ATIS-0700018

ATIS Standard on -

CAPACITY AND PERFORMANCE OF TDMA-SC RTT

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ATIS-0700018, *Capacity and Performance of TDMA-SC RTT*

Is an American National Standard developed by the **Radio Access Network (RAN)** Subcommittee under the **ATIS Wireless Technologies and Systems Committee (WTSC)**.

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ATIS Standard on

Capacity and Performance of TDMA-SC RTT

Alliance for Telecommunications Industry Solutions

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Abstract

This document provides a standard for evaluating the capacity and performance of Time Division Multiple Access-Single Carrier (TDMA-SC) Radio Transmission Technology (RTT) by performing system level simulations for High Speed (HS) outdoor and Wideband General Packet Radio Service (WGPRS) HS indoor.

Foreword

The Alliance for Telecommunication Industry Solutions (ATIS) serves the public through improved understanding between providers, customers, and manufacturers. The Wireless Technologies and Systems Committee (WTSC) develops and recommends standards and technical reports related to wireless and/or mobile services and systems, including service descriptions and wireless technologies. WTSC develops and recommends positions on related subjects under consideration in other North American, regional and international standards bodies.

The mandatory requirements are designated by the word *shall* and recommendations by the word *should*. Where both a mandatory requirement and a recommendation are specified for the same criterion, the recommendation represents a goal currently identifiable as having distinct compatibility or performance advantages. The word *may* denotes a optional capability that could augment the standard. The standard is fully functional without the incorporation of this optional capability.

Suggestions for improvement of this document are welcome. They should be sent to the Alliance for Telecommunications Industry Solutions, WTSC, 1200 G Street NW, Suite 500, Washington, DC 20005.

At the time of consensus on this document, WTSC, which was responsible for its development, had the following leadership:

M. Younge, WTSC Chair (T-Mobile)

D. Zelmer, WTSC Vice-Chair (AT&T)

J. Ragsdale, WTSC RAN Chair (Ericsson)

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The **Radio Access Network [RAN]** Subcommittee was responsible for the development of this document.

Table of Contents

Table of Figures

Table of Tables

ATIS Standard on –

Capacity & Performance of TDMA-SC RTT

1 System Level Simulations for HS Outdoor

1.1 Static Capacity Simulation

In order to evaluate the system performance of the TDMA-SC Radio Transmission Technology (RTT) HS Outdoor concept, static packet data simulations have been performed. The following assumptions have been made:

- 1/3 reuse.
- No frequency hopping.
- Log-normal fading with standard deviation of 10 dB.
- Path loss according to M.1225 Models.
- Pedestrian A, Vehicular A50, and Vehicular A120 environments.
- Exponentially distributed packet size with a mean of 1600 bytes.
- Branch Maximum Ratio Combining (MRC) diversity is used.
- No power control is assumed.
- Ideal Link adaptation is performed every 100 ms, i.e., 5 coding blocks.
- The time step of the simulator is 20 ms, corresponding to one coding block. This means that the interference situation can change 5 times during one link adaptation interval.
- The throughput is measured after channel decoding.
- The offered load was fixed for all cases.

The throughput per carrier distribution for ideal link adaptation is analyzed with fractional loading from which the aggregate average throughput for users in the system is determined. The spectrum efficiency is then evaluated. The spectrum efficiency is calculated in the system simulations as:

$$\upsilon = \frac{\sum_{i=1}^{N} S_i}{MW} \qquad [Mbit/s/MHz/cell]$$

Where S_i is the throughput of user i, N is the number of served users, M is the number of cells, and W is the total available spectrum.

Figure 1.1 shows the throughput distribution for ideal link adaptation, with 8 Level Phase Shift Keying (PSK) coding schemes 8 PSK Coding Scheme (PCS)-1 to PCS-6 for link adaptation. This static simulation uses 40% load and mobile station antenna diversity. Table 1.1 summarizes aggregate average throughput/user and spectrum efficiency for this Pedestrian A simulation.

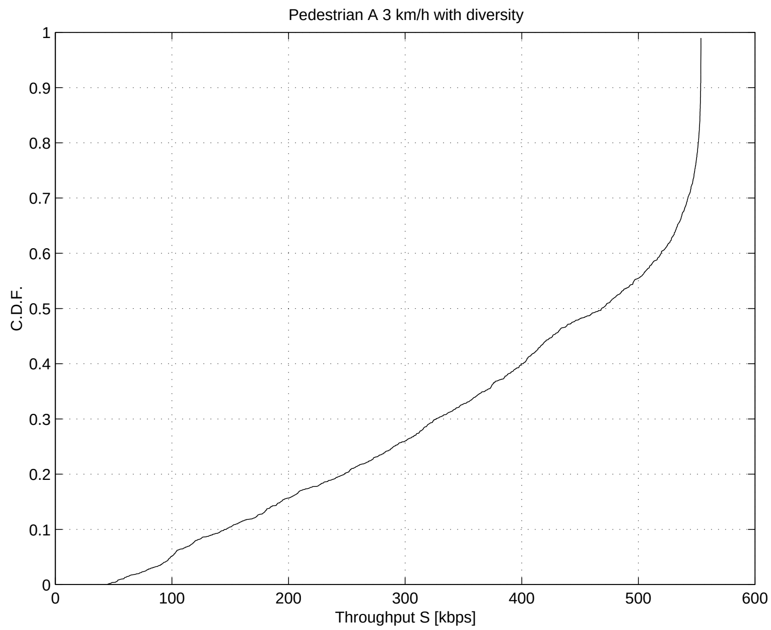

Figure 1.1 – Throughput distribution obtained from static simulation with PCS-6 through PCS-1 for Pedestrian A Environment.

Table 1.1 – Summary of static system simulation results for Pedestrian A.

Aggregate Average throughput/ Timeslot	50.75 kbit/s
Aggregate Average throughput/ Carrier	406 kbit/s
Spectrum Efficiency	0.813 Mbit/s/MHz/site

Figure 1.2 shows the throughput distribution for the Vehicular A50 environment. This static simulation uses 30% load and mobile station antenna diversity. Table 1.2 summarizes aggregate average throughput/user and spectrum efficiency for this Vehicular A50 simulation.

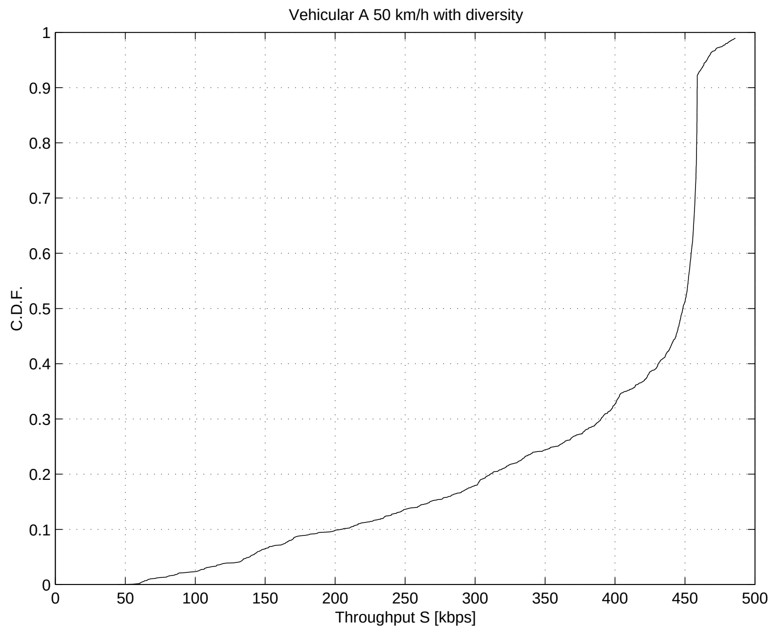

Figure 1.2 – Throughput distribution obtained from static simulation with PCS-6 through PCS-1 for Vehicular A50 Environment.

Table 1.2 – Summary of static system simulation results for Vehicular A50 Environment

Aggregate Average throughput/ Timeslot	48.75 kbit/s
Aggregate Average throughput/ Carrier	390 kbit/s
Spectrum Efficiency	0.585 Mbit/s/MHz/site

These results indicate that in the low speed vehicular environment an aggregate average throughput greater than 384 kbit/s is obtained even with the simple equalizer. These results would improve with the more complex equalizer.

1.1.1 Load Effects

There will be a trade-off between the spectrum efficiency and the quality in the network. System simulations show that by increasing the load (even up to 100%), the spectrum efficiency will increase. However, the throughput for individual users will drop and may result in low throughput. Figure 1.3 shows the spectrum efficiency for the Pedestrian A environment as a function of Load.

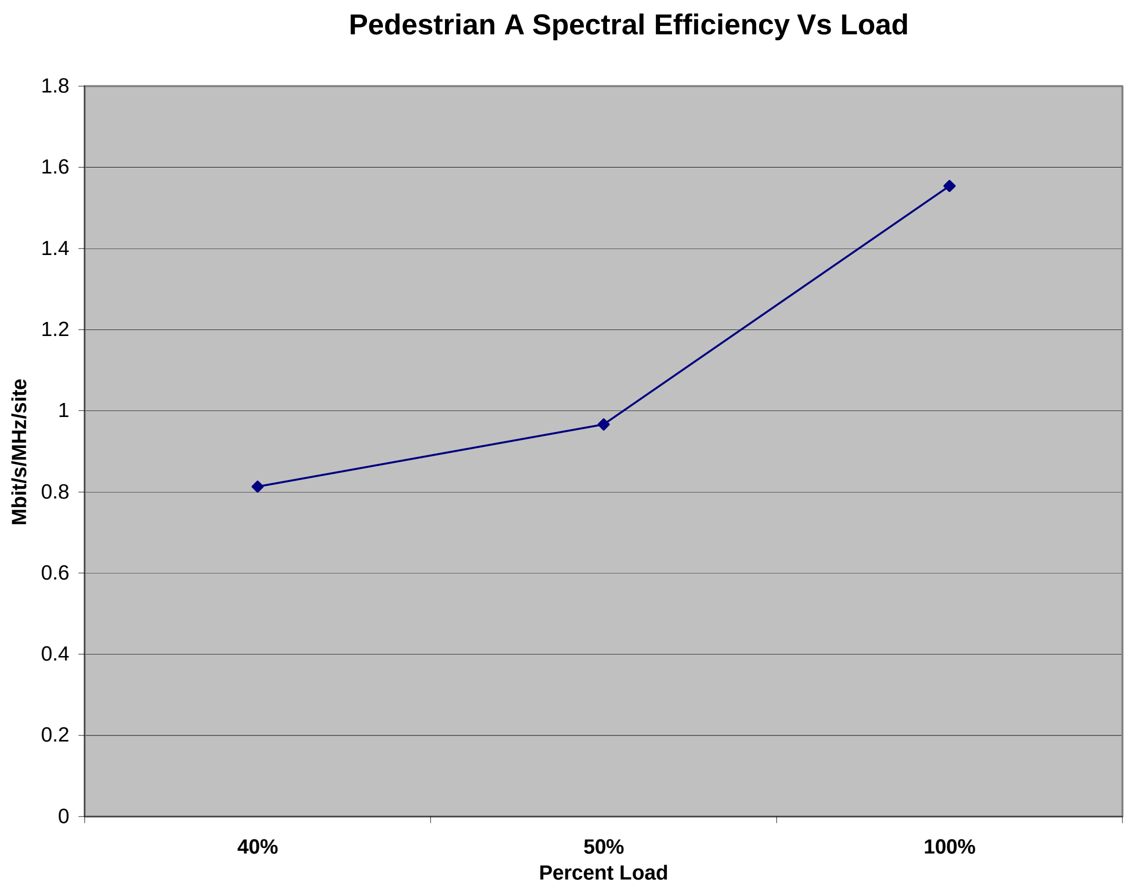

Figure 1.3 – Spectral Efficiency as a Function of Offered Load for Pedestrian A Environment

1.1.2 Coverage Simulations

Figure 1.4 shows how the throughput varies over the cell area for the Pedestrian environment. Note that smart antennas are not assumed. Smart antennas will of course further increase the coverage. The results are shown using an Eb/No distribution corresponding to 95% speech coverage. The distance attenuation is calculated according to the International Telecommunications Union (ITU) Channel Models. The results include mobile antenna diversity (2 branch, maximum ratio combining).

