New approach for system performance study in HIPERLAN/2

Jürgen Rapp

Communication Networks Aachen University of Technology Kopernikusstr. 16 D–52074 Aachen, Germany Tel.: +49 241 80 7911 E-mail: rapp@comnets.rwth-aachen.de

Abstract

Growing demands for bandwidth as well as mobility have led to several research projects which are investigating high speed wireless LANs and within ETSI BRAN a wireless LAN called HIPERLAN/2 is being standardized. Within HIPERLAN/2 it is foreseen to adapt the modulation and code rate to the conditions of the radio link. With seven different combinations of modulation and code-rate, data rates from 6 to 54 Mb/s with different requirements on the C/I and different resilience against transmission errors are possible. In most approaches when simulating system performance under the influence of interference a high number of radio cells has to be simulated to gain reliable results for the innermost cells. This makes it necessary to use simplified models for the scheduling and the ARQ scheme as otherwise simulation times become too high. In this paper another approach is proposed which applies an iterative process and tries to model all interference as coming from only one interfering radio cell. This leads to a slight difference in the distribution of the interference vs the position in the radio cell but then it is possible to use a detailed model of the scheduling, the ARQ scheme and the collision resolution in each iteration as well as mobility and realistic traffic models. Two scenarios are considered and the feasibility of the new approach is shown analytically and by means of simulations for these two scenarios. The results are compared against previously published results for the same scenarios which were gained with a standard approach.

1 Introduction

Growing demands for bandwidth as well as mobility have led to several research projects which are investigating high speed wireless LANs. In Europe, a wireless LAN system, called HIPERLAN/2, is being standardized in ETSI BRAN. It can be used in combination with e.g. ATM or TCP/IP and as part of UMTS. Within HIPERLAN/2 it is foreseen to adapt the modulation and code rate to the conditions of the radio link. With seven different combinations of modulation and code-rate (=Phy. Mode), data rates from 6 to 54 Mb/s with different requirements on the C/I and different resilience against transmission errors are possible [1]. HIPERLAN/2 is a cellular system in which an Access Point (AP) serves as central controller. It decides when a wireless terminal shall receive and when it shall transmit. HIPER-LAN/2 uses Time Division Duplex (TDD) and Time Division Multiple Access (TDMA) with frames of a fixed length of 2ms (cf. fig. 1).

A frame starts with a Broadcast Control CHannel (BCCH) that contains some identifiers, information about transmission power, the start of the Frame Control CHannel (FCCH) and the start and length of the Random CHannel (RCH). After the BCCH follows the FCCH which contains detailed information about the structure of the frame. One Resource Grant Information Element (RG IE) exists in the FCCH for



Fig. 1: Frame structure in HIPERLAN/2

every connection. In the RG IE the connection is identified and the number of Control-PDUs (C-PDUs) and User-PDUs (U-PDUs) as well as the transmission modes for C-PDUs and U-PDUs is given. After the FCCH comes the Random access Feedback CHannel (RFCH) in which the wireless terminals are informed about the result of the previous access attempts to the RCH. For BCCH, FCCH, RFCH and RCH the most robust transmission mode is used. After the RFCH follows the downlink phase and the uplink phase in which bursts are transmitted to wireless terminals and received from wireless terminals. Every burst consists of a preamble and a number of C- and U-PDUs. At the end of the frame comes the RCH. The RCH is used for association and if a terminal has to transmit important information to the AP but no capacity has been scheduled for it. If a wireless terminal did not transmit for some time and it has a new request for capacity, this Resource Request (RR) is sent via the RCH, too. The RR contains some identifiers, the number of requested C-PDUs and U-PDUs, the proposed transmission modes for the C- and U-PDUs and some bits to indicate the channel quality. An binary exponential backoff mechanism with a maximum contention window size of 256 is used for the collision resolution.

2 New Approach for System Performance Investigation

In most approaches when simulating system performance under the influence of interference a high number of radio cells has to be simulated to gain reliable results for the innermost cells. This makes it necessary to use simplified models for the scheduling and the ARQ scheme as otherwise simulation times become too high. In this paper another approach is proposed which applies an iterative process and tries to model all interference as coming from only one interfering radio cell. This leads to a slight difference in the distribution of the interference vs the position in the radio cell but then it is possible to use a detailed model of the scheduling, the ARQ scheme and the collision resolution in each iteration as well as mobility and detailed traffic models.

