Hiperlan/2 System Throughput and QOS with Interference Improving Strategies

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Abstract

There is a growing demand for bandwidth as well as mobility. Within ETSI BRAN a wireless LAN called HIPERLAN/2 has been standardized. While data rates can be as high as 54 Mbit/s for a high carrier to interferer ratio (C/I), more robust combinations of modulation and code-rate have to be used and also retransmissions do occur when interference is present. This leads to much smaller effective data rates. Interference and link adaptation are therefore important topics. In order to have a realistic co-channel interference, two radio cells are implemented which interact with each other. In both radio cells detailed implementations of the protocols are used. Data transmission between the terminals is carried out via TCP/IP. In this paper it is shown how throughput as well as delay can be improved in low and medium load conditions by reducing co-channel interference and more importantly reducing the variations in the interference situation which significantly increases the effectiveness of link adaptation.

1 Introduction

There is a growing demand for bandwidth as well as mobility which led to several research projects which are investigating high speed wireless LANs. Within ETSI BRAN a wireless LAN called HIPERLAN/2 has been standardized which operates in the 5–6 GHz band. It can be used in combination with e.g. ATM or TCP/IP and as part of UMTS.

Within HIPERLAN/2 the modulation and code rate are adapted to the conditions of the radio link. With seven different combinations of modulation and code-rate (=Phy. Mode), data rates from 6 Mbit/s to 54 Mbit/s with different requirements on the C/I and different resilience against transmission errors are possible [2]. HIPERLAN/2 is a cellular system with frames of a fixed length of 2 ms. A frame starts with a Broadcast Channel (BCH) followed by a downlink- and uplink phase and the Random Channel (RCH). HIPERLAN/2 uses Time Division Duplex (TDD) and Time Division Multiple Access (TDMA). An Access Point (AP) serves as central controller. It decides every frame anew when a wireless terminal shall receive and when it shall transmit and which Phy. Modes shall be used for transmission.

2 Goal of this work

While data rates can be as high as 54 Mbit/s for high C/I values (>30dB), more robust Phy. Modes have to be used when interference is present. Also more retransmissions do occur if interference becomes higher. This leads to much smaller effective data rates. Therefore, interference and link adaptation are important topics. In this paper an approach is presented which can improve the interference situation and, most importantly, which can make link adaptation more effective.

3 Improving the interference situation and effectiveness of link adaptation

In low and medium load conditions not all the frame is used for transmission. These silent periods can be exploited to reduce the interference in co-channel radio cells and to make link adaptation easier. Unfortunately, most traffic in LANs is data traffic which is transmitted via TCP/IP. Investigations have shown that this traffic is quite bursty in nature, especially considering WWW or FTP traffic [1]. The burstiness of the data leads to strong variations in the lengths of the silent periods. In low and medium load conditions, there are many frames which are completely filled and also many frames which are almost empty. In fig. 1 the cumulative distribution function for the duration of the silent periods is shown for the approach which does not limit the burstiness of transmission. This approach is called Normal Burstiness (NB) in the following. It can be seen that 45% of the silent periods have a duration smaller than 0.1 ms. This shows that many frames are almost completely filled. The rest of the silent periods has a duration between 0.1 ms and 1.83 ms. Since BCH and RCH are present in every frame, the duration of the silent period can not become longer than 1.83 ms in this scenario. 65% of the silent periods have a duration below 1 ms which means that only 20% have a duration between 0.1 ms and 1 ms. The standard deviation for the duration of the silent periods is 0.62 ms. The strong variations of the silent periods mean also strong variations in the interference situation for the co-channel radio cells which makes link adaptation difficult. For link adaptation it is fortunate if the interference situation that is measured now equals the interference in the future. Link adaptation works best for a slowly changing and predictable interference situation.

