

Exploration of Nakagami Fading in Ultrawideband Wireless Channels

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Abstract

This letter explores the parameters m and Ω of the Nakagami distribution for fading in ultrawideband wireless channels. In contrast to the IEEE 802.15.4a model, it shows the dependency of these parameters on bandwidth, which facilitates optimisation of UWB transceiver systems.

1. Introduction

Small scale fading is a wireless propagation artefact that effects the communication link budget and influences the forward error correction schemes [1]. For ultrawideband channels, the IEEE 802.15.4a model proposes that the m-Nakagami distribution is suitable for rays arriving in clusters [2]. The model does not study the dependency of fading severity on the actual bandwidth employed even though it is known that with the increase of bandwidth, more multipaths can be resolved and the severity of fading decreases as shown e.g. in references [3]-[5].

The references [3]-[5] only studied the standard deviation of the fading whereas the dependency on bandwidth of the parameters in the m-Nakagami distribution is studied in this letter. The conclusions can be used to supplement the IEEE 802.15.4a propagation model to aid the design more efficient UWB transceivers. For instance, using the current IEEE 802.15.4a model with bandwidth independent parameters in the m-Nakagami distribution, there is no incentive to explore the impact of OFDM subcarrier bandwidth on the bit error performance. Given the previous published research reported in [3]-[5] it can be concluded that an increase in bandwidth will lead to reduction of bit-errors. As a result, the fade mitigation measures such as forward error correction and frequency diversity can be relaxed,

thus reducing the requirements on signal processing while maintaining the system performance [6].

This letter studies the parameters of the m-Nakagami distribution as a function of bandwidth to provide a theoretical baseline for system optimization as outlined above.

2. Measurement setup

The analysis of m-Nakagami parameters used measurements conducted in a laboratory environment. The area of the laboratory was approximately 25 m², the walls, ceiling and the floor were constructed from reinforced concrete. The measurement was conducted with transmit signal power density of -41.3 dBm/MHz so that the measurement maximally corresponds to the real conditions for an indoor UWB transmission. There were five sets of measurements each for a different distance between the transmitter and receiver. For each distance, the transmitter was displaced in a grid of 40 × 40 points spaced by 6 mm. The frequency range of the measurements was 3 – 20 GHz. The lower limit was given by the selection of discone antennas with a lower cut off frequency of 2.5 GHz. The upper limit was determined by the available low-noise amplifier. The frequency step size was 0.5 MHz.

3. Data analysis

The probability density function of the m-Nakagami distribution is given as follows [2]:

$$pdf(x) = \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^m x^{2m-1} e^{-\left(\frac{m}{\Omega}x^2\right)}$$

Where x represents the relative attenuation of the channel compared to the local mean, $m \geq 1/2$ is the Nakagami m-factor, Ω is the mean-square value of the amplitude and $\Gamma(m)$ is the gamma function.

For each set of measurements corresponding, a grid of 40 × 40 points was processed and the corresponding channel energy for a selected bandwidth was calculated. From the distribution of the channel energies, the parameters m and Ω of the Nakagami distribution were calculated for bandwidths of between 2 MHz – 5 GHz spaced logarithmically, and for

12 centre frequencies (5.5 GHz – 11 GHz spaced by 0.5 GHz). Fig. 1 presents the shape of the probability density function of the m-Nakagami distribution as calculated for 4 different bandwidths (5 MHz, 50 MHz, 500 MHz, 5 GHz) at a centre frequency of 6 GHz for a distance of 156 cm.

With reference to Fig. 1, the change of the shape of the pdf is apparent. It can be seen that whilst complete loss of the signal is possible for lower bandwidths (5 and 50 MHz) due to the high probability of deep fades, it is extremely unlikely for larger bandwidths (500 MHz and 5 GHz). To further study the impact of bandwidth Fig. 2 presents the dependency of the m-Nakagami parameters m and Ω on the bandwidth at a centre frequency of 6 GHz and for four different distances (126 cm, 156cm, 192 cm, 278 cm).

The decreasing trend of m with distance corresponds to the dependency of the parameter on distance as stated but not fully evaluated in the IEEE 802.15.4a model. Few dips in the trend are caused by the fact that m and Ω are random parameters with lognormal distribution [2].

Thus, for a few combinations of bandwidth, distance and centre frequency of the estimated parameters may diverge from the general trend. These differences are relatively small.

Analysis of the impact of parameters m and Ω on the shape of the pdf reveals that for $m > 5$ and $\Omega < 1.1$ the system can be assumed to be wideband, i.e. a complete erasure of the signal due to fading is extremely unlikely. Quantitatively, for $m > 5$ and $\Omega < 1.1$, there is only 0.62 % of fades 3 dB below the local average. In case of 6 dB fades below the local average, the probability is only $1.24 \cdot 10^{-3}$ %.

Therefore, the first bandwidths for which the two values fulfilled the above conditions were used as the lower limit for wideband channel. Statistics of the 60 available measurements (5 distances and 12 centre frequencies) is presented in Table 1.

