Increasing Throughput and QoS in a HIPERLAN/2 System with Co-Channel Interference

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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 respectively UDP. In this paper it is shown how throughput as well as delay can be improved in all load conditions by reducing co-channel interference and 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 [1]. 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 (DL)- and uplink (UL)- phase and the Random Channel (RCH). HIPERLAN/2 uses Time Division Duplex (TDD) and Time Division Multiple Access (TDMA). In the centralized mode 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 several approaches are presented which can improve the interference situation and which can make link adaptation more effective. First, one approach is described which works under low and medium load conditions. Then it is shown how this approach can be used to improve the situation especially for delay sensitive connections. Finally, an approach is presented which works under all load conditions. It improves system performance if the first mentioned approaches are not used and increases system performance even more if the above mentioned approaches are used.

2.1 Improving the Interference Situation and Effectiveness of Link Adaptation in low and medium Load Conditions

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 [2]. The burstiness of the data leads to strong variations in the lengths of the silent periods. Thus, in low and medium load conditions, there are many frames which are completely filled and also many frames which are almost empty. 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.

In [3] it has been shown that the burstiness in the interference situation is reduced with an approach called Reduced Burstiness (RB). 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. This is shown in Fig. 1 where the duration of the silent periods is shown for RB and the approach that does not limit the burstiness of transmission (Normal Burstiness (NB)).

With RB, the duration of the silent periods is almost equally distributed between 0 ms and the maximum length of the silent periods (see Fig. 1). Since BCH and RCH are present in every frame, the duration of the silent period can

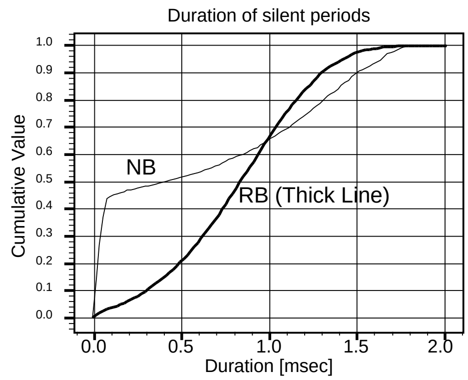

Fig. 1. CDF of duration of silent periods

not become longer than 1.83 ms in this scenario. The standard deviation for the duration of the silent periods is reduced from 0.62 ms 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.

In [3] it has also been shown that with RB the retransmission load is significantly reduced compared to NB. Thus, RB achieves a higher throughput for a given delay requirement or a smaller delay for a given throughput.

Furthermore, it was shown that an intelligent placement of the silent periods is necessary to increase throughput and QoS. Several placements of the silent period were investigated (see 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 burst (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*)).

Since the position of the silent periods can be chosen without any restrictions on a frame per frame basis, the above describe approach works for all offsets which can occur between the frames of two co-channel radio cells [3].

2.2 Improving the Interference Situation for Delay Critical Connections in low and medium Load Conditions

In this paper it will be shown that with RB and an intelligent placement of the silent periods it is possible to improve the situation especially 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

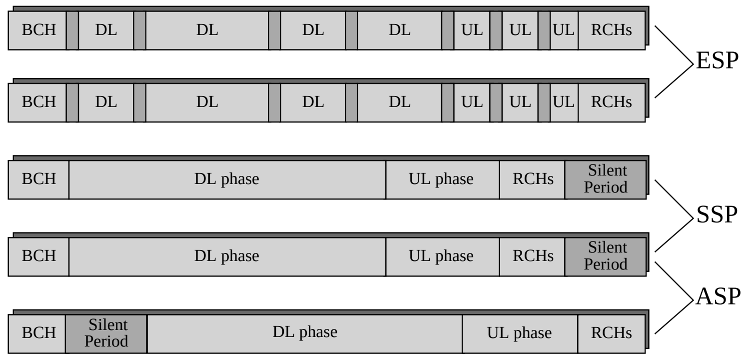

Fig. 2. Different placements of the silent periods

parts of the frame where interference will be usually lower than in other parts of the frame. In order to reduce the interference in certain areas of up- *and* downlink in *both* radio cells, a different version of ASP was used. It is called ASP-Both Links Improved (ASP-BLI) and it's structure is shown in Fig. 3. The most delay critical connections can be transmitted in the areas where interference will be usually lower than in other areas.

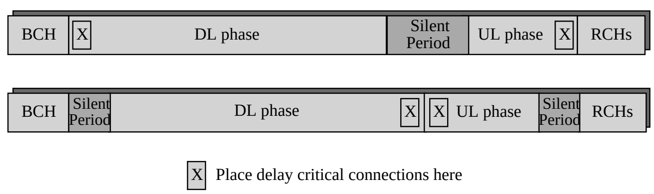

Fig. 3. Placement of the silent periods with ASP-BLI

Please notice that the length of the unused capacity, the length of the downlink and uplink phase and the length of the BCH varies from frame to frame. Nevertheless it will be shown that with this approach it is possible to significantly improve the situation for delay critical connections in *both* radio cells and for *both* up- and downlink.

