Rapidly Deployable Radio Network (RDRN)

Interleaving Requirements

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1 Introduction

This technical report gives an overview of the interleaving requirements for the Rapidly Deployable Radio Network (RDRN). [1] showed that for the single point-to-point radio test link for RDRN, sufficient link margin was achieved. Certain assumptions made in [1], like the assumption about the antenna heights and the use of free space loss for calculating the link margin under fading conditions, have been changed in this report. The modified link budget then justifies the need for fading mitigating techniques.

Section 2 gives the background and the results from the modified link budget. Section 3 considers the necessity of coding and interleaving specific to RDRN traffic. The interleaving method and the resulting requirements are explained in detail in section 4. Sections 5 and 6 illustrate the future work and conclusions. The Okumura model used for path loss calculation has been explained in appendix A.

2 Background

A detailed link budget was developed in [1] for the Rapidly Deployable Radio Network (RDRN) initial prototype test link, with the transmit and receive antenna heights assumed at 2m each. The RDRN test link has a communication range of 10 km and a bit error rate requirement of 10^{-5}. A link budget was done assuming transmission of up to 10 ATM cells as a block of data under slow Rayleigh fading conditions. An important conclusion from [1] is that techniques to combat fading are not necessary for the RDRN test link. It was found the link budget [1] that even for the worst case of a slow Rayleigh fading channel, without coding and interleaving, the RDRN test link was found to close with considerable link margin.

However, the RDRN test link is just for the purpose of demonstration of the RDRN capabilities. Measures to counter fading have to be taken for the RDRN system and the following conditions, for which the RDRN test link will not close, could be the reasons for considering such measures,

- Lower bit error rates
- Increased range of operation
- Increased data rates

2.1 Modified Link Budget

Moreover, the link budget in [1] assumed transmit and receive antenna heights of 2 m each. An approximate topography of the terrain for the RDRN test link has been sketched in [2]. The effective antenna heights, taking into consideration the difference in the altitude between the transmit and receive sites, are different from the assumption made in [1]. The effective transmit antenna height was 54 m and the effective receive antenna height was 2 m. Using these values for the antenna heights, the link budget for the RDRN test link was developed. Free space loss was assumed in [1] for calculating the link margin under fading conditions. This assumption was modified by computing the path loss, used to calculate the link margin under fading conditions, using the Okumura propagation model (See Appendix). For these modified assumptions, the path loss for the two-ray model was calculated to be 119.33 dB and the path loss using the Okumura propagation model was 133.65 dB.

Tables (1) shows the link margin obtained for different propagation models, for bit-by-bit transmission for the RDRN test link. Tables (2), (3) and (4) summarize

Table 1: Summary of transmit power requirements for bit-by-bit transmission for the RDRN test link for different propagation models

Channel model	Receiver NF	Transmit Power required	Link margin
AWGN	5 dB	1.459 mW	35.72 dB
	10 dB	4.613 mW	30.72 dB
AWGN two-ray model	5 dB	4.62 mW	30.91 dB
	10 dB	13.56 mW	25.91 dB
Okumura model	5 dB	0.119 W	16.59 dB
	10 dB	0.377 W	11.59 dB

Table 2: Summary of transmit power requirements for bit-by-bit transmission for the RDRN test link for fading channels with free space loss

Channel model	Receiver NF	Transmit Power required	Link margin
Rayleigh fading	5 dB	4.093 W	1.24 dB
	10 dB	12.94 W	-3.76 dB
Rician fading K = 6 dB	5 dB	0.402 W	11.32 dB
	10 dB	1.27 W	6.32 dB
Rician fading K = 12 dB	5 dB	3.58 mW	21.82 dB
	10 dB	11.32 mW	16.82 dB

Table 3: Summary of transmit power requirements for bit-by-bit transmission for the RDRN test link for fading channels with two-ray model path loss

Channel model	Receiver NF	Transmit Power required	Link margin
Rayleigh fading	5 dB	12.39 W	-3.57 dB
	10 dB	39.17 W	-8.57 dB
Rician fading K = 6 dB	5 dB	1.216 W	6.51 dB
	10 dB	3.85 W	1.51 dB
Rician fading K = 12 dB	5 dB	10.84 mW	27.01 dB
	10 dB	32.28 mW	22.01 dB