In this paper two scenarios are considered and the feasibility of the new approach is shown analytically and by means of simulations for these two scenarios. The first scenario consists of a big exhibition hall with 16 APs and a site to site distance of 60m (cf. [2]). There are 9 frequencies available which means that one frequency is used by two APs. As can easily be seen, this case is exactly what is simulated by the iterative approach with one interfering radio cell.

The second scenario uses the same exhibition hall but only 5 frequencies are available. This means that the frequencies will be distributed for example as shown in fig. 2 and as worst case one frequency is used by 4 APs (frequency no. 1 in this example).



Fig. 2: Exhibition hall with 5 frequency reuse

We are assuming that 75% of the load is on the downlink

and are considering the most demanding case that all radio cells are operated at almost full load. For this case the interference which is caused by the downlink can be calculated by taking into account the actual position of the interfering radio cells and simply adding the interference power of the interfering radio cells.

If the 3 interfering radio cells are to be replaced by only one interfering radio cell its interference power has to be adjusted. This is done by placing the one interfering radio cell as far away from the considered radio cell that it generates the same interference in the middle of the considered radio cell as the 3 interfering radio cells (cf. fig. 3).



Fig. 3: Alternate system with only one interfering radio cell

This means that there will be a difference in the interference outside the middle of the considered radio cell. This difference has been calculated and is shown in fig. 4.

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Fig. 4: Difference of Interference between alternate and original system

As can be seen the difference in the interference is below

2dB in 90% of the radio cell. Furthermore, there is some compensation since the mobile stations are assumed to be equally distributed and the area where the interference is higher than in the 3 interferer case is almost as big as the area where the interference is lower than in the 3 interferer case. Thus, reasonable results can be expected and have indeed been found when running simulations and comparing them with the results presented in [2] (cf. section 4).

The iterative process is as follows. In the first iteration a radio cell is simulated without interference and only attenuation and signal to noise ratio is considered. The attenuation of signals is calculated via the following equation for LOS propagation:

$$L_d[dB] = 46 + 20 * log(distance/1m) \tag{1}$$

Other models like the extended Keenan-Motley model [3] which can be used for office scenarios are not implemented yet but are foreseen for the future. Adjacent channel suppression is assumed to be so high that adjacent channel interference can be neglected.

The mobile terminals are moving with a speed of 3 km/h. When reaching the border of a radio cell, a new direction for the motion vector of a mobile terminal is drawn leading it back into the radio cell.

It is important to have mobility since the distance between current receiving terminal and interferer changes and the MTs are forced to inform the AP about new Phy. Mode proposals. How often the MTs can inform the AP about new Phy. Mode proposals will influence system performance since old and inadequate Phy. Mode proposals will lead to degraded system performance.

While simulation, the distance between AP and active terminal and the duration of the transmission is saved in a file. This data is used in the next iteration as basis for the interference from surrounding radio cells. While reception of a PDU in the second iteration, the distance between the current receiver and the interferer is calculated. If the interferer changes while reception of a PDU, the occurring interference powers P_{I_k} are weighted according to their length L_{I_k} and the total length of the current reception L_{Rec} (cf. eq. 2).

$$P_I = \sum_{k=1}^{n} \frac{L_{I_k}}{L_{Rec}} \times P_{I_k} \tag{2}$$

Up till now no power control is used and all terminals send with equal transmission power. Applying equation 1 and the distance to the interferer, the C/I value is calculated. Furthermore, lognormal fading with a standard deviation of 2 dB is added in order to model shadowing caused by e.g. people moving around.

According to files generated out of link level simulations [4] the calculated C/I corresponds to a PER which is then applied to this PDU.

In the current state of the simulation perfect measurement of the C/I values is assumed. The AP stores the last N C/I values of the received PDUs for every mobile terminal. These

values constitute the basis for the decision of the AP which Phy. Mode is used for which terminal in uplink direction. The MTs also store the last N C/I values of the received PDUs and make a Phy. Mode proposal for C-PDUs and U-PDUs in downlink direction. This Phy. Mode proposal is sent to the AP in a resource request or acknowledgement [5]. The Phy. Mode for C-PDUs and U-PDUs can be chosen separately for every terminal and both up- and downlink direction. Which strategies can be used for the selection of the Phy. Modes is still under investigation.

Since interference is considered in the second iteration, more robust Phy. Modes with lower nominal bit rates will be chosen and retransmissions will happen. This changes the times and durations of when a terminal transmits and by that the interference situation for the next iteration. In every iteration the distance between the AP and the active terminal and the duration of the transmission is saved in a file.