4. Conclusion

This letter has studied the dependency of the m and Ω parameters of the m-Nakagami distribution that can be used to describe small scale amplitude fading in wireless UWB channels. It confirms previous works in it shows that the severity of the fading is reduced for

larger bandwidths. Compared to previous works, it provides the shape of the probability density function and characteristics of the parameters as a function of bandwidth. It is shown that for bandwidth above 500 MHz a drop of received energy 6 dB below the local average occurs only for $1.24 \cdot 10^{-3}$ % of positions. As a result, this study can be used as a supplement to the IEEE 802.15.4a model and provide a tool for subcarrier bandwidth optimisation in UWB OFDM systems.

References:

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Figures

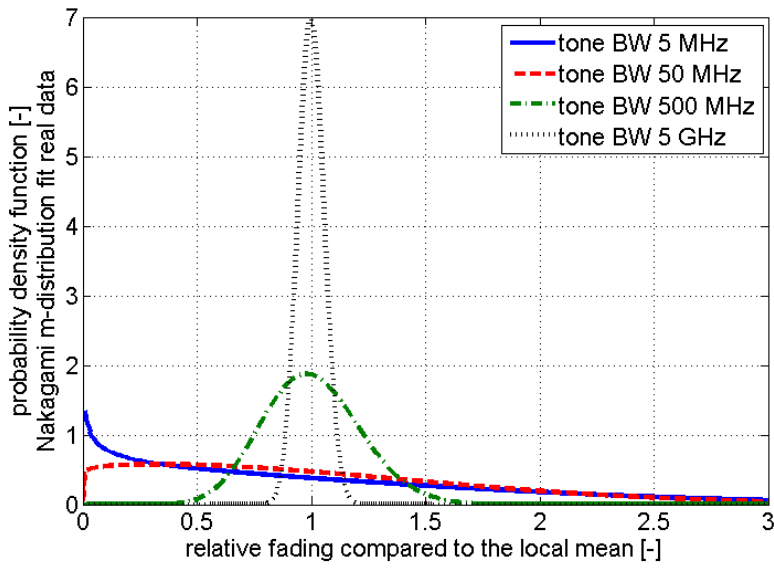


Figure 1 Change of probability density function with increase of signal bandwidth

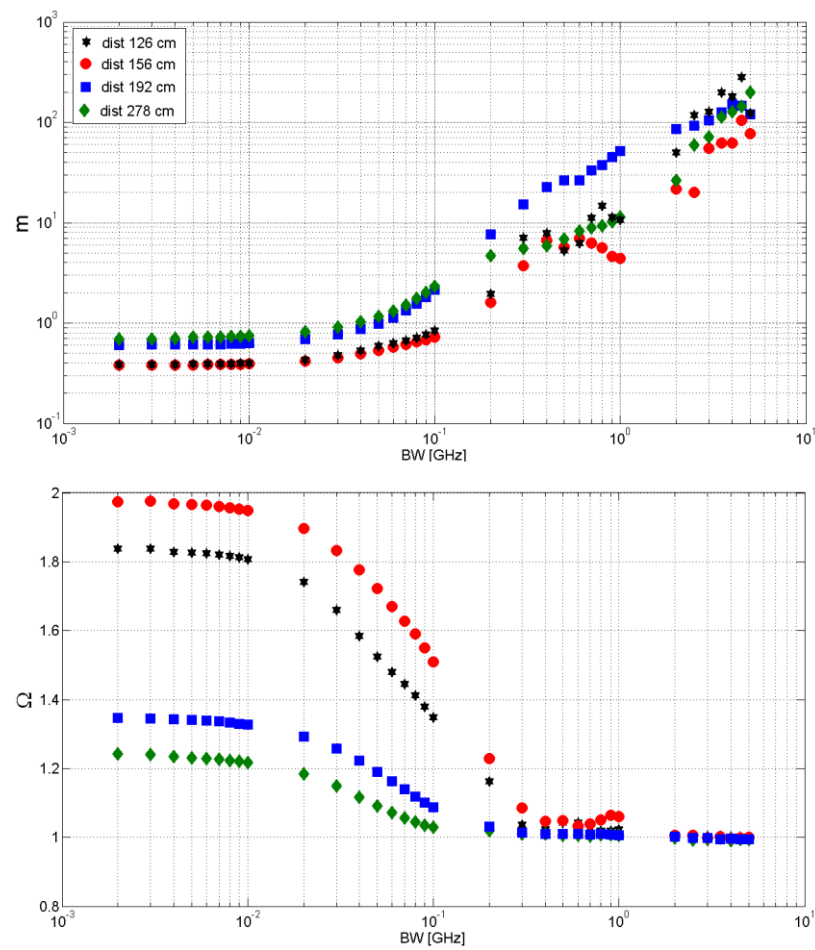


Figure 2 Dependency of m and Ω parameters on bandwidth

Tables

Table 1 Statistics for minimum bandwidth for which $m > 5$ and $\Omega < 1.1$

	Mean BW	Median BW	80 th percentile BW
$m > 5$	540 MHz	500 MHz	600 MHz
$\Omega < 1.1$	303 MHz	330 MHz	400 MHz