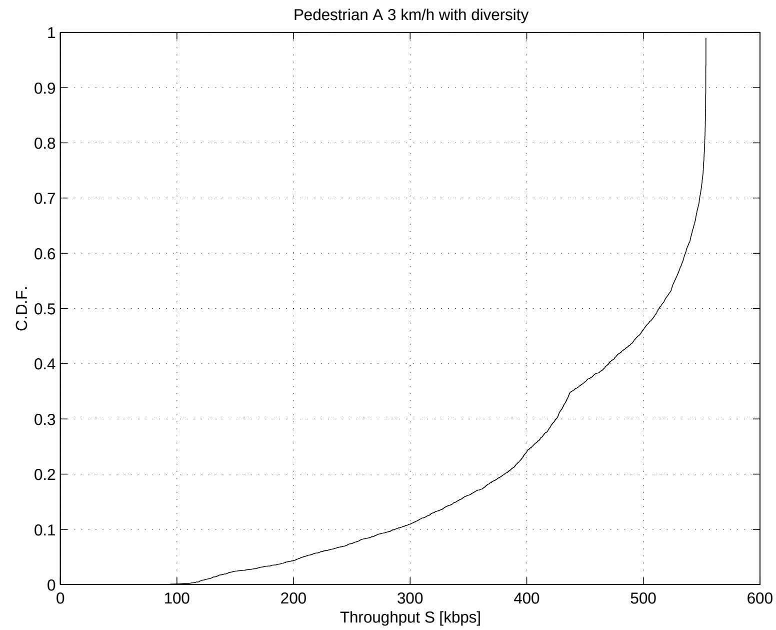

Figure 1.4 – Coverage with mobile receiver diversity for Pedestrian A Environment

Figure 1.5 shows the results for the low speed Vehicular A50 Environment using the same criteria as used in Figure 1.4. Figures 1.6 shows the results for the higher speed Vehicular A120 Environment using the same criteria as used in Figure 1.4. These results are for the simple equalizer.

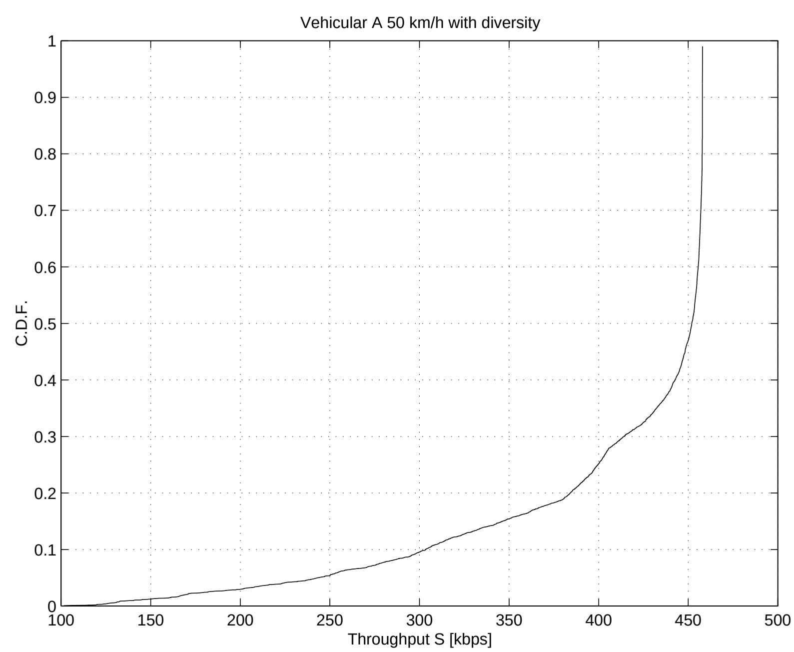

Figure 1.5 – Coverage with mobile receiver diversity for Vehicular A50 Environment

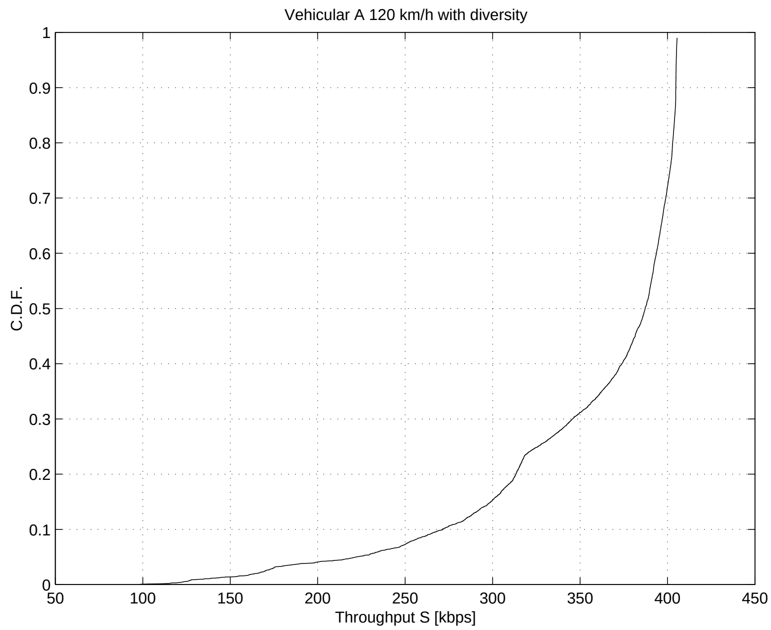

Figure 1.6 – Coverage with mobile receiver diversity for Vehicular A120 Environment

1.2 Dynamic System Simulations

In order to further evaluate the system performance of the HS Outdoor bearer using ITU Models, additional dynamic packet data simulations have been performed. The following assumptions have been made:

- Interference Limited.
- 1/3 reuse.
- No frequency hopping.
- Log-normal fading with standard deviation of 10 dB.
- Path loss according to M.1225 ITU Models.
- Pedestrian Channel A and B, Vehicular Channel A and B 50 km/hr, Vehicular Channel A and B 120 km/hr environments.
- Power control is not used.
- Branch MRC diversity is used.
- Ideal Link adaptation.
- The time step of the simulator is 20 ms, corresponding to one coding block. Each radio block is explicitly simulated.
- 27 cell sites are used.

These additional simulations provided more detailed analysis of the system.

1.2.1 Traffic Model

A session-based traffic model is used. In-session users may be both active and idle. The number of packets sent in a session is geometrically distributed with a mean of 10. A packet is defined as for example a web page rather than an IP packet. Sessions arrive according to a Poisson process. Packets are sent to users at the rate of 0.3 packets/sec.

The bursty behavior of a packet data system is modeled using a truncated Pareto distribution for the packet interarrival times.

The packet (file) sizes are lognormally distributed with a mean of 12 kbytes.

1.2.2 Simulation

Each radio block was explicitly simulated included queuing, retransmission, etc. The time step of the simulator was 20 msec. The total simulation time is 300 sec. Ideal link adaptation is used. Packets are scheduled using an ideal G-based scheduling algorithm.

1.2.2.1 Dropping Criteria

A leaky bucket algorithm is used for user dropping. Each user is assigned a counter initialized at 32. The counter is decreased by one for a Negative Acknowledgement (NACK) and increased by 2 (up to a maximum of 32) for an Acknowledgement (ACK). The user is dropped if the counter reaches zero.

1.2.2.2 Performance Criteria

Since users in a packet data system will have different user throughputs, a quality measure is defined. The quality measure for the 384 kbit/s service is that 95% of the users should have a session throughput exceeding 10% of 384 kbit/s (or 38.4 kbit/s). The same quality measure is used for the 64 kbit/s service which means that the system can be 100% loaded. Therefore the spectral efficiency is obtained at 100% load for the 64 kbit/s service.

The session throughput is defined as the total number of bits a user transmitted in a session divided by the total time for the transmissions. Dropped users are given a session throughput of zero even if they transmitted some data before being dropped.

Simulations were performed with increasing load until the quality measure was reached. At this load, the spectral efficiency is calculated.

1.2.3 384 kbit/s Service Results

For the 384 kbit/s packet data service, Figure 1.7 shows the spectrum efficiency results (per sector) versus the lowest 5% percentile session throughput with the quality measure indicated by the horizontal dashed line. Results for Pedestrian A, Vehicular A50 and Vehicular A120 are shown. Note that the spectral efficiency per site would be obtained by multiplying by 3.

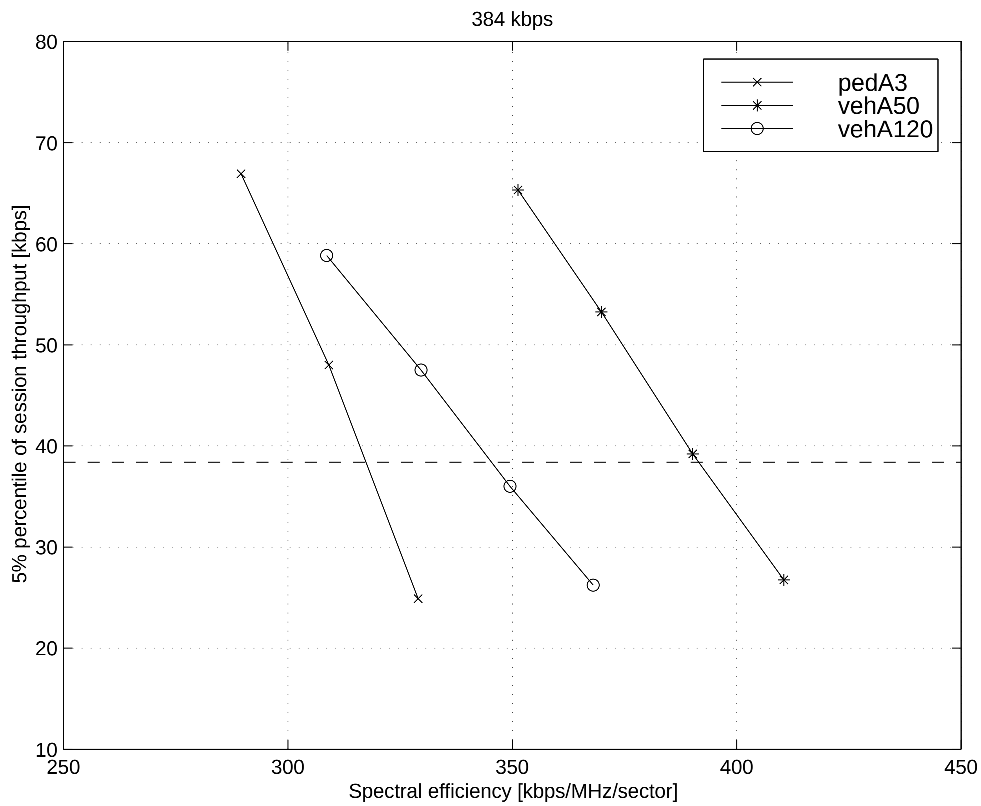

Figure 1.7 – Spectral Efficiency Performance for 384 kbit/s Packet Data Service Environment A.

Figure 1.8 shows the loading results (in number of users per sector) for the 384 kbit/s packet data service, versus the lowest 5% percentile session throughput with the quality measure indicated by the horizontal dashed line. Results for Pedestrian A, Vehicular A50 and Vehicular A120 are shown.

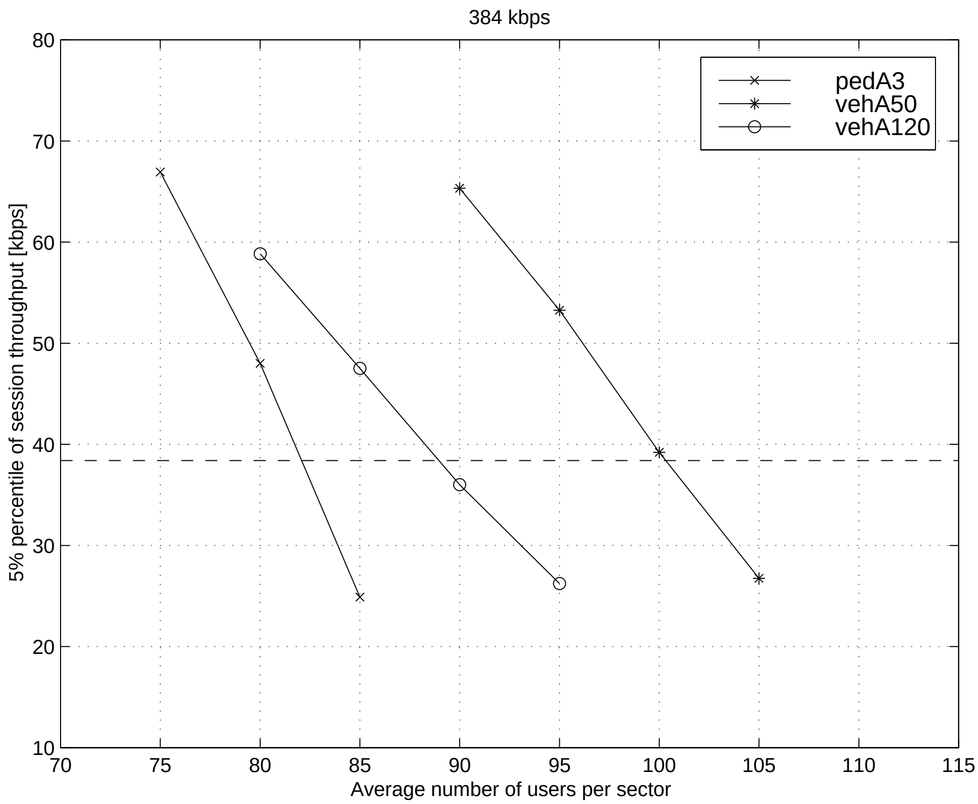

Figure 1.8 – Loading Performance for 384 kbit/s Packet Data Service Environment A.