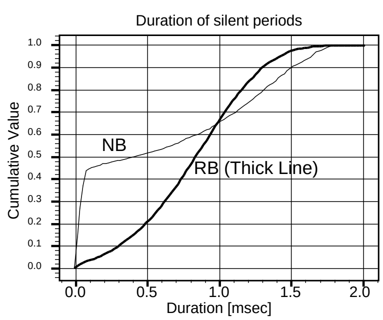

Figure 1. CDF of duration of silent periods

The burstiness in the interference situation is reduced with the following approach which will be called Reduced Burstiness (RB) in the following. Even if big TCP segments arrive at the AP, the scheduler does not permit one terminal to use the whole frame even if the current system load would allow this. Instead every terminal is allowed to use a certain percentage of the frame at maximum. This percentage depends on the number of active terminals and their expected mean load. It is chosen in a way that no terminal can use the whole frame by its own but that all active terminals together can fill the whole frame. By limiting the percentage of a frame that can be used by one terminal the burstiness of transmission is reduced. Even if no other active terminal has something to transmit not the whole frame is used by this terminal but the data is transmitted in some consecutive frames. This implies two things: First of all some silent period remains in most frames in low and medium load conditions. The length of the silent periods does not vary as much as without this approach and can be used to reduce the interference in co-channel radio cells and to make prediction of the interference situation for link adaptation easier. Secondly, transmission of data in low load conditions seems to take longer since it is transmitted in consecutive frames. But this is only true if the influence of interference is not considered. In the results presented in this paper it will be shown that delay and throughput instead are improved when using this approach.

With RB, the duration of the silent periods is almost equally distributed between 0 ms and the maximum length of the silent periods (Fig.1). The standard deviation for the duration of the silent periods is reduced to only 0.38 ms. These results were obtained for a load that led to a mean frame usage of 60% which means that in average 60% of the frame were used.

Furthermore, several placements of the silent period will be investigated (Fig.2):

- The silent period is divided by the number of scheduled terminals. An equal duration of the silent period is inserted before every scheduled PDU train (Equal Silent Period Placement (*ESP*)).
- The silent period is inserted as one piece before the BCH in both co-channel radio cells (Symmetric Silent Period Placement (*SSP*)).
- The silent period is inserted as one piece before the BCH in one radio cell and after the BCH in the co-channel radio cell (Asymmetric Silent Period Placement (*ASP*)).

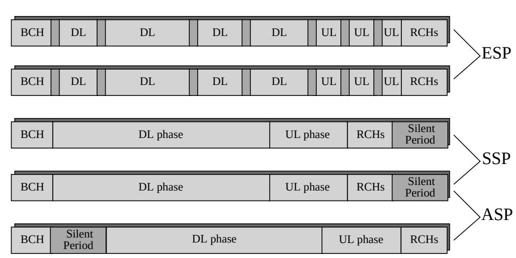

Figure 2. Different placements of the silent periods

In the following it will be shown that the reduction of the burstiness of transmission leads to a more predictable interference situation which improves overall throughput and delay. Furthermore, it will be shown how an intelligent placement of the silent periods in the frame is necessary to achieve improved throughput and delay.

4 Scenario and simulation environment

In this paper the following scenario is considered. It consists of a big exhibition hall with 16 APs and a site to site distance of 62.5m. There are 8 frequencies available which means that one frequency is used by two APs. Per radio cell, 10 active Mobile Terminals (MTs) are moving around with a speed of 3 km/h. Each active MT sustains a bidirectional connection with the AP. 75% of the generated user load is in downlink direction and 25% is in uplink direction. The attenuation of signals is calculated via the following one slope model for LOS propagation in indoor large open spaces:

$$L_d[dB] = 46.7 + 24 \cdot log(distance/1m) \qquad (1)$$

Adjacent channel suppression is assumed to be so high that adjacent channel interference can be neglected. 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, log-normal fading with a standard deviation of 7 dB is added in order to model shadowing caused by e.g. people moving around. A model which was proposed in [6] is applied. It uses the following correlation function with a decorrelation length d_{corr} of 3.5 m [5]:

$$R(\triangle x) = e^{-\frac{|\triangle x|}{d_{corr}} \cdot ln2} \qquad (2)$$

According to files generated out of link level simulations [7] 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 and the MTs store the last N C/I values of every connection. These values constitute the basis for the decision which Phy. Mode is used.

5 Modelling of co-channel interference

In order to have a realistic co-channel interference, two radio cells are implemented which interact with each other. In both radio cells detailed implementations of the protocols for AP and MTs are used. The sources generate data which is transmitted via TCP/IP between the terminals. In the convergence layer the TCP segments are segmented to fit into User-PDUs (U-PDUs) [3]. The U-PDUs are then transmitted via the wireless link. An Selective Repeat ARQ scheme with bitmap acknowledgements is implemented in detail as described in [4] with a limited ARQ window size (128 in the presented simulations). The collision resolution is implemented in detail as described in [4].

No simplifications are made with respect to the described protocols.