Table 4: Summary of transmit power requirements for bit-by-bit transmission for the RDRN test link for fading channels with Okumura model path loss

Channel model	Receiver NF	Transmit Power required	Link margin
Rayleigh fading	5 dB	334.96 W	-17.89 dB
	10 dB	1059.25 W	-22.89 dB
Rician fading K = 6 dB	5 dB	32.89 W	-7.81 dB
	10 dB	103.99 W	-12.81 dB
Rician fading K = 12 dB	5 dB	0.293 W	12.39 dB
	10 dB	0.927 W	7.39 dB

the link budget, for bit-by-bit transmission under different fading channels, using the free space loss, two-ray model path loss and Okumura model path loss respectively. It is apparent from table (4) that if the Okumura model path loss was used to calculate the link budget, the RDRN test link closes only for a Rician fading channel with K = 12 dB. The link budget for packet transmission under slow Rayleigh fading condition and using Okumura model path loss is summarized in table (5). The test link closes only when the receiver noise figure is 5 dB and the number of ATM cells sent as a block of data is more than 4. So it can be concluded from the modified link budget that fading has to be countered for RDRN using some form of fading mitigating technique.

3 Coding and Interleaving for RDRN traffic

The previous section established the need for some sort of technique to counter the effects of fading. Some of the techniques used to avoid fading losses are diversity combining, coding and interleaving, spread-spectrum and smart antennas.

Table 5: Link analysis for transmission of ATM cells for a fixed bit error rate

No. of ATM cells	$\gamma_{o\_no\_code}$	Packet Error Rate	$\left(\frac{E_b}{N_o}\right)_{req}$ dB	Rx NF dB	Tx power req in W	Link margin dB
1	4.5292	0.00423	30.28	5	13.96	-4.09
				10	44.16	-9.09
2	5.1634	0.00844	27.85	5	7.98	-1.66
				10	25.23	-6.66
3	5.5373	0.01264	26.39	5	5.7	-0.2
				10	18.03	-5.2
4	5.8038	0.01682	25.34	5	4.48	0.85
				10	14.16	-4.15
5	6.0110	0.02098	24.53	5	3.72	1.66
				10	11.75	-3.34
6	6.1806	0.02512	23.86	5	3.18	2.33
				10	10.07	-2.67
7	6.3244	0.02924	23.29	5	2.79	2.9
				10	8.83	-2.1
8	6.4491	0.03335	22.79	5	2.49	3.4
				10	7.87	-1.6
9	6.5592	0.03744	22.35	5	2.25	3.84
				10	7.11	-1.16
10	6.6578	0.04151	21.96	5	2.06	4.23
				10	6.50	-0.77

Table 6: Link margin for the RDRN test link in Rayleigh fading for voice traffic with a packet error rate of 10^{-3}

No. of ATM cells	γ_o	Bit Error Rate	$\left(\frac{E_b}{N_o}\right)_{req}$ dB	Rx NF dB	Link margin dB
1	4.5292	0.236e-5	36.56	5	8.76
				10	3.76
4	5.8038	0.059e-5	37.64	5	7.68
				10	2.68
6	6.1806	0.039e-5	37.91	5	7.41
				10	2.41
8	6.4491	0.029e-5	38.09	5	7.22
				10	2.22
10	6.6578	0.024e-5	38.23	5	7.08
				10	2.08

Implementation of diversity combining and spread-spectrum require re-designing of antennas and receivers and extra hardware. Coding and interleaving can be relatively easily incorporated into the present system using either hardware or software. Therefore, coding and interleaving can be chosen to counter fading losses for RDRN. A half-rate convolutional encoder with a Viterbi decoder can be used a coding and decoding schemes for RDRN.