Figure 1.9 shows the spectrum efficiency results for the 384 kbit/s packet data service (per sector) for the Pedestrian B, Vehicular B50 and Vehicular B120 environments using the same criteria as in Figure 1.7. The results are shown versus the lowest 5% percentile session throughput with the quality measure indicated by the horizontal dashed line. Again it should be noted that the spectral efficiency per site would be obtained by multiplying by 3.

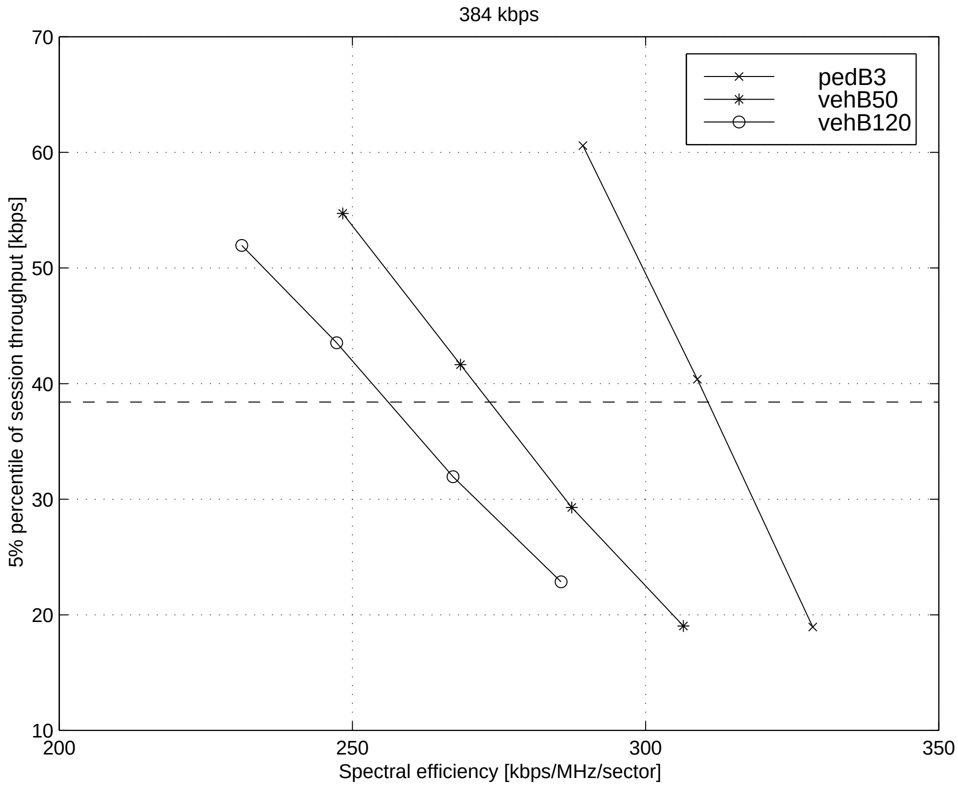

Figure 1.9 – Spectral Efficiency Performance for 384 kbit/s Packet Data Service Environment B.

Figure 1.10 shows the loading results (in number of users per sector) for the 384 kbit/s packet data service for the Pedestrain B, Vehicular B50 and Vehicular B120 environments using the same criteria as in Figure1.9. The results are shown versus the lowest 5% percentile session throughput with the quality measure indicated by the horizontal dashed line.

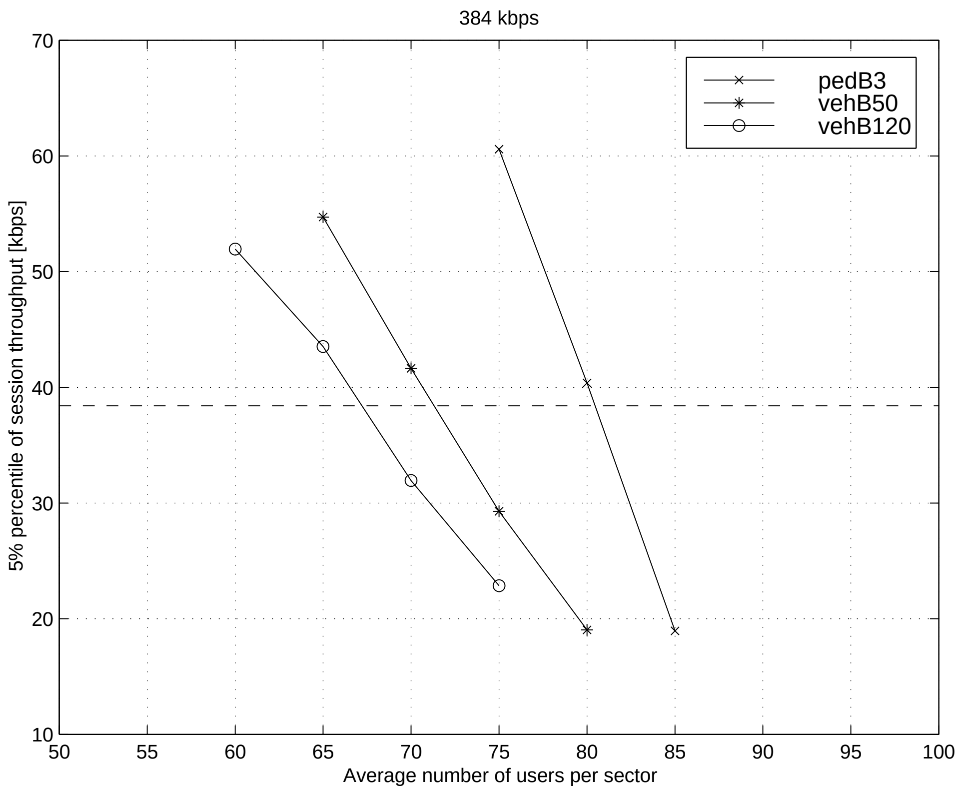

Figure 1.10 – Loading Performance for 384 kbit/s Packet Data Service Environment B.

Additional spectral efficiency results are given in the Deployment Matrix.

2 WGPRS HS Indoor Simulations

2.1 Link Level Results

This section presents link level simulation results of WGPRS HS Indoor. The results are obtained with Communication System Simulation and Application Processor (COSSAP). Both non-real time service results with Automatic Repeat Request (ARQ) and real time service results with Forward Error Correction (FEC) are presented. For Real time (RT) services the interference averaging concept relies heavily on the link adaptation. Therefore a few link adaptation options are presented for RT services. For providing input to system simulations the link level simulations are run against one co-channel interferer and for range calculations against Gaussian noise.

The results in this section are shown against average(C)/average(I). The interface between link and system level simulations does not directly utilize these curves but the burst-by-burst collected information. For more information about the interface see the following chapter.

The basic assumptions and technical choices of the link level simulations are shown in the Table 2.1 below.

WGPRS HS Indoor is proposed for the Indoor Office environment, data services only. However, in order to fully evaluate WGPRS HS Indoor, simulations have been performed also for some other combinations of environment and services.

Table 2.1 – Link level assumptions and technical choices

Channel estimator	Correlator, delay search window of 3 symbols, Independent estimation from burst-to-burst
Equalizer	Decision Feedback Equalizer (DFE) or Soft Output Viterbi Algorithm (SOVA)
Number of equalizer taps	ITU Indoor A: 3 taps ITU Outdoor to indoor A: 3 taps
Modulation	Binary-O-Quadrature Amplitude Modulation (B-O-QAM) Quaternary-O-QAM (Q-O-QAM)
Channel coding	Convolutional codes, K=9, puncturing / repetition for rate matching Concatenated code for Low Constrained Delay (LCD) 144 and LCD 384: Reed-Solomon (500,400) or Reed-Solomon (210,168) + Convolutional code ($K=9$)
Power control	Slow power control, not modelled in link level
Interference modeling	One co-channel interferer (for capacity) Gaussian noise (for range)
Antenna diversity	Not used in Cochannel Interference (C/I) simulations (C/I simulations are for downlink capacity) Used in E_b/N_0 simulations for uplink range
Frequency hopping	Frame-by-frame hopping or slot-by-slot hopping Uncorrelated frequencies
Time hopping	Included in link level frequency hopping for interference diversity, not separately modelled in link level

The simulation results for each service and environment are shown in the following sections.

2.1.1 Validation of Simulation Chains

The link level COSSAP simulation chains of WGPRS HS Indoor has been validated by comparing the simulation results in non-fading Additive White Gaussian Noise (AWGN) channel (Figure 2.1) and in 1-path Rayleigh fading channel (Figure 2.2) to the theoretical Bit Error Rate (BER)-curves.

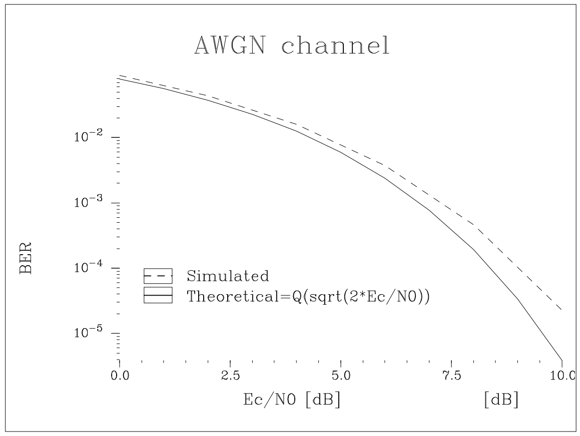

Figure 2.1 – Simulated results compared to theoretical value in AWGN channel (overhead due to training sequence and tail bits is not taken into account in E_c/N_0)

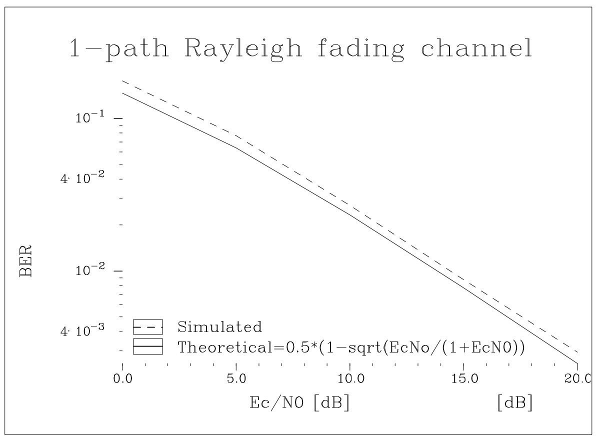

Figure 2.2 – Simulated results compared to theoretical value in 1-path Rayleigh fading channel

The simulated results are a little worse than theoretical values as expected. This is due to the non-ideal channel estimation.

2.1.2 LCD 384 in ITU Indoor A

Four different link adaptation options have been simulated for LCD 384 service in Indoor A environment. Two of them use Binary Quaternary Offset Quadrature Ampitude Modulation (B-O-QAM) modulation and 6 and 8 slots per frame, respectively, whereas two other options use Quaternary Offset Quadrature Ampitude Modulation (Q-O-QAM) modulation and 3 and 4 slots per frame, respectively. The rate 4/5 Reed-Solomon code (500, 400) has been used as outer code and punctured convolutional code as inner code. The bit interleaving is done after the inner code over 30 Time Division Multiple Access (TDMA) frames (138 ms).

The C/I curves for LCD 384 in Indoor A are presented in Figure 2.3. With case 4 (B-O-QAM, 8 slots per frame), C/I requirement for BER 10^{-6} is 2 dB. In the other end, C/I of 15.5 dB is required when 3 slots and Q-O-QAM modulation are used.