6 Results

With the scenario described above, simulations are carried out to evaluate the approach described above.

What influence the usage of RB has on the retransmission load is shown in fig. 3. The diagram shows the retransmission load for NB and RB and it can be seen that retransmission load is significantly lower if RB is applied. This has mainly to do with less variations in the interference situation and that link adaptation can work much more effectively under such conditions. This will be shown later (cf. fig. 5 and corresponding explanations).

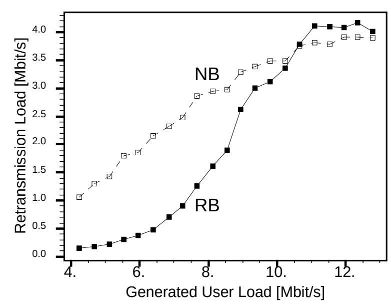

Figure 3. Retransmission load for RB and NB

It has been shown that by limiting the percentage of the frame that can be used by one terminal, the variation in the duration of the silent periods can be reduced and also retransmission load is significantly reduced. It will now be shown which influence the placement of the silent period has.

The following diagrams (Fig.4 to fig.6) show the retransmission load and the cumulative distribution function of the C/I as well as TCP segments delay for the three different placements of the silent period. In all presented results RB is used. In the diagram showing the retransmission load, the generated user load refers to pure user data *without any overhead*. Due to TCP timeouts, segment retransmissions do occur and due to duplicate TCP acknowledgements, fast segment retransmissions do occur, which are not counted as generated load. Also, no TCP/IP, convergence layer or HIPERLAN/2 overhead was included in the generated user load.

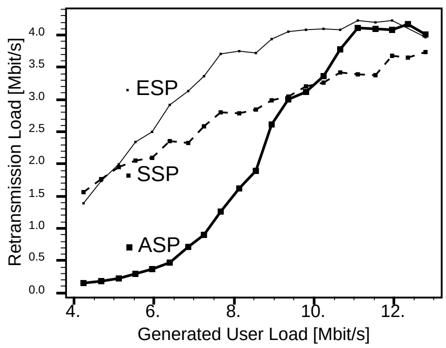

Figure 4. Retransmission load for RB with ASP, SSP and ESP

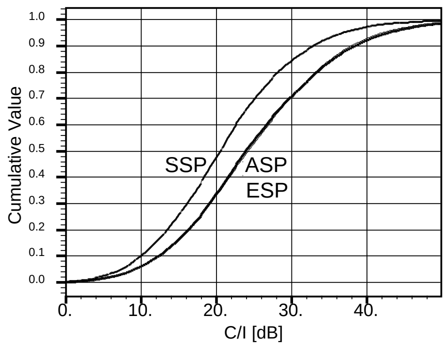

Figure 5. CDF of C/I for RB with ASP, SSP and ESP

It can be seen that ASP has by far the best performance with respect to retransmission load and delay. Taking a look at the C/I cumulative distribution function (Fig. 5), it can be seen that the much lower retransmission load does not result from lower interference only. While ASP and ESP have almost identical C/I distributions (no difference is visible in the diagram), the difference in the retransmission load between them is significant. This is due to the fact that with ASP the interference situation is less variable than with ESP and link adaptation can work much more effective. This can be explained by the following. The C/I is counted on a PDU basis. For every transmitted PDU the C/I value is measured in the simulations and counted in the C/I distribution function. With ESP, only short silent periods are inserted before the scheduled trains. For the co-channel radio cell this means that in a PDU burst, there may be some PDUs that overlap with the silent period in the co-channel radio cell and there are other PDUs of the same PDU burst that overlap with transmissions in the co-channel radio cell. This means that in one PDU burst belonging to one connection there are PDUs which have a high C/I value and other which have a lower C/I value. This is a difficult situation for the link adaptation to cope with since there is no optimal Phy. Mode for this situation. If a too high Phy. Mode is used, many retransmissions do occur. If a too robust Phy. Mode is used, transmission capacity is wasted. With ASP there exists only one long silent period. In the co-channel radio cell will be some PDU bursts which overlap completely with the silent period and others which do not overlap with the silent period at all. Then the PDUs of a PDU burst have either a high or a low C/I value. While the number of PDUs that overlap with the silent period in the co-channel radio cell is almost the same for ASP and ESP (leading to an almost identical C/I distribution), link adaptation can work much more effectively with the situation produced by ASP.

