rms delay spreads. Each of these methods has associated problems related to the volume of data that must be reported, or ambiguity of reported results. In particular [1], the reporting of rms delay spreads without a knowledge of the noise exclusion threshold that was used during their computation or the shape of the impulse response leads to considerable difficulty in the interpretation of reported results. This paper presents a method for modelling radio channel impulse response estimate measurements in the form of statistical models that are compact and free of ambiguities.

It is proposed that the new models be called statistical impulse response models (SIRMs) for a particular channel type, and that such models be computed from measured data, as follows.

a) For static channels (e. g. indoor radio links in buildings where no people are moving), SIRMs should be computed from the median and 90th percentile of the maximum delays, with respect to their centroid, at which the powers of individual measured impulse response estimates are −10,−15,−20,−25 and −30 dB with respect to the peak power in the estimate. The data pool used in computations for the model should come from samples of impulse response estimates between transmit and receive locations that are uniformly distributed in space over an area throughout which digital transmission is planned among multiple fixed stations (e. g. in wireless LANS);

b) For time variant channels (e. g. indoor channels in dynamic environments, or mobile radio channels), SIRMs should be computed from the median and 90th percentile of the maximum delays, with respect to their centroid, at which the relative powers of temporal or spatial average impulse response estimates have the values specified in a) above, with respect to their peak powers. Averages used in computations for the model should be calculated over spatial or temporal intervals that are considered typical of transmission intervals in planned systems.

Such models can be used to accurately portray the severity of multipath propagation on measured channels. It is anticipated that future research will lead to a method by which they can also be used in the prediction of digital system performance on modelled channels.

The centroid of impulse response estimates was chosen as the reference for delays used in computing the proposed models, since this is the delay [2] to which a receiver using a phase locked loop for bit timing recovery would synchronize. This delay, denoted τ_{ave}, can be calculated as:

$$\tau_{ave} = \frac{\sum_{k=1}^{N} \tau_k \tilde{P}(\tau_k)}{\sum_{k=1}^{N} \tilde{P}(\tau_k)} - \tau_0,$$

where:

k orders the N samples in the power representation of a specific measured impulse response estimate $\tilde{P}(\tau)$ for a static channel, or an average of estimates $\tilde{P}_{ave}(\tau)$ for a time variant channel; and,

τ_0 is the earliest delay at which there is power in the estimate above the noise floor of the system used for the channel measurements.

To clarify the foregoing explanation, Fig. 1 shows the logarithmic plot of an impulse response estimate, its centroid, and excess delays at relative power levels of -10, -20 and -30 decibels with respect to its peak. Fig. 2 shows a SIRM (markers show every 4th data point) which has been found to characterize static indoor radio channels in an older, partitioned building under non-line-of-sight conditions.

2. Examples of SIRMs for indoor radio channels

The first example is a SIRM that was computed from static channel measurements [1] over half-second intervals in 100 different locations throughout an older, brick, three storey building. The measurement system was a spread spectrum system with a sliding correlator type receiver. The system bandwidth was 80 MHz centred on 910 MHz, and measured impulse response estimates had a temporal resolution of 25 ns. The SIRM is plotted in figure 2, and shows the extent of time dispersion at the median and 90th percentile on non-line-of-sight channels between a central station in a hallway of the measured building and the 100 scattered locations. It should be noted that models were computed from various numbers of spatial samples, ranging from 10 to 100, and it was found that results converged to the model in the figure after about 20 samples.

The SIRM in Fig. 3 was computed from measurements using the same equipment on the top floor of a very modern open-concept office building. In this building the central station was located at the centre of the open space defined by the outer walls of the building, with its receive antenna at a height of approximately 50 cm above floor level. For each measurement, the transmit antenna was in a different location, and was also fixed at 50 cm above floor level so that line of sight to the receive antenna was almost always blocked by office furnishings and cubical partitions. The median SIRM in the figure is remarkedly similar to that in Fig. 2, even though the buildings in which the measurements were taken are very different. The SIRM which represents the 90th percentile, however, indicates the presence of larger multipath spreads at the lower relative power levels in the older building which has permanent partitions.

The same measurement configuration as that used for the derivation of the model in Fig. 3 was also employed during a new set of measurements, with the transmit and receive antennas elevated above the level of most furniture and cubical partitions. The resulting model is shown in Fig. 4. Comparison of the models in Figs. 3 and 4 shows very little change in the median. A significant reduction in multipath spreads is shown at the 90th percentile, however, for the case of line of sight conditions. The experiments that produced the models in Figs. 3 and 4 were conducted twice, in the same area of the open-concept building, at times separated by almost two years, using spread spectrum measurement equipment with completely different designs, and for two different arrangements of furniture. The models computed from results for the two different experiments can be reported to be almost identical. This attests to the robustness and accuracy of the proposed models. The knowledge conveyed by these models is extremely important to systems engineers in the design of wideband systems and this example shows that the portrayal is clear, concise and reliable.