	Link adaptation options			
	Case 1	**Case 2**	**Case 3**	**Case 4**
User bit rate	390 kbit/s			
Number of slots used / frame	3 slots / frame	4 slots / frame	6 slots / frame	8 slots / frame
Slot size	1/16			
Modulation	Q-O-QAM		B-O-QAM	
Coding block	1800 for Radio Service (RS) encoder/2250 for convolutional encoder			
Coding rate	0.44	0.33	0.44	0.33
Outer code	Rate 4/5 Reed-Solomon code	Rate 4/5 Reed-Solomon code	Rate 4/5 Reed-Solomon code	Rate 4/5 Reed-Solomon code
Inner code	1/2-rate Convolutional Code (CC) with puncturing	1/3-rate CC with puncturing	1/2-rate CC with repetition	1/3-rate CC with repetition
Interleaving depth	30 frames (138 ms)			
Type of interleaving	block interleaving			
Frequency hopping	slot-by-slot			
Mobile speed	3 km/h			
Channel model	ITU Indoor A			
E_b/N_0 UL/DL *($BER=10^{-6}$)*	- / -	- / -	- / -	- / -
C/I UL/DL *($BER=10^{-6}$)*	- / 15.5	- / 11.5	- / 6.0	- / 2.0

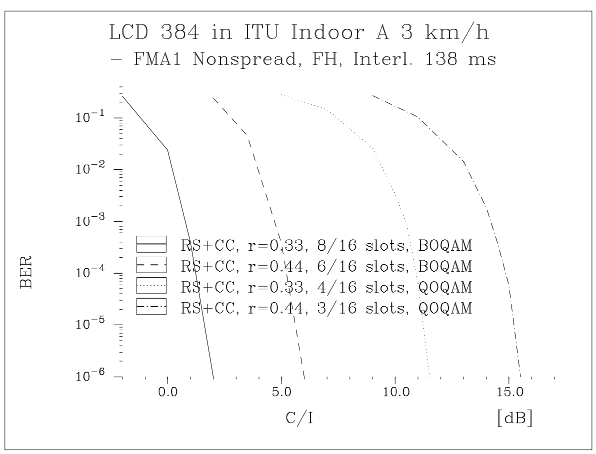

Figure 2.3 – LCD 384 in ITU Indoor A, C/I

2.1.3 LCD 144 in ITU Outdoor to Indoor A

Four different link adaptation cases have been simulated for LCD 144 service. Two of them use B-O-QAM modulation and 3 and 4 slots per frame, respectively, whereas two other ones use Q-O-QAM modulation and 1 and 2 slots per frame, respectively. The rate 4/5 Reed-Solomon code (210, 168) has been used as outer code and punctured convolutional code as inner code. Between the outer and the inner code, symbol interleaving has been used. The bit interleaving is done after the inner code over 30 TDMA frames (138 ms).

The C/I curves for LCD 144 are presented in Figure 2.4 and the E_b/N_0 curves in Figure 2.5. Those figures suggest that the tight BER requirement for LCD services (10^{-6}) can be achieved with the proper code design. C/I ratios near 0 dB are achievable with the total code rate of 0.24. The LCD 144 service can be provided even with one 1/16th slot (Q-O-QAM modulation, code rate 0.49). E_b/N_0 values have been derived for cases 2 and 4 that use 2 slots (B-O-QAM) and 4 slots (Q-O-QAM) per frame, respectively.

	Link adaptation options			
	Case 1	**Case 2**	**Case 3**	**Case 4**
User bit rate	145.6 kbit/s			
Number of slots used / frame	1 slot / frame	2 slots / frame	3 slots / frame	4 slots / frame
Slot size	1/16			
Modulation	Q-O-QAM		B-O-QAM	
Coding block	672 for RS encoder/840 for convolutional encoder			
Coding rate	0.49	0.24	0.33	0.24
Outer code	Rate 4/5 Reed-Solomon code	Rate 4/5 Reed-Solomon code	Rate 4/5 Reed-Solomon code	Rate 4/5 Reed-Solomon code
Inner code	1/2-rate CC with puncturing	1/4-rate CC with puncturing	1/3-rate CC with repetition	1/4-rate CC with repetition
Interleaving depth	30 frames (138 ms)			
Type of interleaving	Block interleaving			
Frequency hopping	slot-by-slot			
Mobile speed	3 km/h			
Channel model	ITU Outdoor to Indoor A			
E_b/N_0 UL/DL *($BER=10^{-6}$)*	- / -	- / 11.4	- / -	- / 6.4
C/I UL/DL *($BER=10^{-6}$)*	- / 22.0	- / 10.0	- / 4.0	- / 1.0

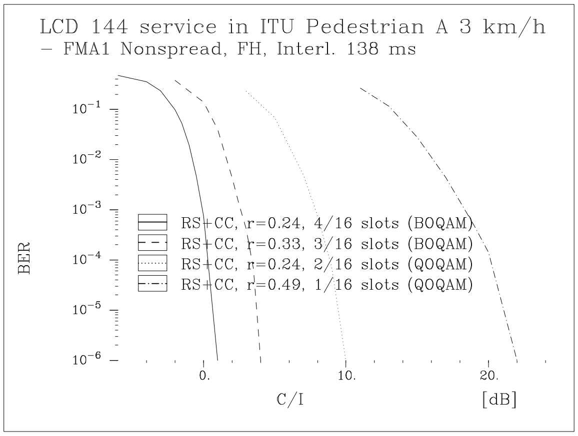

Figure 2.4 – LCD 144 BER vs. C/I in ITU Outdoor to Indoor A, DL

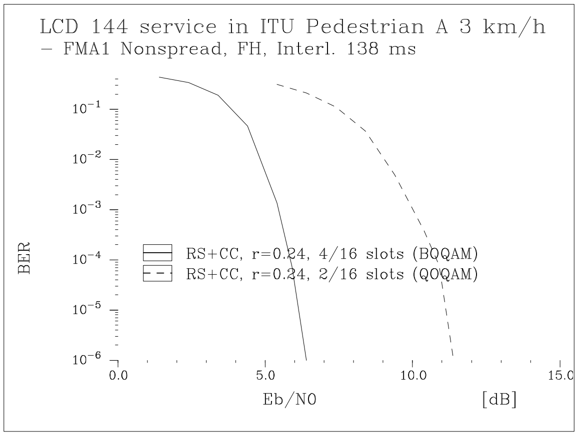

Figure 2.5 – LCD 144 BER vs. E_b/N_0 in ITU Outdoor to Indoor A, UL

2.1.4 Unconstrained Delay Data (UDD) 144 in ITU Indoor A

	Case 1	Case 2	Case 3
Number of slots used / frame	2 slots / frame	4 slots / frame	8 slots / frame
Slot size	1/16		
Modulation	B-O-QAM (Q-O-QAM results are found in figures.)		
Coding rate	Variable		
Basic code	1/2-rate convolutional code		
Interleaving depth	8 slots		
Type of interleaving	block interleaving		
Frequency hopping	slot-by-slot (need not be consecutive)		
Mobile speed	3 km/h		
Channel model	ITU Indoor A		
E_b/N_0 UL/DL	2.7 / -	2.3 / -	- / -
C/I UL/DL	- / 2.1	- / -3.8	- / -

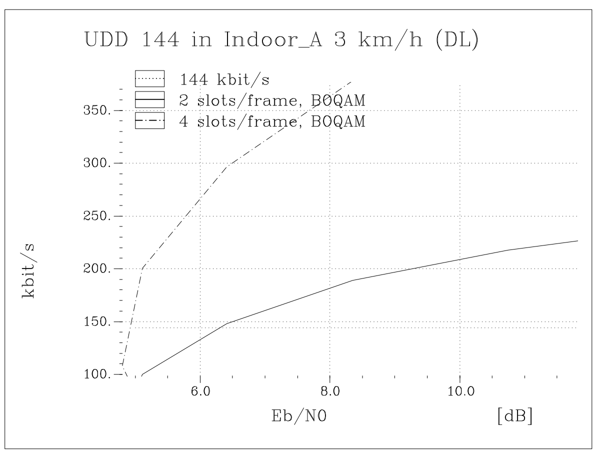

Figure 2.6 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Indoor A, UL

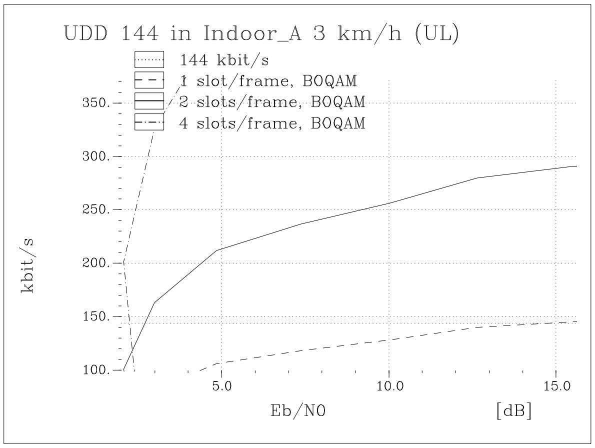

Figure 2.7 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Indoor A, DL

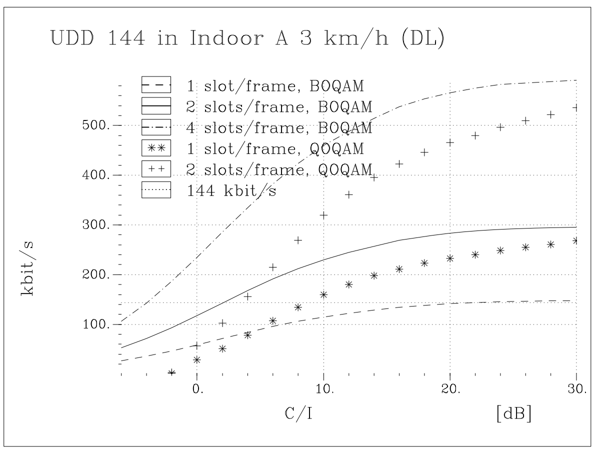

Figure 2.8 – UDD 144 throughput (kbit/s) vs. C/I in ITU Indoor A, UL

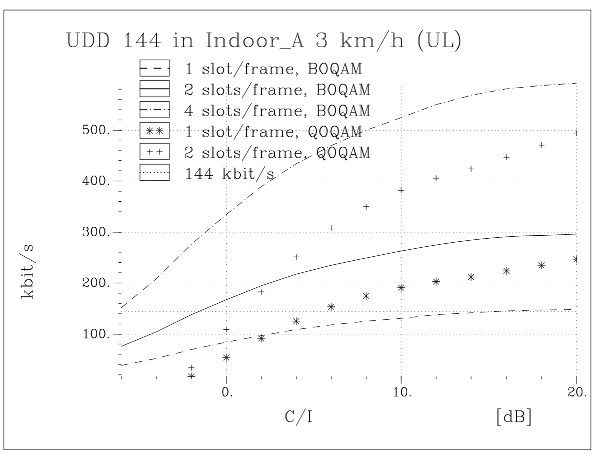

Figure 2.9 – UDD 144 throughput (kbit/s) vs. C/I in ITU Indoor A, DL

2.1.5 UDD 144 in ITU Outdoor to Indoor A

The simulation parameters of UDD 144 are shown in the table below. The packet services of WGPRS HS Indoor are based on Type II Hybrid ARQ. Two different modulations, B-O-QAM and Q-O-QAM, are used. The basic code has been CC(1,2,9), i.e., 1/2-rate convolutional code with constraint length of 9. Interleaving was over 8 frames and the slot size of 1/16 is used.