RDRN carries two types of traffic namely, delay-sensitive traffic like voice and delay-insensitive traffic like data. It must be determined whether both types of traffic need interleaving. Assuming a packet error rate of 10^{-3} and parameters from the link budget in [1], for voice traffic in a Rayleigh fading environment and without coding and interleaving, we find that the RDRN test link closes comfortably (table (6)). With the same parameters, voice traffic can be transmitted up to a maximum distance of 22.62 km without any increase in power requirements and without coding and interleaving, under Rayleigh fading conditions. So, it can be concluded that

Table 7: Link margin for the RDRN test link in Rayleigh fading for data traffic with a bit error rate of 10^{-8}

No. of ATM cells	γ_o	Packet Error Rate	$\left(\frac{E_b}{N_o}\right)_{req}$ dB	Rx NF dB	Link margin dB
1	4.5292	4.24e-6	60.29	5 10	-14.97 -19.97
4	5.8038	16.96e-6	55.34	5 10	-10.03 -15.03
6	6.1806	25.44e-6	53.86	5 10	-8.54 -13.54
8	6.4491	33.92e-6	52.79	5 10	-7.47 -12.47
10	6.6578	42.4e-6	51.96	5 10	-6.64 -11.64

voice can be transmitted without being coded and interleaved. In that case, voice traffic will have only propagation delay.

For the delay-insensitive traffic like data, assuming a bit error rate of 10^{-8} and parameters from the link budget in [1], under Rayleigh fading conditions and without coding and interleaving, we find from table (7) that the RDRN test link does not close. Therefore, data traffic needs to be coded and interleaved in order to avoid fading losses.

4 Interleaving Method and Requirements

Interleaving between blocks of data can be used for RDRN, since fading is slow. Inter-block interleaver takes an input block of NB symbols and disperses N symbols to each of the next B output blocks [4], [5]. For RDRN, N symbols of data from an ATM cell can be interleaved into B subsequent ATM cells. If x is the coded symbol