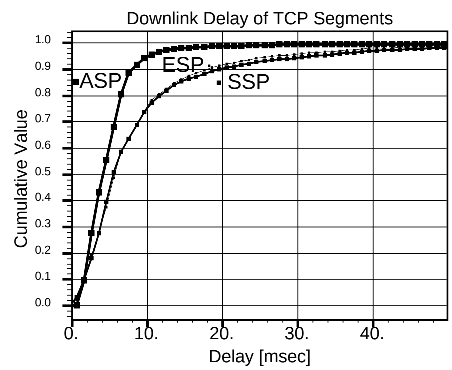

Figure 6. CDF of downlink delay of TCP segments for RB with ASP, SSP and ESP

For a frame usage of 60%, which equals a generated user load of 6.4 Mbit/s, up- and downlink delay performance of ASP is significantly better than with the other approaches. In uplink direction the values are similar. For higher load values all approaches show almost the same performance since then the silent periods become too short to have a significant impact on system performance.

In the results presented it is assumed that the the frames of the two APs are synchronised. The AP that becomes active secondly with the same frequency might deduce the position of the BCH and the placement of the silent periods in the co-channel radio cell e.g. by measurements carried out. Even if it is not possible to have synchronised frames, delay and throughput will be improved with RB and an intelligent placement of the silent periods. While the offset of the frames between the radio cells is fixed during the whole lifetime of the AP once the AP has become active, the placement of the silent periods can be decided independently of any other conditions and at any instant. This makes it possible to adjust the placement of the silent periods according to the offset between the frames of the radio cells and the placement of the silent period in the other radio cell. In fig. 7 the retransmission load for different offsets between the frames of two co-channel radio cells is shown.

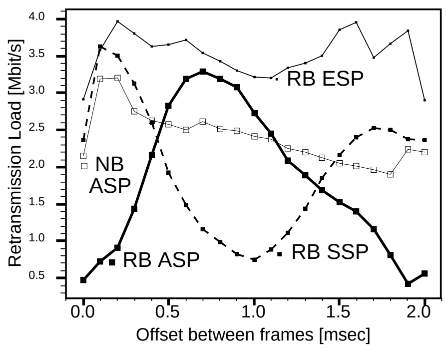

Figure 7. Retransmission load for different offsets between the frames of two co-channel radio cells

It can be seen that without an offset (0 ms offset or 2 ms offset) RB with ASP shows the best results. For an offset of 1 ms lowest retransmission load is obtained for RB and SSP. Due to the different offsets, ASP for 0 ms offset results in almost the same asymmetric placement of the silent periods as SSP for 1 ms offset. The situation is not completely the same since other parts of the frames do overlap (downlink with downlink or downlink with uplink etc.) but the important thing is that with RB, long silence periods in one piece are used and they do not overlap with each other. This reduces the variability of the interference situation and makes link adaptation much more effective as has been shown above. It can also be seen that ESP has always worse performance than ASP or SSP which already has been explained by the higher variability in the interference situation which makes link adaptation much more difficult (cf. fig. 5 and corresponding explanations). The importance to apply RB is also underlined. RB with an intelligent placement of the silent periods as described above is always significantly better than NB. Results for NB are only shown for ASP but are similar for SSP and ESP.

7 Summary and conclusion

In a HIPERLAN/2 system with co-channel interference, interference and link adaptation are important topics. In order to have a realistic co-channel interference, two radio cells are implemented which interact with each other. In both radio cells detailed implementations of the protocols for AP and MTs are used. Data transmission between the terminals is carried out via TCP/IP.

It has been shown that co-channel interference can be reduced and link adaptation can become more effective in low and medium load conditions. This is done by limiting the burstiness of transmissions and an asymmetric placement of the silent periods in two co-channel radio cells. It has also been shown that the approach works for all offsets between two co-channel radio cells.

The reduction of interference has an impact on throughput and delay but the most important point is that with the presented approach the interference situation is less variable and link adaptation can work much more effectively. This leads to a much lower retransmission load and significantly reduced delay. It is then possible to have much smaller delays for a given load value or respectively a higher throughput for a given delay requirement.

Furthermore, as an outlook, it is possible to improve the situation for delay sensitive connections which must not suffer any or many retransmissions. This can be done by the above described approach and scheduling delay sensitive connections in parts of the frame where interference will be usually lower than in other parts of the frame. In the future it will also be investigated how this approach can be used if several co-channel interferers are present.

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