	Case 1	Case 2	Case 3
Number of slots used / frame	2 slots / frame	4 slots / frame	8 slots / frame
Slot size	1/16		
Modulation	B-O-QAM (Q-O-QAM results are found in figures.)		
Coding rate	Variable		
Basic code	1/2-rate convolutional code		
Interleaving depth	8 slots		
Type of interleaving	block interleaving		
Frequency hopping	slot-by-slot (need not be consecutive)		
Mobile speed	3 km/h		
Channel model	ITU Outdoor to Indoor A		
E_b/N_0 UL/DL	2.8 / -	2.1 / -	- / -
C/I UL/DL	-1.5 / 2.3	-6.2 / -3.7	- / -8.0

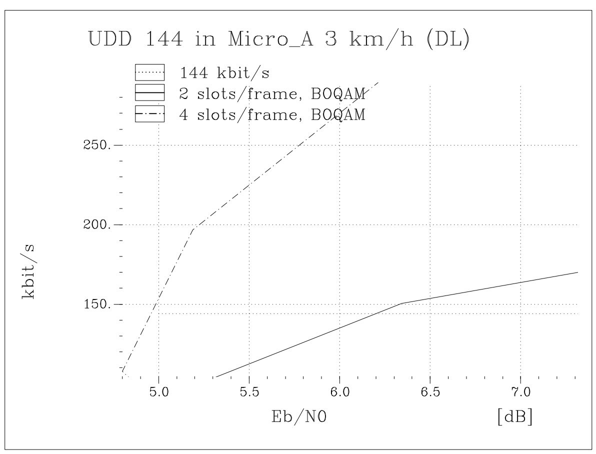

Figure 2.10 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Outdoor to Indoor A, DL

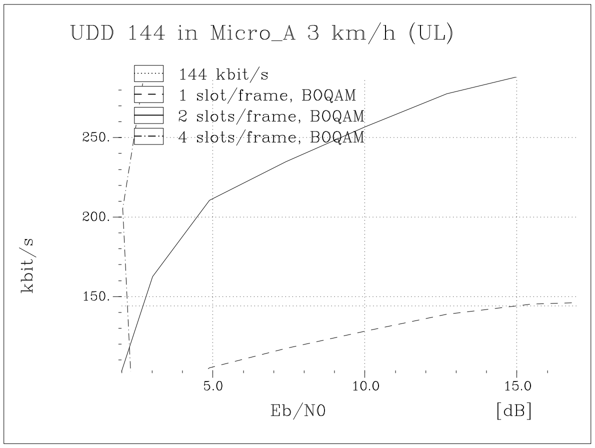

Figure 2.11 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Outdoor to Indoor A, UL

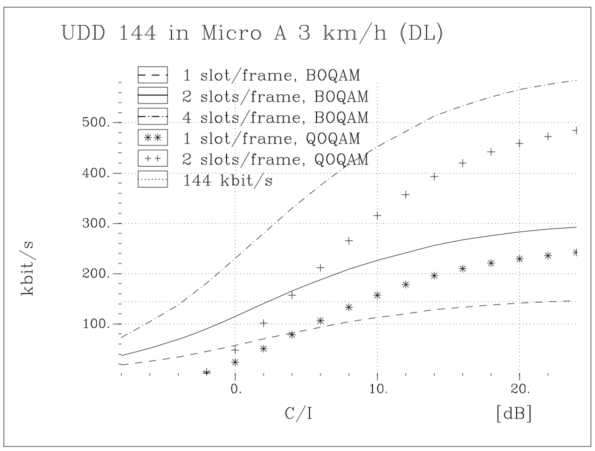

Figure 2.12 – UDD 144 throughput (kbit/s) vs. C/I in ITU Outdoor to Indoor A, DL

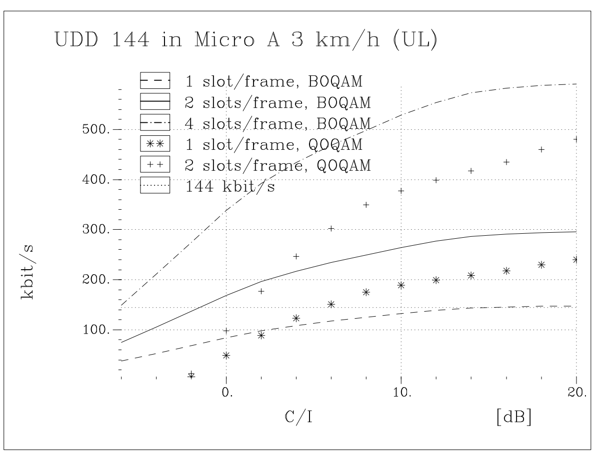

Figure 2.13 – UDD 144 throughput (kbit/s) vs. C/I in ITU Outdoor to Indoor A, UL

2.1.6 UDD 384 in ITU Indoor A

	Case 1	Case 2	Case 3	Case 4
Number of slots used / frame	4 slots / frame	8 slots / frame	12 slots / frame	16 slots / frame
Slot size	1/16			
Modulation	B-O-QAM (Q-O-QAM results are found in figures.)			
Coding rate	Variable			
Basic code	1/2-rate convolutional code			
Interleaving depth	4 or 8			
Type of interleaving	block interleaving			
Frequency hopping	slot-by-slot (need not be consecutive)			
Mobile speed	3 km/h			
Channel model	ITU Indoor A			
E_b/N_0 UL/DL	- / -	2.1 / 5.1	- / -	2.4 / 4.9
C/I UL/DL	- / -	-4.6 / -1.8	- / -	- / -

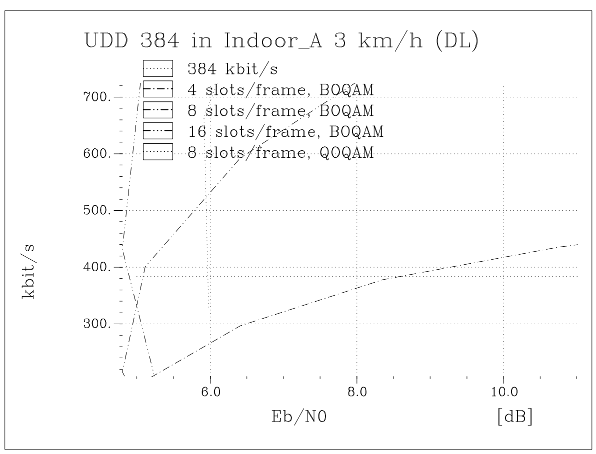

Figure 2.14 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Indoor A, DL

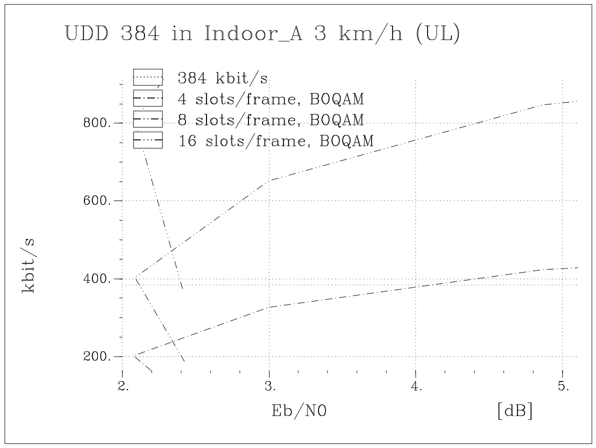

Figure 2.15 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Indoor A, UL

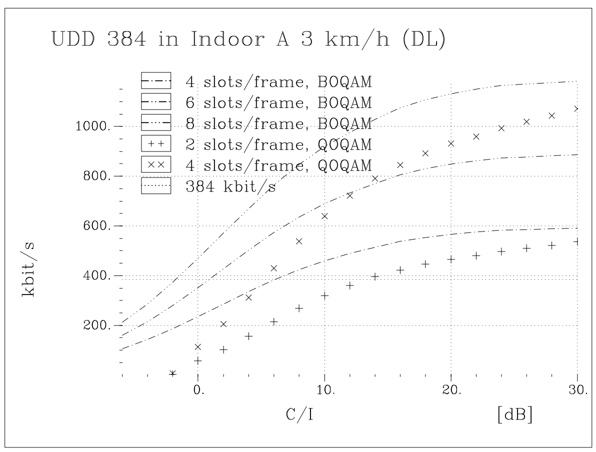

Figure 2.16 – UDD 144 throughput (kbit/s) vs. C/I in ITU Indoor A, DL

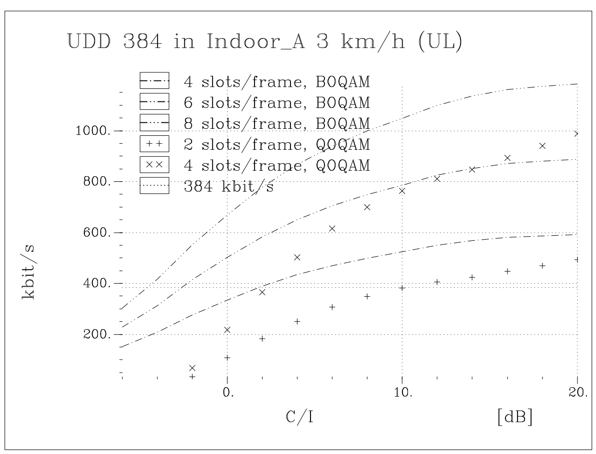

Figure 2.17 – UDD 144 throughput (kbit/s) vs. C/I in ITU Indoor A, UL

2.1.7 UDD 384 in ITU Outdoor to Indoor A

	Case 1	Case 2	Case 3	Case 4
Number of slots used / frame	4 slots / frame	8 slots / frame	12 slots / frame	16 slots / frame
Slot size	1/16			
Modulation	B-O-QAM (Q-O-QAM results are found in figures.)			
Coding rate	Variable			
Basic code	1/2-rate convolutional code			
Interleaving depth	4 or 8 slots			
Type of interleaving	block interleaving			
Frequency hopping	slot-by-slot (need not be consecutive)			
Mobile speed	3 km/h			
Channel model	ITU Outdoor to Indoor A			
E_b/N_0 UL/DL	- / -	2.0 / -	- / -	2.3 / -
C/I UL/DL	- / -	-4.6 / -1.5	- / -	- / -6.5

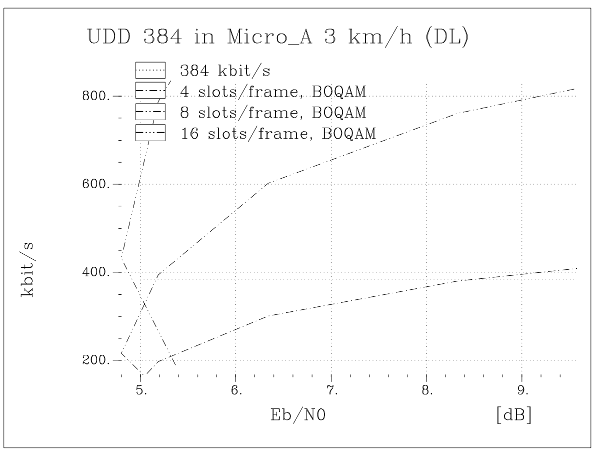

Figure 2.18 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Outdoor to Indoor A, DL

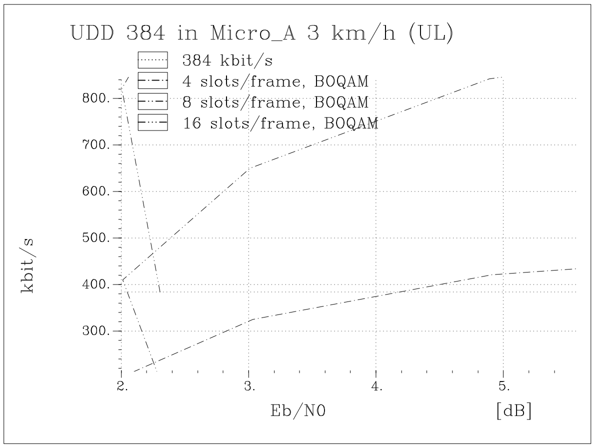

Figure 2.19 – UDD 144 throughput (kbit/s) vs. E_b/N_0 in ITU Outdoor to Indoor A, UL

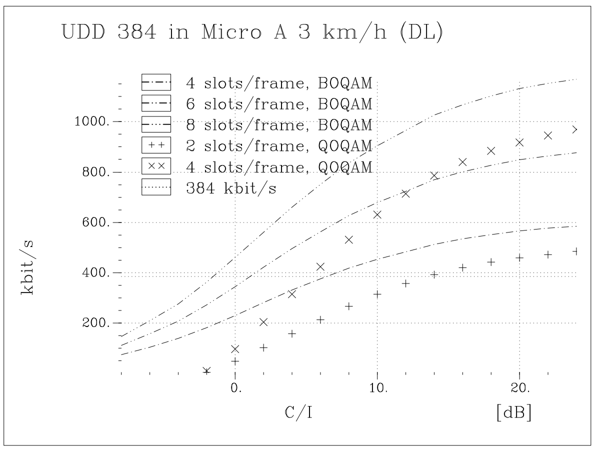

Figure 2.20 – UDD 144 throughput (kbit/s) vs. C/I in ITU Outdoor to Indoor A, DL

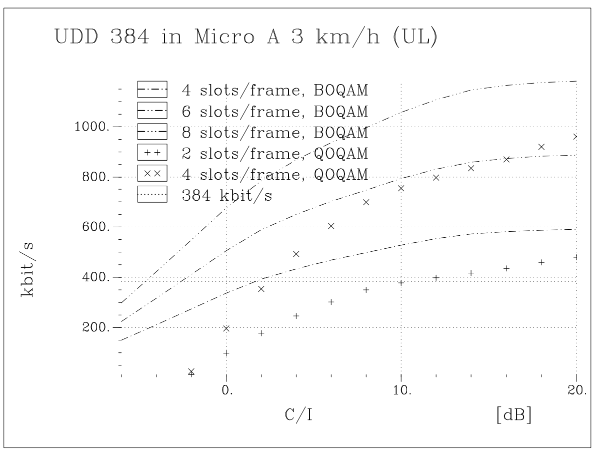

Figure 2.21 – UDD 144 throughput (kbit/s) vs. C/I in ITU Outdoor to Indoor A, UL

2.1.8 UDD 2048 in ITU Indoor A

	Case 1	Case 2
Number of slots used / frame	8 slots / frame	16 slots / frame
Slot size	1/16	
Modulation	Q-O-QAM (B-O-QAM results are found in figures.)	
Coding rate	Variable	
Basic code	1/2-rate convolutional code	
Interleaving depth	8 slots	
Type of interleaving	block interleaving	
Frequency hopping	slot-by-slot (need not be consecutive)	
Mobile speed	3 km/h	
Channel model	ITU Indoor A	
E_b/N_0 UL/DL	- / -	4.6 / 7.0
C/I UL/DL	- / -	4.2 / 7.6