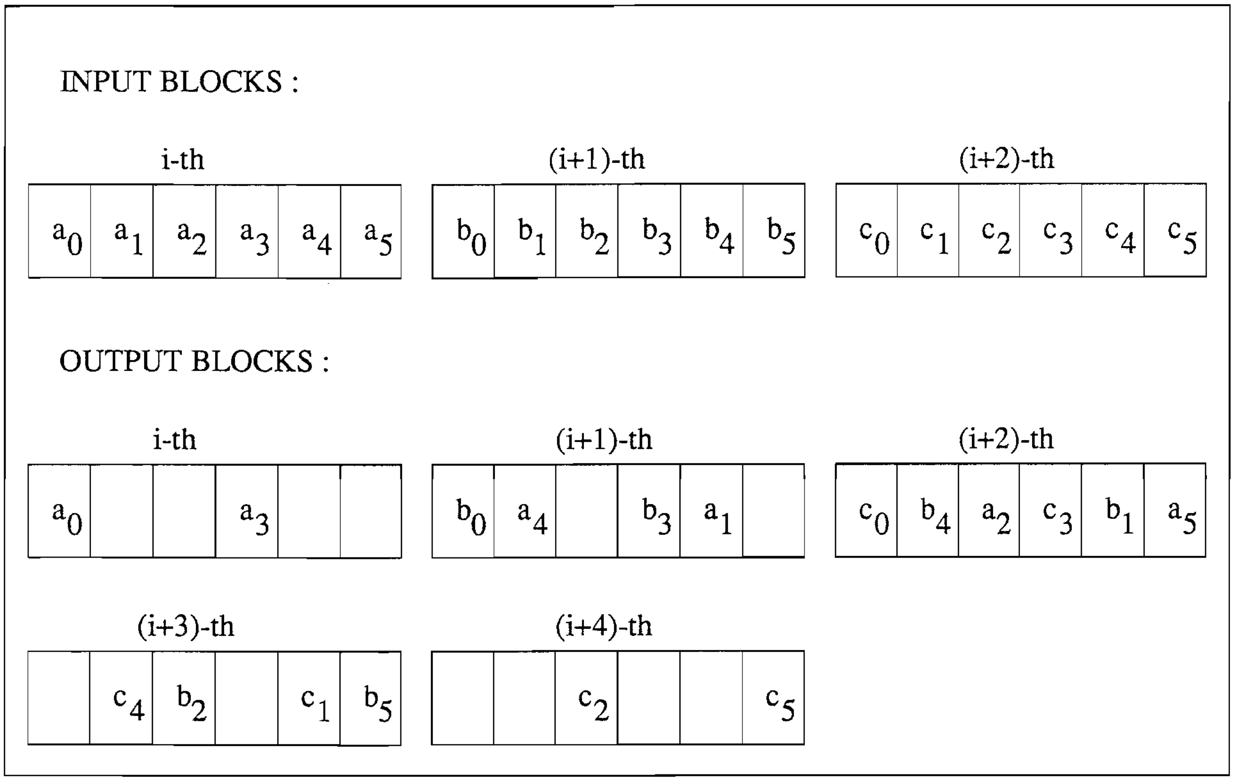

Figure 1: Example of inter-block interleaving with B = 3 and N =2

from the encoder and y is the output symbol from the interleaver, the mapping of the m-th symbol of the i-th coded input block to the $(j + Bt)$-th interleaved symbol of the $(i + j)$-th output block is given by

$$y(i+j, j+Bt) = x(i, m) \text{ for all } i$$

with $j = m \bmod B$ and $t = m \bmod N$. Figure (1) illustrates an example of inter-block interleaving using this mapping [4]. In our case, a byte of data symbols (N = 8) from an ATM cell can be interleaved into 53 (B = 53) subsequent ATM cells. That is, if a frame or block carries 10 ATM cells, data symbols from one ATM cell are dispersed into 5 subsequent frames or blocks. Figure (2) shows the packet error rate in Rayleigh fading. When ideal interleaving is used along with coding, we find that there is a large improvement in performance compared to the case when neither coding nor interleaving is used. It is this improvement in performance when interleaving is used that will help close the link even under fading conditions.

The data from several frames have to be stored before they can be interleaved into subsequent frames. The buffer requirement therefore depends on the value of B and N. For K ATM cells per frame, the buffer requirement would be $(B+K)*BN$ symbols. If B = 53, N = 8 and K = 10, the buffer requirement would be 26712 symbols. For RDRN, the maximum number of ATM cells per frame is 10. So, the value of buffer requirement is thus a worst case requirement.

4.1 Delay

The delay due to interleaving and de-interleaving for this inter-block interleaver would be B^2N symbols per ATM cell. For a data rate of 1 Mbps, this delay would be B^2N μsec. For 10 ATM cells per frame and for B = 53 and N = 8, the interleaving