As a final example of the usefulness of SIRMs in propagation studies, Figs. 5 and 6 show SIRMs computed from measurements recorded along the centreline of the open-concept building under furnished and empty conditions respectively. The multipath spread in the model of Fig. 6, representing the empty condition, can be seen to be significantly greater at both the median and 90th percentile. Such comparisons can be used both as a tool in attempting to explain the physics of propagation on the channel under study, and as a guide in the design of communication systems. From this example, one could conclude that, for the case of the empty building, multipath characteristics are influenced more by reflections from the floor and adjacent buildings. The greater influence due to reflections from adjacent buildings arises because, in the absence of furniture, these are visible from almost any position on the office floor. One could also conclude that transmission of high speed digital signals in empty buildings (e. g. shopping malls) of similar construction to that in which the measurements were made would suffer more degradation than high speed transmission of such signals in furnished buildings of the same size.

3. Summary and conclusions

This paper has reported new statistical models that can be used for the quantification and reporting of multipath characteristics on static and time varying radio channels. It is proposed that these models be referred to as Statistical Impulse Response Models, or SIRMs. Examples have been given, which show that a considerable amount of information can be portrayed clearly, concisely and reliably by these models and that conclusions that are useful both in understanding the physics of multipath propagation, and in radio system design can be drawn by examination and comparison of SIRMs for different channels. A compilation of such models from measurements on different channels would yield considerable information in a form that could be utilized for a variety of applications.

Research is currently being performed on methods for the utilization of SIRMs in the prediction of performance on digital radio systems. It is anticipated that the results of this research will be ready for presentation at the symposium. Other SIRMs computed from indoor experiments in different buildings and at other frequencies, as well as from land mobile measurements in several Canadian cities and in the Canadian Rockies will also be presented.

References

1 Bultitude, R.J.C., et al., "A comparison of indoor radio propagation characteristics at 910 MHz and 1.75 GHz", IEEE Journal on Selected Areas in Communications, Vol. SAC-7, pp 20-30, January 1989.

2 Chuang, Justin C-I,"The effects of time delay spread on portable radio communication channels with digital modulation", IEEE Journal on Selected Areas in Communications, Vol. SAC-5, No. 5, pp 879-889, June 1987.

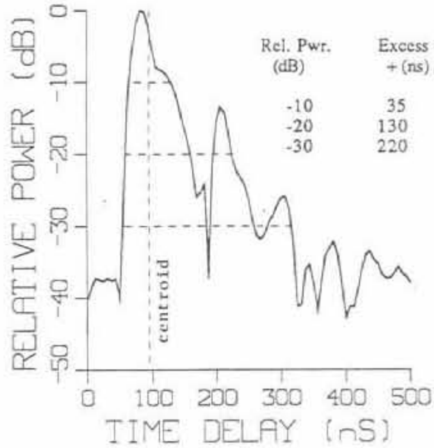

Fig. 1. Individual static indoor channel impulse response estimate.

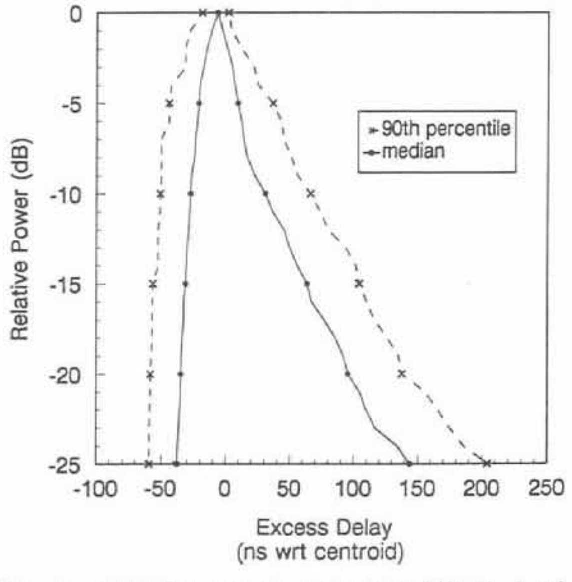

Fig. 2. SIRM for non-line-of-sight 900 MHz band radio channels in an older 3-story brick building with permanent partitions.