2.3 Further Improvement of the Interference Situation and Effectiveness of Link Adaptation for all Approaches in all Load Conditions

The above described approaches work well under low and medium load conditions. For higher load values their effect becomes very small since they depend on the existence of unused capacity in the frame. Now another approach will be presented which works under all load conditions. It can be used in combination with the above described approaches or without them. If it is used together with the above described approaches it leads to a further improvement of system performance.

In [3] it was shown that the effectiveness of LA is increased if the interference situation becomes less varying. This is also tried to achieve with the following approach. It is called Maximum Similarity (MSI) and tries to achieve as much likeliness between consecutive frames in a radio cell as is possible. If consecutive frames in one radio are similar, then also the interference situation for neighbour radio cells is similar. This means also that the interference situation is less varying. To achieve this goal the following simple steps have to be performed. The scheduler stores the start and the end of its own transmissions in a frame. In the next frame, after the scheduling has been performed, an additional step is inserted. Within the DL phase and also within the UL phase the order of transmission of the scheduled PDU bursts can be chosen without any restrictions. The scheduler tries to find the order of transmission in the DL phase as well as in the UL phase that gives the most resemblance to its previous frame. In the current implementation it does this by brute force. It calculates all possible permutations of the transmission order of the scheduled bursts and calculates a measure for the resemblance between the frames.

The transmission order is chosen which gives the highest resemblance to its previous frame. This ensures that the interference situation varies as little as possible.

In Fig. 4 an example for the unsorted transmission order and for the transmission order with MSI is given. They have been extracted out of one of the simulations performed. On behalf of a clear representation only the downlink phase is shown but the same behaviour applies for the uplink phase.

Please notice that the scheduling is performed as given by any possible algorithm. Only after the scheduling has been performed, does the scheduler try to find the transmission order that gives the maximum similarity between the frames.

3 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 62.5 m. There are 8 frequencies available which means that one frequency is used by two APs. Per radio cell, a number of active Mobile Terminals (MTs) are moving around with a speed of 3 km/h. Each active MT sustains a bi-directional connection with the AP. In a TCP connection, 75% of the generated user load is in downlink direction and 25% is in uplink direction. In a UDP connection, 50% of the generated user load is in downlink direction and in uplink direction each.

The attenuation of signals is calculated via the following one slope model for LOS propagation in indoor large open spaces:

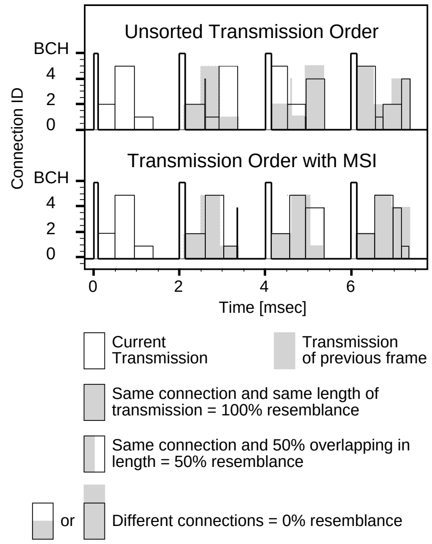

Fig. 4. Comparison between unsorted transmission order and transmission order with MSI

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

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 [4] 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 [6] 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 for the link adaptation. 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.

4 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 respectively UDP between the terminals. In the convergence layer the TCP or UDP segments are segmented to fit into User-PDUs (U-PDUs). 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 [7] with a limited ARQ window size (128 in the presented simulations). The collision resolution for the RCH is implemented in detail as described in [7]. The scheduling of acknowledgements and data is performed in every frame on PDU basis.

No simplifications are made with respect to the described protocols.

5 Results

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

In order to show how much the delay for delay critical connections can be improved with RB and ASP-BLI and placing the delay critical connections in an area of the frame where interference will usually be lower than in other areas of the frame the following scenario was used. It consists of the above described scenario with a mix of UDP and TCP connections. There are 10 active bi-directional connections per radio cell. 12% of the load are generated by the UDP sources and 88% by the TCP sources. In average 55% of the frame are used.

In Fig. 5 and Fig. 6 the delay for the UDP connections is shown for RB with ASP-BLI and ESP. Although the length of the unused capacity, the length of the downlink and uplink phase and the length of the BCH varies from frame to frame it can be seen that ASP-BLI significantly improves the situation for delay critical connections. Down- and uplink delay are significantly better for ASP-BLI than for ESP. The improvement of the delay performance is stronger in the uplink direction than in downlink direction. If PDUs get lost in uplink direction, the MT has to inform the AP first about additional capacity requests before they can be transmitted. This leads to a further increase of the delay if PDUs get lost. Thus it is very important to reduce the number of retransmissions especially in uplink direction if delay critical connections are concerned. Results are only shown for one radio cell but they are very much the same for the other radio cell.