In the third iteration the values of the second iteration are read from the generated file meaning that the interfering radio cell in the third and in all further iterations is a cell which itself was influenced by interference. After some iterations a quasi stationary state is reached.

3 Used Protocols

Four different scheduling strategies are implemented and might be modified or supplemented according to the needs which result from interference and selection of Phy. Modes. The scheduling for data and acknowledgements is performed on PDU basis. In the presented results a scheduling algorithm was used which gives equal capacity on the link to every connection.

As ARQ scheme an Selective Repeat ARQ scheme with bitmap acknowledgements is implemented in detail as described in [5] with a limited ARQ window size (128 in the presented simulations).

The collision resolution is implemented in detail as described in [5].

4 Verifying Correctness of new Approach and Results

To verify the correctness of this approach it is compared with an approach which simulates a high number of radio cells. In [2] an exhibition hall with a high number of APs is simulated and the corresponding cumulative distribution function for the C/I values is presented. This scenario was also simulated with the new approach. The number of frequencies was 9 respectively 5 for the results shown here, meaning that in the given exhibition hall there are 2 respectively 4 APs which use the same frequency. Some further simulation parameters are given in table 1.

In fig. 5 the Signal to Noise Ratio (SNR) (iteration 0) and C/I curves for different iterations are shown for the scenario with 5 frequency reuse.

Quasi stationary equilibrium is reached quite fast. In itera-

Table 1: Important simulation parameters

Simulation Parameter	Value			
Number of frequencies	9/5			
System Load	$\approx 100\%$			
Downlink Traffic	75 %			
AP/MT Transmission Power	20 dBm			
Noise Power	-95 dBm			
Antennas (omni)	0 dBi			



Fig. 5: SINR for different iterations (5 frequency reuse)

tion #0 there is only noise and SNR values are so high that always the highest Phy. Mode is used. If interference is present, lower Phy. Modes have to be used and retransmissions do occur. This means that more capacity of the frame is used than in the cases without interference. The load was chosen in a way that in the case with interference around 100% of the frame is used. Since the interference situation varies over time there are also times when high Phy. Modes can be used and not the whole frame is used for transmission. Then, the unused capacity is divided by the number of scheduled trains and a silent phase of this length is inserted before every train. How the silent phase is distributed over the frame has also an influence on the distribution of the C/I values. If the silent phase would be inserted as one long silent phase in the frame, the offset between the frames in different radio cells had a great impact on the C/I distribution. If the frames were synchronised silent phases would mostly overlap with other silent phases and would have no impact on the C/I. If otherwise silent phases would overlap with the BCH or downlink or uplink phases they had an impact on the C/I.

In reality, the frames in different radio cells are unsynchronised and have a certain and fixed offset to each other. This offset is fixed during the whole operation time of the radio cells and the value of the offset has an influence on the interference. If the frames were synchronized and downlink and uplink phases in the radio cells had the same length, this would mean that receiving MTs in the downlink phase were always interfered by the AP of the other radio cells. If there is some offset between the frames of different radio cells, receiving MTs in one radio cell are interfered by other MTs which are currently transmitting in their uplink phase. Since the distance to the interferer is different if a downlink phase is interfered by a downlink phase or by an uplink phase the distribution of the interference is too. Another point is that RCHs have to be provided which will not always be used. If the frames are not synchronised, unused RCHs in the interfering radio cell mean silent phases that will lower the interference in the considered radio cell. To make results comparable, parameters in the simulation were chosen in a way to have very few unused RCHs. In the simulations the mean length of unused RCHs was $20 \mu sec$. An additional silent phase directly after the RCH comes from the transceiver turn around time which is $6\mu sec$. The following figure shows the difference between synchronised frames (Oms offset) and two other offset values for the 9 frequency reuse case (fig. 6).



Fig. 6: SINR for different offsets between interfering frames

No offset resembles the highest interference and 0.2 ms offset is a representative of lowest interference. The interference is lowest if the offset lies between 0 and the length of the BCH, which has a mean value of 0.288 ms in the simulations. This is due to the fact that all MTs are receiving the BCH and unused RCHs in the interfering radio cells do lessen the interference for all MTs. The interference for an offset that lies between the length of the BCH and the downlink phase lies between the worst and best case curve and is the same for all offset values in this range (cf. 0.4 ms offset). Higher offset values lead to an interference situation that approximates the worst case the nearer the offset values gets to the synchronised case (not shown here due to reasons of visibility). In the following an offset of 0.4 ms was chosen.