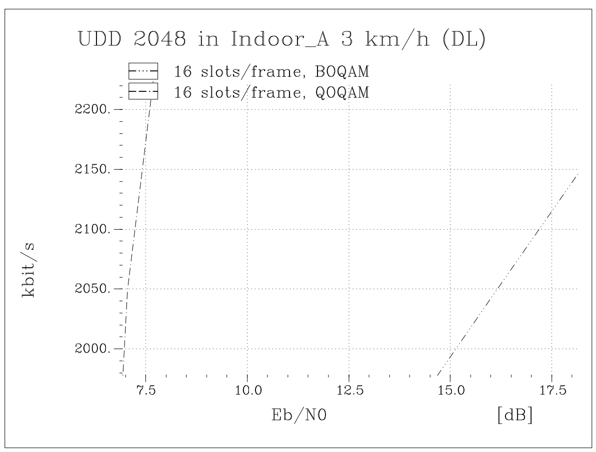

Figure 2.22 – UDD 2048 throughput (kbit/s) vs. E_b/N_0 in ITU Indoor A, DL

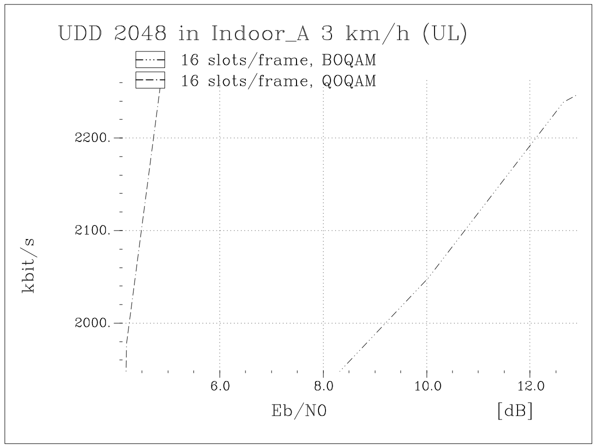

Figure 2.23 – UDD 2048 throughput (kbit/s) vs. E_b/N_0 in ITU Indoor A, UL

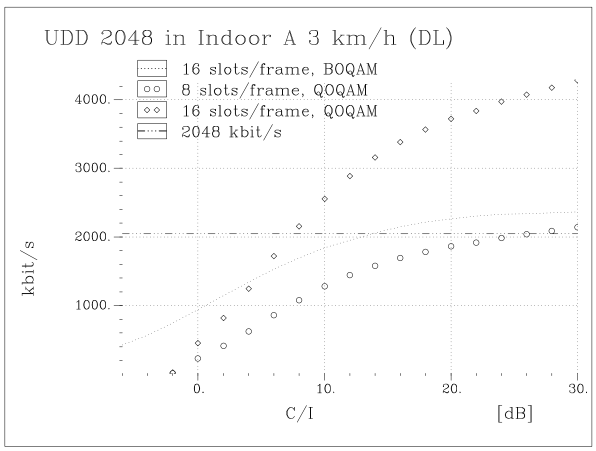

Figure 2.24 – UDD 2048 throughput (kbit/s) vs. C/I in ITU Indoor A, DL

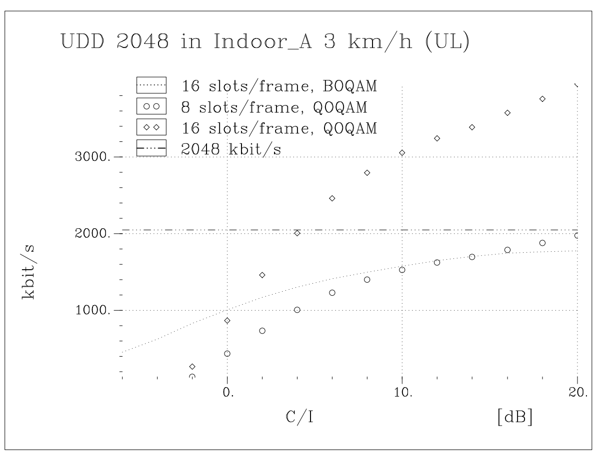

Figure 2.25 – UDD 2048 throughput (kbit/s) vs. C/I in ITU Indoor A, UL

In Figure 2.24 and Figure 2.25 it is shown how bit rate of 2.048 Mbit/s can be achieved with WGPRS HS Indoor. It is possible to transmit 2 Mbit/s with B-O-QAM modulation if at least 14 slots/frame are allocated for the bearer and the C/I is high enough. If Q-O-QAM modulation is used, the 2 Mbit/s can be achieved with 8 slots and by allocating all 16 slots the maximum bit rates exceeds 4 Mbit/s.

2.1.9 Effect of Frequency Hopping on Packet Services

The effect of frequency hopping can be illustrated by the following simulation results. In the sense of the throughput frequency hopping decreases the performance about 0.7 dB.

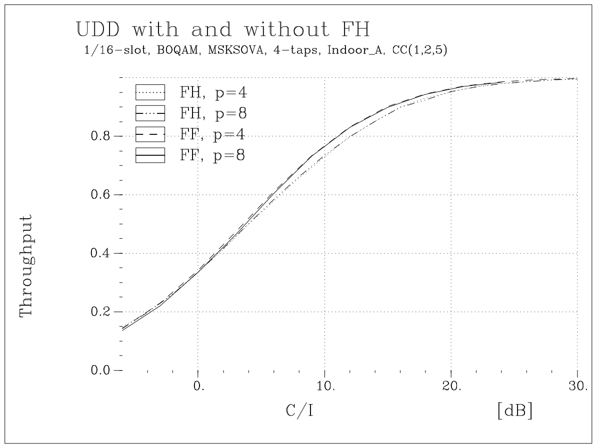

Figure 2.26 – ARQ with (FH) and without frequency hopping (FF)

However, throughput is not the only measure for packet service quality. It is also beneficial that ARQ-scheme does not produce very high occasional delay. In this sense, frequency hopping improves the performance and it also helps to average the interference caused to other users.

Without frequency hopping there are occasionally longer delays for individual packets. However, because the average delays in these two cases are about the same, there are also low delays in the non-hopping case.

In indoor_A channel delays over 10 bursts (~46 ms) were not present if C/I was over 10 dB. With C/I = 0 dB the maximum delay is measured to be 20 bursts (less than 100 ms). Without frequency hopping maximum delays at C/I of 10 dB can exceed 20 bursts and with C/I = 0 dB maximum delays can exceed 60 bursts (~ 280 ms). In the non-hopping case the delay distribution has longer tail than in the hopping case.

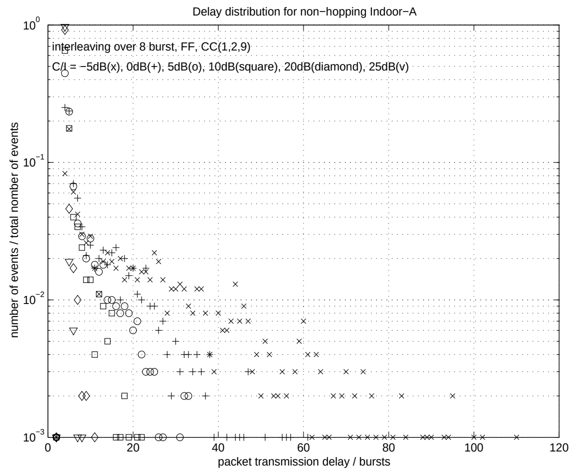

Figure 2.27 – Delay distribution for non-hopping UDD

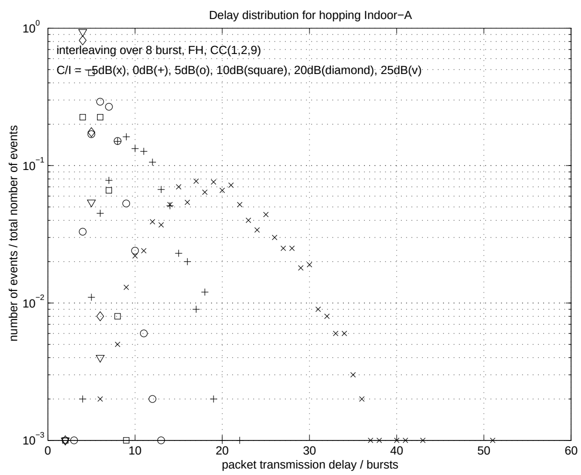

Figure 2.28 – Delay distribution for hopping UDD

2.2 System Level Results

This section describes the executed system level simulations and the assumptions used in them. WGPRS HS Indoor is simulated utilizing Interference Averaging (IA) concept. The main features of the IA-concept are frequency hopping on the whole operator bandwidth, time hopping, link adaptation, type II hybrid ARQ, and quality based Handover (HO). Frequency Hopping (FH) and Time Hopping (TH) provide interference averaging and Link Adaptation (LA) provides interference diversity, which are the cornerstones of the scheme.

2.2.1 Basic Assumptions

Only the *downlink* direction is considered. It is expected that downlink will be the capacity limiting direction. Advanced receiver techniques such as antenna diversity can be used in the uplink to make its capacity exceed that of the downlink. Additionally, the locations of the interfering transmitters (mobile stations) will also change providing more interference diversity gain through FH and TH in the uplink. Hence the lower limit for performance is presented.

In the following the major assumptions that have effect on the performance are presented.

2.2.1.1 General Models

Test environments, propagation models, mobility models and quality of service (QoS) criteria for RT users is modeled according to [1]. In addition, for packet services, if a user receives all requested bits within 150 ms the user is regarded as a satisfied user.

2.2.1.2 Channel Allocation

Channels are allocated frame by frame independently in each Base Transceiver Station (BTS). RT services are prioritized over Near Real Time (NRT) services. Channel allocation for RT services is based on 'first come first served' principle. Within NRT services users having difficulties to maintain the minimum bit rate and NRT users with lowest transmitted power per slot are prioritized over the rest of the NRT users.

For channel allocation, a channel matrix for each BTS is defined. It contains $f \times t$ slots, where f is the amount of frequencies available for the BTS and t is the amount of slots in one *WGPRS HS Indoor* frame. A channel separation of 1.6 MHz is used, thus the maximum size for the channel matrix is nine frequencies and 64 or 16 time slots for 1/64 and 1/16 slots structures respectively. However, to speed up simulations with some simulation cases less frequencies and/or time slots have been used. The amount of used frequencies and time slots in each simulation case are indicated together with the simulation results. Use of less frequencies and time slots (smaller channel matrix) in the simulation than the maximum number available on the band causes less diversity and more blocking, thus this is a pessimistic assumption and worse performance is obtained.

2.2.1.3 Frequency & Time Hopping

Random uncorrelated memoryless frequency hopping is applied. The random hopping introduces interference diversity; uncorrelated means that the channel fading of different frequencies are uncorrelated; memoryless means that each frequency has the same probability to be chosen regardless of the previously used frequencies. As an example, if nine frequencies are used in a BTS, there is 1/9 probability that two consecutive slots of one particular connection use same frequency. For time hopping there are no restrictions on which time slots a terminal can use. User carrier and interfering carrier are slot synchronized but this is not utilized in the simulations, e.g., for interference suppression.

2.2.1.4 Power Control

Slow pathloss based power control is applied. The dynamic range of the power control is 30 dB or less.

2.2.1.5 Handover

Simple pathloss based handover with hand over margin of 3 dB is used, i.e., handover is performed to a new base station if the pathloss to the new base station is 3 dB lower than to the serving base station. In indoor simulations, HO to a BTS in a different floor is prohibited. Taking into account very high standard deviation (12 dB) for indoor slow fading, this probably has a negative effect on the capacity.

2.2.1.6 Link Adaptation

For RT users quality based link adaptation is used. The channel coding rate is increased when the connection experiences a bad frame and if the serving BTS has extra radio resources available. Amount of channel coding will be decreased if less channel coding would have continuously been sufficient for certain amount of frames. If needed, LA can be done at the beginning of an interleaving period.

For NRT the link adaptation is performed with type II hybrid ARQ, thus the coding rate depends on the amount of retransmission. The modulation is kept constant over the whole simulation.