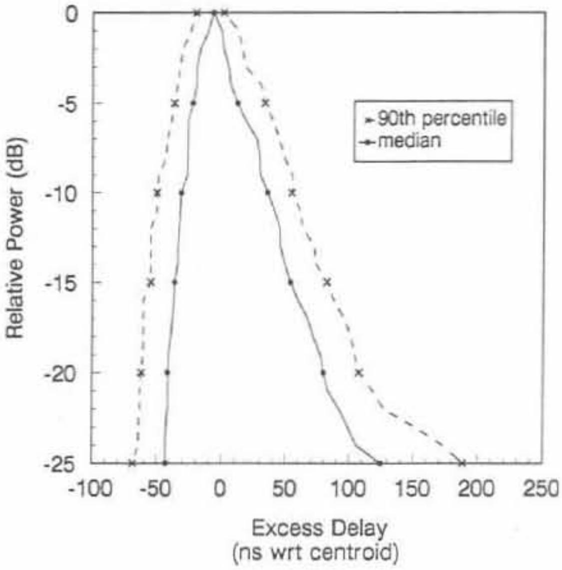

Fig. 3. SIRM for non-line-of-sight 900 MHz band radio channels in a modern 3-story furnished open-concept office building.

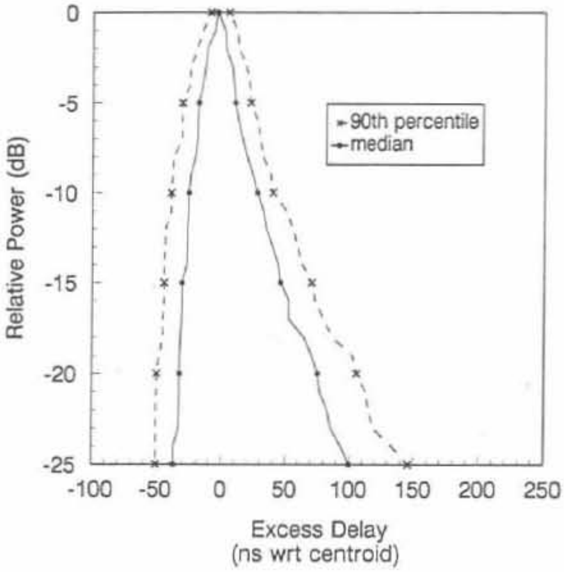

Fig. 4. SIMR for line-of-sight 900 MHz band radio channels between scattered locations in a modern 3-story furnished open-concept office building.

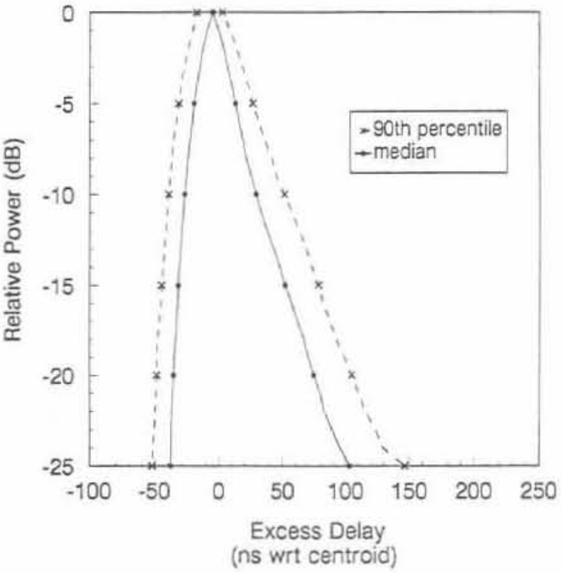

Fig. 5. SIRM for line-of-sight 900 MHz band radio channels along the building centreline in a modern 3-story furnished open concept office building.

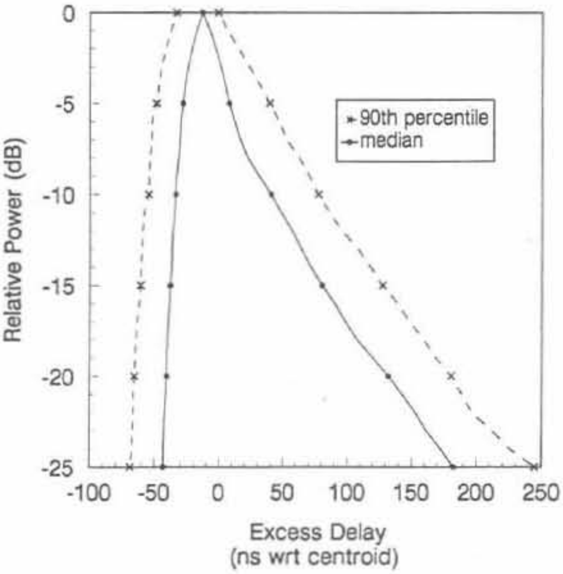

Fig. 6. SIRM for line-of-sight 900 MHz band radio channels along the building centreline in a modern 3-story empty open-concept office building.