As can be seen when comparing results presented in [2] and

results gained with the new approach (cf. fig. 7), cumulative distributions for C/I values are very similar.



Fig. 7: Downlink C/I curves for 9 and 5 frequency reuse

With the new approach also values for throughput, protocol overhead and retransmission load and explanation to these values can be given. The scheduling and scenario was chosen in a way to make comparison with C/I distribution results presented in [2] easier. There, a large number of users and a calculation of the throughput similar to equal capacity scheduling is applied. In the simulated system, around 20 connections were scheduled in every frame. Then the protocol overhead (preambles, transceiver turn around times, BCH, acknowledgements, resource requests, RCHs), meaning everything but the pure data transmission, was 31.8% and 31.1% respectively of the frame on average for the 9 and 5 frequency reuse case which is undesirably high. In a more realistic scenario with file transfer and WWW session and other scheduling strategies, around 5 to 10 connections will be scheduled per frame which would lead to a total overhead of around 10%. With the new approach, the effects of realistic source behaviour and applied scheduling strategy on overhead, throughput and delay can and will be investigated in the future.

Another important point is the retransmission load. Especially in the 5 frequency reuse case, retransmission load is higher than the generated load which shows that the used very simple link adaptation algorithm has poor performance under these conditions. In the considered very simple link adaptation algorithm the Phy. Mode is changed if a certain C/I value is reached. These values were chosen only as a first starting point and the impact of the link adaptation on the retransmission load and the overall system throughput has to be investigated in much more detail. Furthermore, a realistic selective repeat ARQ scheme with bitmap acknowledgements and limited ARQ window size is used and acknowledgements do get lost due to transmission errors. These realistic restrictions influence retransmission load and overall throughput. With the new approach these effects, and how they have to be considered in the link adaptation algorithm, can and will be investigated, too. Some more load values are given in table 2.

Table 2: Load statistic

	9 frequencies	5 frequencies
Generated Load	17.8 Mb/s	6.6 Mb/s
Retransmission Load	5.4 Mb/s	6.9 Mb/s
Unused Capacity	2 %	1.5 %

Having shown the feasibility of the approach it is now possible to investigate all aspects of the system in detail. As a first example for what a more detailed view into the system can be, the progression of the mean C/I and the chosen Phy. Mode for MT 1 and a time of 40 frames (80 ms) is shown (fig. 8).



Fig. 8: Progression of C/I and choice of Phy. Mode

It is e.g. important how many measured values are used for the calculation of the mean values or whether instead the median value should be used for the choice of the Phy. Mode. In the simulations the last 10 measured C/I values were used for the calculation of the mean C/I value. These effects as well as more elaborated link adaptation algorithms and the influence of the traffic source behaviour, scheduling algorithms, realistic ARQ and mobility on system performance can be investigated in the future.

5 Summary and Conclusions

In most approaches when simulating system performance under the influence of interference a high number of radio cells has to be simulated to gain reliable results for the innermost cells. This makes it necessary to use simplified models for the scheduling and the ARQ scheme as otherwise simulation times become too high. In this paper another approach was proposed which applies an iterative process and tries to model all interference as coming from only one interfering radio cell. This leads to a slight difference in the distribution of the interference vs the position in the radio cell but then it is possible to use a detailed model of the scheduling, the ARQ scheme and the collision resolution in each iteration as well as mobility and realistic traffic models. Two scenarios were considered and the feasibility of the new approach was shown analytically and by means of simulations for these two scenarios. The results were compared with previously published results for the same scenarios which were gained with a standard approach and a good resemblance was found. In addition it was shown how further realistic assumptions influence system behaviour and can be investigated with the new approach. The effects of realistic source behaviour and applied scheduling strategy on overhead, throughput and delay can and will be investigated in the future. Furthermore, a realistic ARQ scheme with limited ARQ window size and imperfect performance due to lost acknowledgements has a great impact on retransmission load which can be investigated with the new approach approach. The system performance is also influenced by how the measured C/I values are averaged, over how long time they are averaged, and what limits of the averaged C/I values and strategies are applied for the change of Phy. Mode. These effects can and will be investigated with the new approach in the near future.

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7 **Biographies**

Jürgen Rapp received his Dipl.-Ing. degree in electrical engineering in 1995. Since 1996 he is working as research assistant at the chair of communication networks at Aachen University of Technology. His main research interests are protocols of communication networks especially MAC and LLC protocols taking into account the interaction with TCP/IP.