2.2.1.7 Type II Hybrid ARQ

In the ARQ scheme used, user data is coded with ½-rate convolution code and interleaved over four bursts. The interleaving is done in such a way that decoding is possible after two of four bursts have been received. Thus the effective coding rate is one. If the decoding is not successful, a third burst is sent and decoding is redone. After the third burst the coding rate is 2/3. If the decoding is still not successful, a fourth burst is sent and decoding is done again, now with the coding rate of 1/2. If the decoding is still not successful, the burst with the lowest C/(I+N) value is resent and the original burst and the retransmitted burst are combined by adding their C/(I+N) values (maximal ratio combining). This repetition coding is repeated until the decoding is successful.

2.2.1.8 DTX

Radio resources of speech user are released during the Discontinuous Transmission (DTX) period. If there are no resources available after the DTX period bit error rate of 0.5 is applied until resources are allocated or call is dropped.

2.2.1.9 Modulation Adaptation

Simple modulation adaptation algorithm is used for UDD services. Preferred modulation is Q-O-QAM but B-O-QAM is used for small packets.

2.2.1.10 Frequency Planning

A characteristic feature of the simulated IA concept is very simple frequency planning with frequency re-use 1. Thus all the frequencies can be used at each base station. Through fractional loading the load in each cell is always less than 100%.

2.2.1.11 Interface between System & Link Level Simulation

Link level simulation and system level simulations are connected to each other by using the actual value interface. The actual value interface makes it possible to simulate fast radio resource algorithms on the system level. The actual value interface also increases the simulation realism considerably.

The actual value interface is a novel way to connect link and system level simulations. In the actual value approach the link level simulation data, e.g., bit errors, are measured for every burst or frame. However, this means that possible de-interleaving and decoding has to be considered on the system level. The performance of receiver algorithms, such as decoding, are not measured or analyzed in the system level simulations, but their performance is considered on the link level. The effect of receiver algorithms is seen in the link level results that are given as inputs to the system level simulation.

If the system level simulation is done with an actual value interface, fast fading has to be taken into account in addition to slow fading and pathloss. With the average value interface fast fading was neglected, since the input from the link level and correspondingly the channel was averaged over a long period (and the fast fading characteristics were included on the link level). With the actual value interface, non-averaged link level simulations are used. Thus fast fading has to be considered on the system level. The same kind of correlated fading process is used both in link and system level simulations, modeled as Rayleigh, with a certain Doppler frequency.

The strength of an actual value interface, compared to the average value interface, is that all the radio resource management algorithms can be simulated on the system level accurately since the simulation resolution is as accurate as the resolution of the mentioned algorithms. The actual value interface enables possible gain or loss of frequency hopping, ARQ, and link adaptation algorithms. If frequency hopping was simulated on the link level and the average value interface was used, interference diversity gain could not be modeled. This is because in the link level simulations only interfering user(s) operating with the same frequency as the observed user can be considered. Correspondingly, if ARQ was simulated on the link level, the varying interference conditions that have their impacts to ARQ performance could not be taken into account. Link adaptation can be simulated thoroughly only on the system level since adaptation decisions depend only on the changing interference conditions. If the link adaptation algorithm was fast the average value interface could not be used.

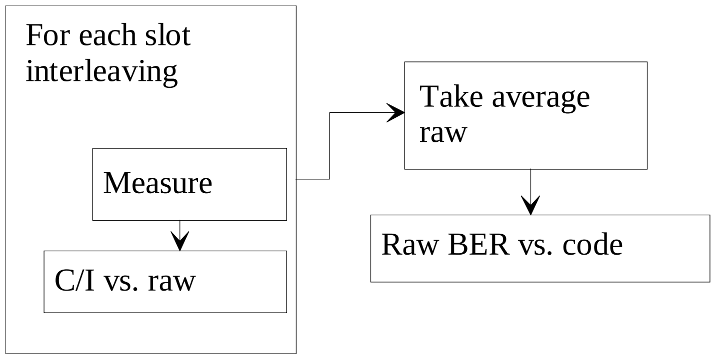

Figure 2.29 – Block diagram of interface for RT bearers

In the method presented here, link level simulation results are collected on a burst-by-burst basis, i.e., C/I and BER values are collected for each burst and coded BER/Frame Erasure Rate (FER) values for each interleaving period. e.g., if the target service has interleaving over 4 bursts, then C/I values for 4 bursts are observed directly from the fading channel and BER/FER of the coding block is measured over the interleaving period. In the link level simulation raw BER (BER before decoding and de-interleaving) versus C/I ratio is measured for each burst within the interleaving block. In the system level the C/I ratio is measured for each burst within the interleaving block and is mapped to raw BER by using a *raw BER vs. C/I curve* from the link level. De-interleaving is modeled so that the average raw BER within the interleaving block is calculated. Further, decoding is modeled by mapping the de-interleaved raw BER to the coded BER/FER by using the measured *mean raw BER vs. coded BER/FER curve*. The actual value interface for *WGPRS HS Indoor* is depicted in Figure 2.29.

2.2.2 System Level Performance Results

Simulation results are collected to Table 2.2. Detailed description of the simulations carried out are presented in the following sections.

Table 2.2 – Summary of the system simulation results

Deployment model	Service	Capacity [Mbit/s/MHz/cell]	Notes
Indoor	UDD2048	**.332**	
Indoor “with walls”	UDD2048	**.743**	Wall attenuation 5 dB
Outdoor to indoor and pedestrian	UDD384	**.811**	
Isolated cell (high C/I)	UDD	**> 2.000**	*Single cell capacity*

2.2.2.1 Performance with Indoor Deployment Model

2.2.2.1.1 UDD2048

The simulated spectrum efficiency is **0.332 Mbit/s/MHz/cell**. Of all sessions 98.4% fulfill quality criteria. If all bits the user requests during a session are received correctly within 150 ms, the user is regarded as a satisfied user independent of active bit rate. Insufficient active session throughput is the limiting reason for most sessions not fulfilling the performance criteria.

The average active session throughput is 713 kbps and 0.4 % of the sessions have active session throughput 2048 kbps or higher. If offered load is reduced the average active session throughput and ratio of the users having active session throughput 2048 kbps or higher increases. Reuse 1 is used with fractional load of 48%. The distribution of active session throughputs can be seen in Figure 2.30. In Figure 2.31 histogram for needed transmissions per a hybrid II ARQ packet is presented.

With Indoor UDD2048 simulations the channel matrix was 16 time slots x 9 frequencies. The preferred modulation is Q-O-QAM, but the modulation is switched to B-O-QAM if offered traffic does not require Q-O-QAM. If the BTS buffer has less bits that can be transmitted in a one radio packet, the radio packet is filled with dummy bits. These overhead dummy bits are not included into spectrum efficiency figure nor into active session throughput. The dynamic range of the power control is 30 dB.

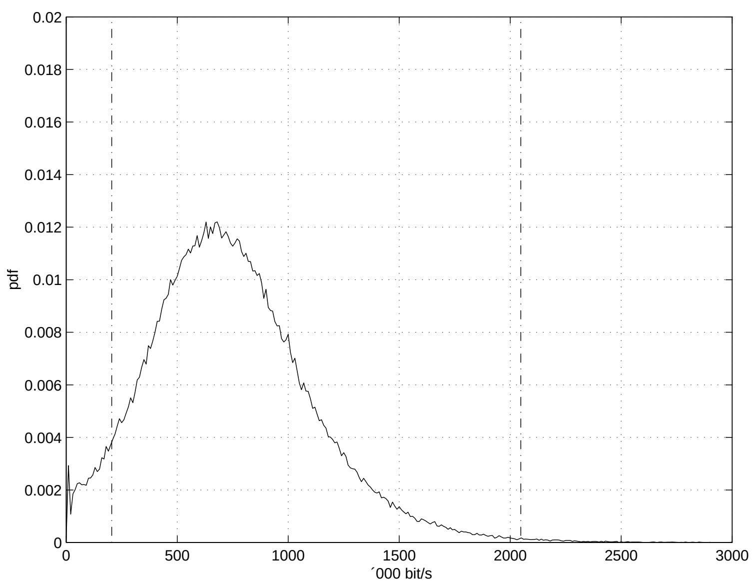

Figure 2.30 – Histogram for session throughputs

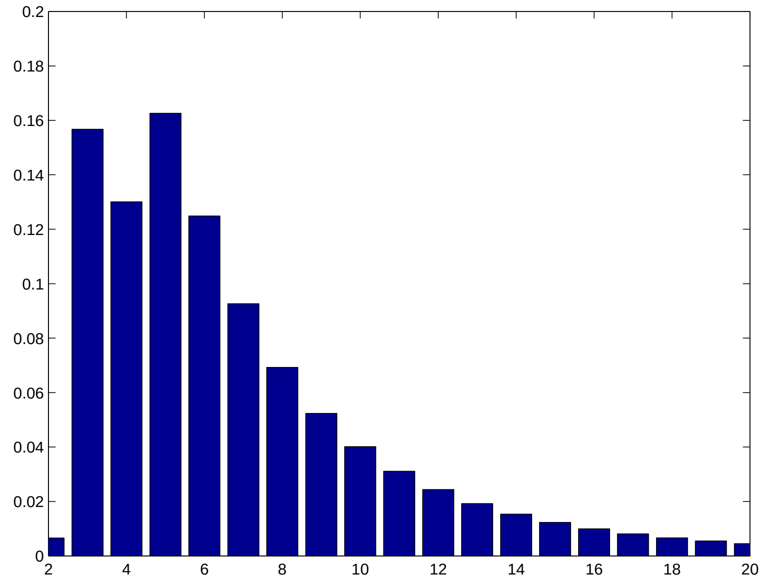

Figure 2.31 – Histogram for needed transmissions per hybrid II ARQ packet. Both Q-O-QAM and B-O-QAM packet are included.

2.2.2.2 Performance with Indoor Deployment Model with Walls

2.2.2.2.1 UDD2048

Indoor model defined in [1] has hardly any isolation between cells on the same floor. Therefore additional simulations with walls were carried out. UDD2048 simulation with walls is otherwise identical to UDD2048 simulation without walls presented in section 2.2.2.1.1, except it has additional wall attenuation of 5 dB and standard deviation of slow fading is reduced from 12 dB to 4 dB.

The simulated spectrum efficiency is 0.743 Mbps/MHz/cell. Of all sessions 98.7% fulfill quality criteria. If all bits the user requests during a session are received correctly within 150 ms, the user is regarded as a satisfied user independent of active bit rate. Insufficient active session throughput is the limiting reason for most sessions not fulfilling the performance criteria.

The average active session throughput is 692 kbps and 0.4% of the sessions have active session throughput 2048 kbps or higher. If offered load is reduced, the average active session throughput and ratio of the users having active session throughput 2048 kbps or higher increases. Reuse 1 is used with fractional load of 86%. The distribution of active session throughputs can be seen in Figure 2.32. In Figure 2.33 histogram for needed transmissions per a hybrid II ARQ packet is presented.

With pico cell UDD2048 simulations the channel matrix was 16 time slots x 8 frequencies. The preferred modulation is Q-O-QAM, but the modulation is switched to B-O-QAM if offer traffic does not require Q-O-QAM. If the BTS buffer has less bits that can be transmitted in a one radio packet, the radio packet is filled with dummy bits. These overhead dummy bits are not included into spectrum efficiency nor into active session throughput. The dynamic range of the power control is 30 dB.

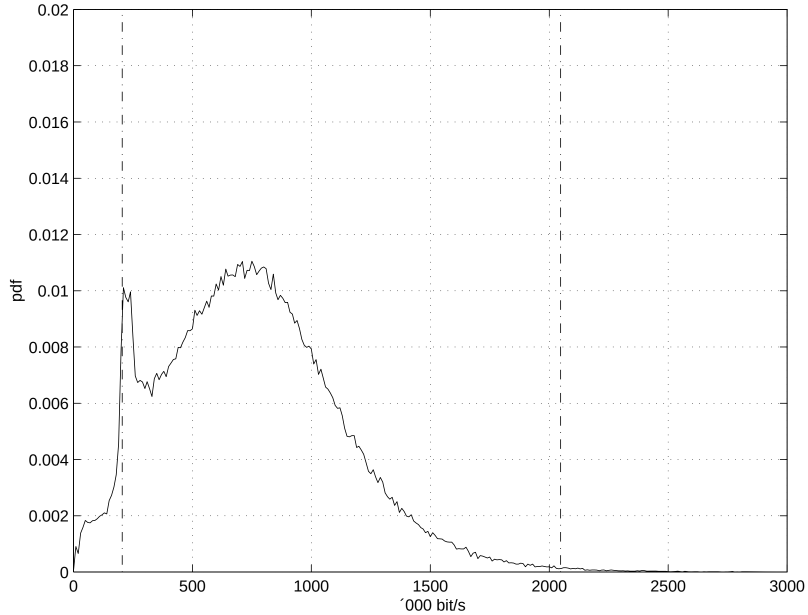

Figure 2.32 – Histogram for session throughputs.