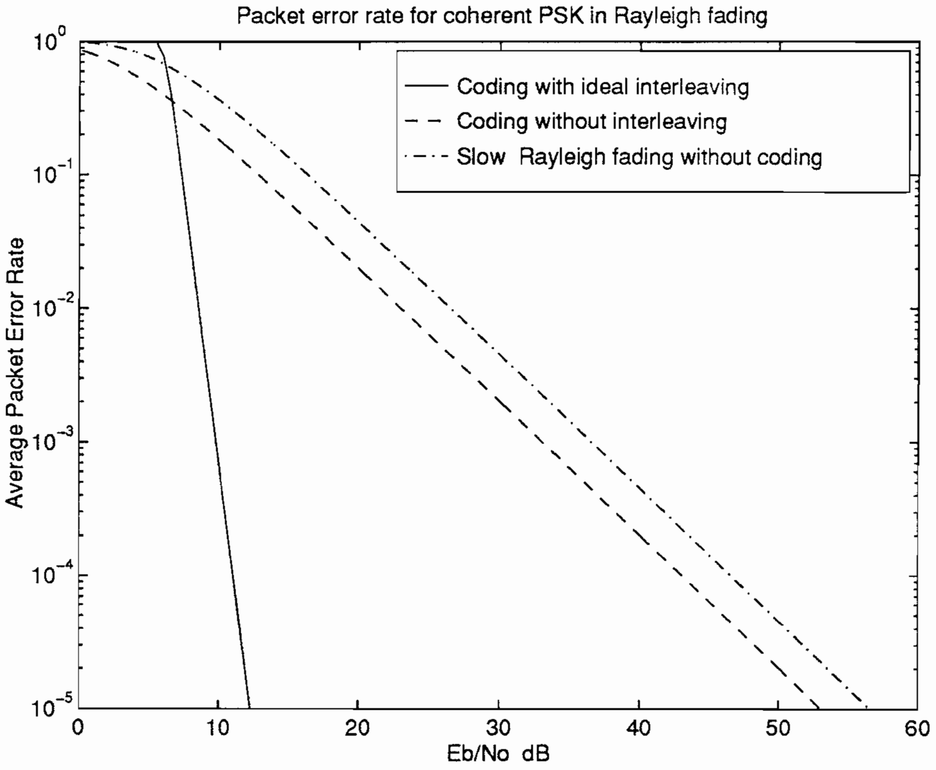

Figure 2: Packet error probability under Rayleigh fading

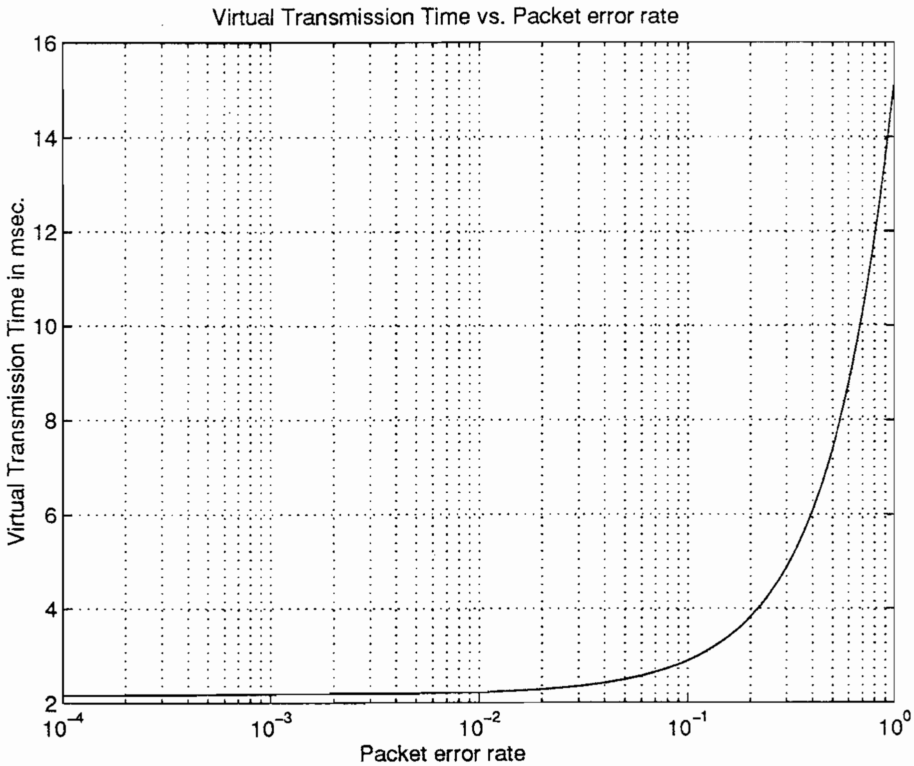

Figure 3: Virtual transmission time for HDLC frame transmission

delay per ATM cell would be 22.47 msec. This translates to a interleaving delay of 0.2247 sec per frame of data. This delay represents the maximum delay due to interleaving, since transmission of 10 ATM cells per HDLC frame is considered.

4.1.1 Retransmission Delay

In addition to the interleaving delay, the delay due to retransmission of errored HDLC frames must be taken into consideration. An analysis of the retransmission delay was done using the work done in [6]. Figure (3) shows the virtual transmission time as a function of the packet error rate. Virtual transmission time is defined as the time taken for a frame to be received correctly at the receiver and it includes delay due the retransmission. For a packet error rate of 10^{-3} and for RDRN parameters, the virtual transmission time was found to be 2.2 msec. This is negligible compared to the interleaving delay. However, if interleaving is used, the effective throughput will be more compared to the case when interleaving is not used, due to the fact the number of retransmissions will reduce under fading conditions.