The following scenario is used to show the influence of MSI on system performance. It consists of 5 active bi-directional TCP connections per radio cell. 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.

In Fig. 8 it can be seen that MSI significantly reduces the retransmission load for ASP. In order not to overload Fig. 8 the curves for SSP-MSI and ESP-MSI are not shown. The relative improvement of MSI for SSP is similar to that of ASP. For ESP the improvement with MSI is very small and hardly visible. This is due

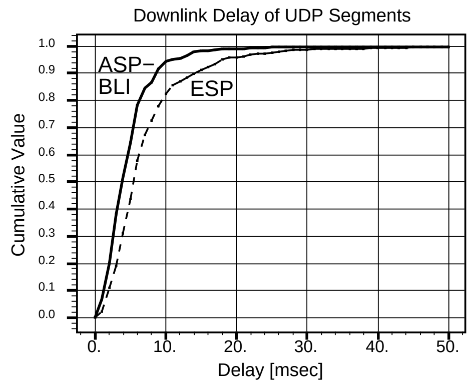

Fig. 5. CDF of downlink delay of UDP segments for RB with ASP-BLI and ESP

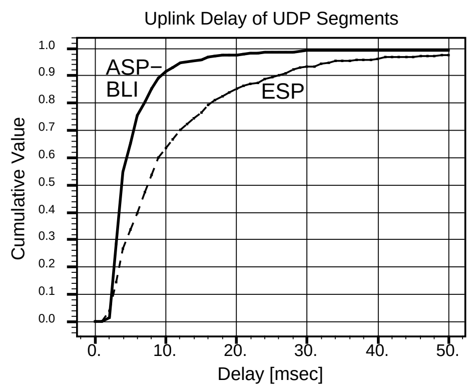

Fig. 6. CDF of uplink delay of UDP segments for RB with ASP-BLI and ESP

to the fact that ESP leads to a high variance in the interference situation. Taking a look at the C/I cumulative distribution function (see Fig. 7), it can be seen that ASP and ESP have almost identical C/I distributions (no difference is visible in the diagram), but 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 bursts. 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 others 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. This behaviour of ESP makes it impossible for MSI to gain much improvement since the variance in the interference situation produced by ESP is too dominating.

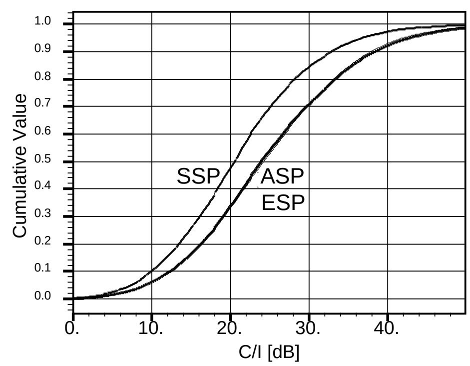

Fig. 7. CDF of C/I for RB with ASP, SSP and ESP

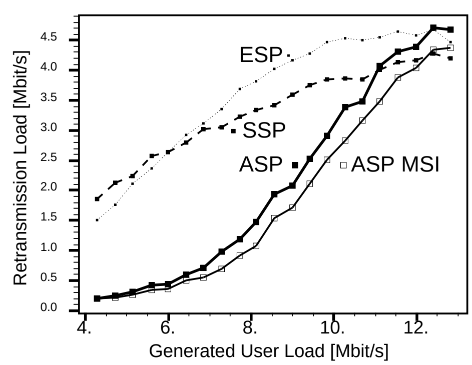

Fig. 8. Retransmission Load for RB and several placements of the silent periods (with and without MSI)

6 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 and UDP.

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. With a modified asymmetric placement of the silent periods it is possible to improve the interference situation in certain areas of the frame for *both* up- and downlink and in *both* co-channel radio cells. This improvement can be exploited to significantly reduce the delay of delay critical connections which can be scheduled in areas of the frame where interference will be usually lower than in other areas of the frame. These approaches work well for low and medium load conditions but their effect becomes very small in higher load conditions since they depend on the existence of unused capacity in the frame. Another approach was presented which works under all load conditions. With an easy algorithm and independent of any other conditions it optimizes the similarity between consecutive frames in one radio cell. If consecutive frames in one radio cell are similar so is the interference situation for co-channel radio cells. It has been shown that it is possible to significantly reduce the retransmission load under all load conditions if this approach is applied. In this paper an ideal measurement of the C/I values is assumed for the link adaptation. In the future the effect of the described approaches will be investigated for a realistic link adaptation and actual available measures for the radio link quality.

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