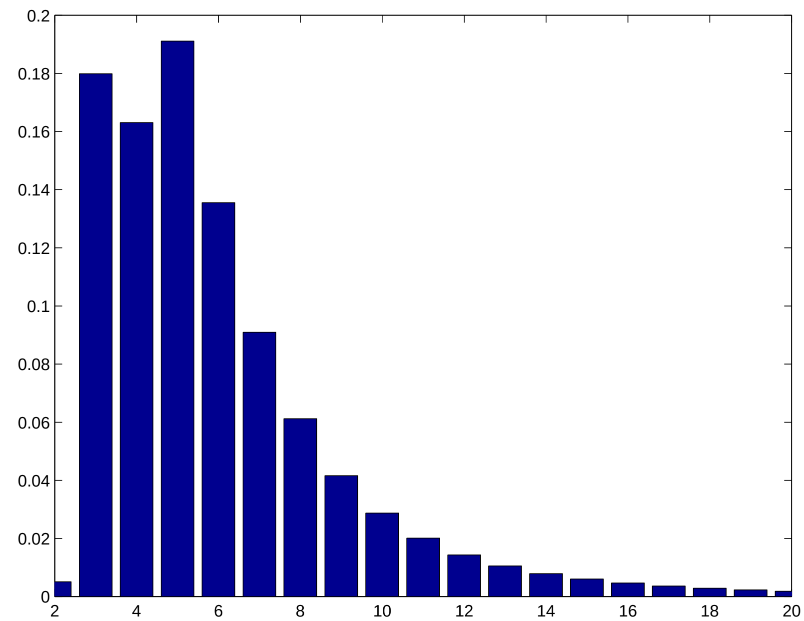

Figure 2.33 – Histogram for needed transmissions per hybrid II ARQ packet. Both Q-O-QAM and B-O-QAM packet are included.

2.2.2.3 Performance with Outdoor to Indoor & Pedestrian Deployment Model

2.2.2.3.1 UDD384

The simulated Spectrum efficiency is 0.811 Mbps/MHz/cell. Of all sessions, 99.7% fulfill all quality criteria. Dropping is the major reason for not fulfilling all quality criteria; the bad quality criterion does not have any practical effects.

The average active session throughput is 405 kbps and 46% of the sessions have active session throughput 384 kbps or higher. The respective ratios for 512 kbps, 1Mbps and 2Mbps are 24%, 3.1% and 0.25%. Thus higher bit rates are also possible in outdoor to indoor / pedestrian environment. The distribution of active session throughputs can be seen in Figure 2.34. Reuse 1 is used with fractional load of 79%. In the Figure 2.35 a histogram for needed transmissions per a hybrid II ARQ packet is presented.

With the micro cell UDD384 model simulations the channel matrix is 16 time slots x 5 frequencies due to simulation complexity reasons (with assumption of 15 MHz spectrum 9 frequencies could have been used). Thus channel diversity gain and specially the statistical multiplexing gain is reduced. The preferred modulation is Q-O-QAM, but the modulation is switched to B-O-QAM if offer traffic does not require Q-O-QAM. If fewer bits that can be transmitted in one radio packet are sent, the radio packet is filled with dummy bits. These overhead dummy bits are not included into spectrum efficiency nor into active session throughput. The dynamic range for the power control is 30 dB.

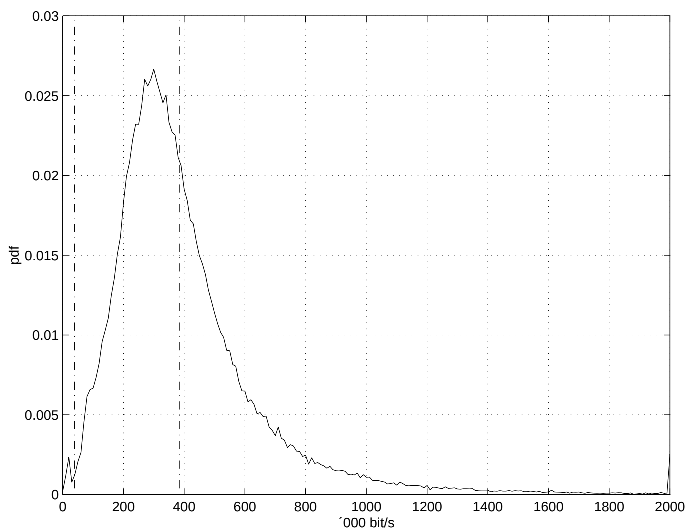

Figure 2.34 – Histogram for session throughputs

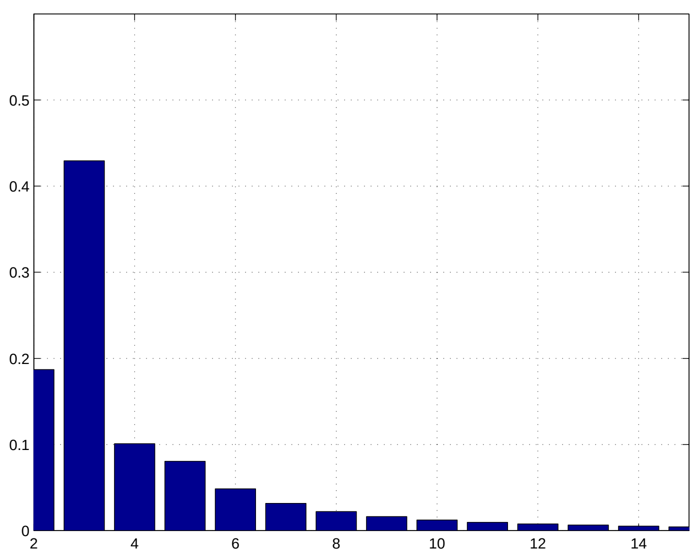

Figure 2.35 – Histogram for needed transmissions per hybrid II ARQ packet. Both Q-O-QAM and B-O-QAM packet are included.

2.3 Discussion

System simulation results for *WGPRS HS Indoor* are shown. The radio resource management scheme used in these simulations is based on the interference averaging principle. In order to be able to study the effects of fast algorithms such as ARQ and Frequency hopping, the actual value interface between link and system level is implemented.

The results represent a lower bound case in several aspects: only downlink results are presented, all the possible enhancements by the interference averaging radio resource management algorithms are not implemented and network parameter optimization is not completed.

Issues for further studies include several items. Among these are interference cancellation, antenna diversity, application of ARQ to LCD data, better coding schemes (e.g., increased constraint length, optimal puncturing, and concatenated codes), optimized mapping of user data into packets, fast power control, and channel allocation to cells.

3 Deployment Model Result Matrix

Table 3.1 – Deployment Matrix for 384 kbit/s Service Pedestrian Environment.

Input assumptions				
Test environment	Pedestrian/Outdoor 3 km/hr			
Test service	384 kbit/s Packet Data			
Base station antenna height (m)	15 Meters above average rooftop			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)	Three sector sites, Directional antennas (pd1132 antenna)			
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2 /site)	Spectrum efficiency (Mbit/s/MHz/site) for data
27	75	N/A	0.0899 M.1225 1.347 Optimized	0.9495 (0.3165 per sector) A 0.9318 (0.3106 per sector) B

Table 3.2 – Deployment Matrix for 384 kbit/s Vehicular A50 Environment.

Input assumptions				
Test environment	Vehicular 50 km/hr			
Test service	384 kbit/s Packet Data			
Base station antenna height (m)	15 meters above average rooftop			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)	Three sector sites, Directional antennas (pd1132 antenna)			
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2 /site)	Spectrum efficiency (Mbit/s/MHz/site) for data
27	75	N/A	11.63 M.1225 32.51 Optimized	1.176 (0.392 per sector) A 0.820 (0.2733 per sector) B

Table 3.3 – Deployment Matrix for 384 kbit/s Vehicular A120 Environment.

Input assumptions				
Test environment	Vehicular 120 km/hr			
Test service	384 kbit/s Packet Data			
Base station antenna height (m)	15 meters above average rooftop			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)	Three sector sites, directional antennas (pd1132 antenna)			
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2 /site)	Spectrum efficiency (Mbit/s/MHz/site) for data
27	75	N/A	6.619 M.1225 17.566 Optimized	1.038 (0.346 per sector) A 0.7682 (0.256 per sector) B

Table 3.4 – Deployment Matrix for 64 kbit/s Service Pedestrian Environment.

Input assumptions				
Test environment	Pedestrian/Outdoor 3 km/hr			
Test service	64 kbit/s Packet Data			
Base station antenna height (m)	15 Meters above average rooftop			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)	Three sector sites, Directional antennas (pd1132 antenna)			
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2 /site)[1]	Spectrum efficiency (Mbit/s/MHz/site) for data
27	75	N/A	0.1797 M.1225 2.687 Optimized	1.554 (0.5147 per sector) A 1.533 (0.511 per sector) B

[1] Uses 144 kbit/s PCS-1.

Table 3.5 – Deployment Matrix for 64 kbit/s Service Vehicular A50 Environment.

Input assumptions				
Test environment	Vehicular 50 km/hr			
Test service	64 kbit/s Packet Data			
Base station antenna height (m)	15 Meters above average rooftop			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)	Three sector sites, Directional antennas (pd1132 antenna)			
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2 /site)[1]	Spectrum efficiency (Mbit/s/MHz/site) for data
27	75	N/A	28.555 M.1225 75.8 Optimized	1.422 (0.474 per sector) A 1.017 (0.339 per sector) B

Table 3.6 – Deployment Matrix for 64 kbit/s Service for Vehicular A120 Environment.

Input assumptions				
Test environment	Vehicular 120 km/hr			
Test service	64 kbit/s Packet Data			
Base station antenna height (m)	15 Meters above average rooftop			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)	Three sector sites, Directional antennas (pd1132 antenna)			
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2 /site)[1]	Spectrum efficiency (Mbit/s/MHz/site) for data
27	75	N/A	27.295 M.1225 72.44 Optimized	1.176 (0.392 per sector) A 0.894 (0.298 per sector) B

Table 3.7 – Deployment Matrix for 2 Mbit/s Service Indoor Environment.

Input assumptions				
Test environment	Indoor A 3 km/hr			
Test service	2 Mbit/s Packet Data			
Base station antenna height (m)	Ceiling height			
Any other assumptions made by the proponent (e.g., antenna pattern, sectorization etc.)				
Deployment results				
Total number of cell sites	Total number of RF channels	Number of voice channels per RF channel	Coverage efficiency (km^2/site)	Spectrum efficiency (Mbit/s/MHz/site) for data
14	9	N/A	0.02 km^2/site.	0.332 W/O Walls 0.743 With Walls (5 dB Attenuation)

[1]

[1]ITU-R Doc.8-1/INFO/2, Seattle, January 19 – 23, 1998

Appendix A: Acronyms

8-PSK	8-ary Level Phase Shift Keying
ACK	Acknowledgement
ARQ	Automatic Repeat Request
ATIS	Alliance for Telecommunications Industry Solutions
AWGN	Additive White Gaussian Noise
B-O-QAM	Binary Quaternary Offset Quadrature Ampitude Modulation
BER	Bit Error Rate
BTS	Base Transceiver Stations
C/I	Carrier to Interference Ratio
CC	Convolutional Code
COSSAP	Communication System Simulation and Application Processor
DFE	Decision Feedback Equalizer
DTX	Discontinuous Transmission
FEC	Forward Error Correction
FER	Frame Erasure Rate
FF	Fixed Frequency (Without Frequency Hopping)
FH	Frequency Hopping
HO	Handover
HS	High Speed
IA	Interference Averaging
ITU	International Telecommunication Union
LA	Link Adaptation
LCD	Low Constrained Delay
MRC	Maximum Ratio Combining
NACK	Negative Acknowledgement
NRT	Near Real Time
O-QAM	Offset Quadrature Amplitude Modulation
PCS	8 PSK Coding Scheme
Q-O-QAM	Quaternary Offset Quadrature Ampitude Modulation
QoS	Quality of Service

RS	Radio Service
RT	Real Time
RTT	Radio Transmission Technology
SOVA	Soft Output Viterbi Algorithm
TDMA	Time Division Multiple Access
TDMA-SC	Time Division Multiple Access – Single Carrier
TH	Time Hopping
UDD	Unconstrained Delay Data
WGPRS	Wideband General Packet Radio Service
WTSC	Wireless Technologies and Systems Committee