5 Future Work

The performance improvement this inter-block interleaving offers for the RDRN system will have to be verified using simulation techniques. Also depending on the delay that can be tolerated by the higher level protocols in RDRN, the depth of interleaving need to be set. Other issues that need further research are the following

- If voice is classified as a priority traffic, the interleaving process may have to be interrupted when a voice packet occurs while data packets are being interleaved.
- Depending on the channel conditions, the number of ATM cells transmitted in a HDLC frame will vary. The interleaving scheme should be made adaptive to such changes in the number of cells per frame.

Though diversity, as a scheme, has not been considered for RDRN, it will be interesting to find if the RDRN phased array antenna offers any diversity gain.

6 Conclusions

The modified link budget for the fading channel models, with the path loss calculated using the Okumura propagation model, does not close for the RDRN test link parameters. This and the other reasons given in section 2 justify the need for some fading mitigation technique for the implementation of RDRN as a system. Coding and interleaving were chosen as the scheme to combat fading for RDRN, as opposed to diversity and smart antennas, mainly due to the ease of implementation. Diversity combining and smart antennas will require significant changes to the existing RDRN hardware.

A half-rate convolutional encoder with Viterbi decoder can be used as a coding/decoding scheme for RDRN. Since fading can be categorized as slow for RDRN [1], inter-block interleaving should be done to obtain maximum gain out of the interleaver. An inter-block interleaving scheme for RDRN suggested in this report, disperses N symbols from one ATM cell into B subsequent ATM cells. The maximum interleaving delay has been calculated to be 0.2247 seconds and the buffer requirement was approximately 27000 symbols, when 10 ATM cells per HDLC frame is sent. However, this delay and buffer requirement, will be less depending on the number of ATM cells transmitted per HDLC frame and the depth of interleaving necessary.

7 References

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[6] W. Bux, K. Kummerle and H. L. Truong, "Balanced HDLC Procedures: A Performance Analysis," *IEEE Trans. Comm.,* vol. 28, no. 11, pp. 1889-1898, November 1980.

A Appendix - Okumura Propagation model

Okumura's model [3] is one of the simplest and accurate model for path loss prediction for cellular and land mobile radio systems. This model is valid for frequencies in the range 150 MHz to 1920 MHz and distances of 1 km to 100 km. This model is based on a set of curves developed for the median attenuation relative to free space (A_{mu}) with a effective base station antenna height of 200m and a mobile antenna height of 3 m. So determine the path loss using the Okumura's model, the free space loss (L_F) must be determined, and then the value of $A_{mu}(f,d)$ (from the curves) is added as a correction factor. The loss can then be expressed as

$$L(dB) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \qquad \text{(A.1)}$$

where $G(h_{te})$ and $G(h_{re})$ are the base station antenna and mobile antenna gain factors. G_{AREA} is the gain due to the type of environment. The base station antenna and the mobile antenna gain factors are given by

$$\begin{aligned} G(h_{te}) &= 20log(\frac{h_{te}}{200}), \;\; 1000m > h_{te} > 10m && \text{(A.2)} \\ G(h_{re}) &= 10log(\frac{h_{re}}{3}), \;\; h_{re} \leq 3m && \text{(A.3)} \\ G(h_{re}) &= 20log(\frac{h_{re}}{3}), \;\; 10m > h_{re} > 3m && \text{(A.4)} \end{aligned}$$

For this model, the common standard deviations between the predicted and measured path loss values are around 10 dB to 14 dB.

For the RDRN test link, the effective transmit and receive antenna heights were 54 m and 2 m respectively. Quasi open area was assumed to calculate the correction factor, G_{AREA}. The transmit and receive antenna gain factors were determined to be -11.37 dB and -1.76 dB respectively. For an operating frequency of 1.27 GHz and a communication range of 10 km, the value of $A_{mu}(f,d)$ was 29 dB. The correction factor G_{AREA} for a quasi open area was found to be 23 dB. Therefore, for a free space loss of 114.52 dB, Okumura model predicts a total path loss (L) of

$$\begin{aligned} L(dB) &= 114.52 + 29 + 11.37 + 1.76 - 23 \\ &= 133.65 \ \ \text{dB} \end{aligned} \tag{A.5}$$