JOINT LAYER OPTIMIZATION FOR OFDM BASED RADIO SYSTEMS

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Abstract - The objective of this paper is the design of a joint layer approach in a mobile communication system, which should outperform the conventional layered model such as ISO/OSI reference model. The two lowest layers: **D**ata **L**ink **C**ontrol (*DLC*) and **PHY**sical (*PHY*) layer are taken as an example. Simulation results show that the joint layer approach with the flexible **O**rthogonal **F**requency **D**ivision **M**ultiplexing (*OFDM*) transmission technique and an intelligent resource allocation policy can increase the bandwidth efficiency and better fulfill the end-user **Q**uality-**o**f-**S**ervice (*QoS*) requirements.

I. INTRODUCTION

As the people begin to design a communication system, they recognize that it is a highly complicated task. The development of one standard for the entire system seems to be impossible. A reasonable solution is to divide the whole system into several sub-systems and design the sub-systems independently of each other. The well-known ISO/OSI reference model [1], which is created by the International Organization for Standardization (ISO), is one of these approaches and consists of seven sub-systems (layers): Application, Presentation, Session, Transport, Network, Data-Link and Physical layer. In this hierarchical system, each layer, except the top-layer, provides services to the layer above and uses the services from the layer below (except the bottom layer).

The independent design of each layer was one the major advantages of the ISO/OSI layered model, because of the feasibility and the relative simplicity of the development of the protocols in each layer. But in a modern communication system, this former advantage prevents further improvement of the system performance due to the following reasons:

- The end-user QoS, which is highly heterogeneous and should be guaranteed in a modern mobile communication system, is defined in the top-layer. In the conventional layered model, these QoS requirements of the application layer cannot be well transferred and implemented in the physical layer because of the information loss in the other layers.
- The protocol of one layer is just designed in order to provide services for its direct upper layer, the status in the underlying layers and in the physical channels are never taken into consideration. This strategy, which is limited due to the hierarchical model, cannot be feasible in a mobile communication system, where the mobile channel is highly time variant and frequency selective.

As an answer to the mentioned problems the information exchanges of one layer with other layers and the physical channels must be enhanced. The protocol for one layer should not be developed independently of the other layers and the physical channels. A joint optimization of the layers should be carried out. Of course these information exchanges should be kept to a necessary minimum, unless the communication will be slowed down.

II. JOINT LAYER OPTIMIZATION FOR THE EXAMPLE OF DLC AND PHY LAYER

In this paper, the joint layer optimization is explained for the example of the two lowest layers: the DLC and PHY layer. The main task of the DLC layer is the allocation of the scarce radio resources to the different **W**ireless **T**erminals (*WT*). The potentially highly heterogeneous QoS requirements, i.e. different throughput, delay and reliability, should be guaranteed. In contrast to a protocol in the conventional layered model, which just gets control information from the direct upper layer and provides services to this layer, a protocol in the new joint layer approach makes also use of the QoS informations of the application layer and even the transmission parameters in the PHY layer and the channel state reports from the mobile channels. In this way, the dynamic of the mobile channels and the data sources can be fully exploited and an intelligent allocation of the radio resources can be performed. This joint optimization approach is illustrated in the figure 1. For the PHY layer, the OFDM transmission technique [2] is applied due to its strong performance and its flexibility. The system parameters can be adjusted and adapted in the light of different service requirements.

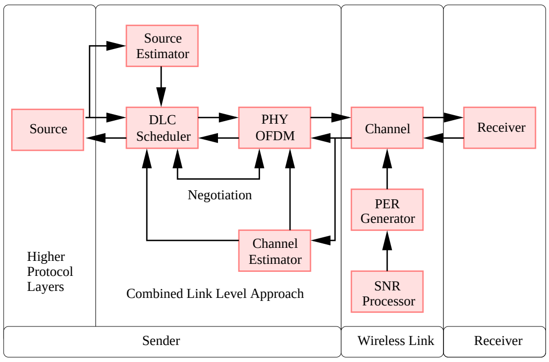

Fig. 1. Transmission chain for combined optimization of DLC and PHY layer

III. PROTOCOL WITH OR WITHOUT JOINT LAYER DESIGN

A cellular radio network with a single Access Point (AP) and several WTs in each cell is considered (see Fig. 2). All WTs communicate with the central AP, whose coverage defines the cell boundaries. The analyzed protocols are based on a single cell environment. The OFDM transmission technique combined with a TDMA scheme and with the focus of the downlink situation are assumed for the investigation. MPEG-4 encoded real time video data [3], which belongs to the major and more complicated applications for 3G and 4G wireless systems, are transmitted between the AP and the WTs.

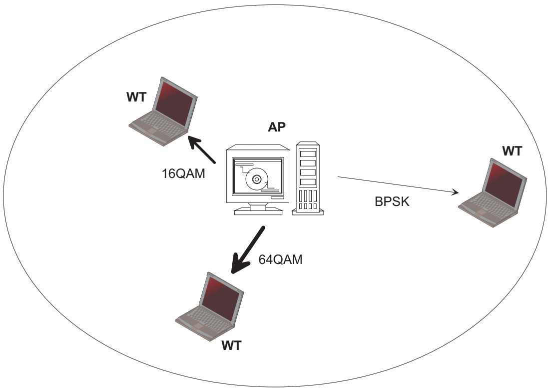

Fig. 2. A single radio cell, where a link adaptation technique is applied

In the AP, video segments (= video frames) with the same time duration of 40 ms and different lengths (variable data rate) are passed to the DLC layer (see Fig. 3). MAC frames are organized in the DLC layer in a similar way as in the HIPERLAN/2 [4] standard. These segments are split up into so called DPDUs in the DLC layer. All DPDUs have the same length. In order to map the DPDUs onto the MAC frame according to the HIPERLAN/2 standard, the length of the DPDU is set to be the same as the LCH length (Long Transport Channel, 54 Byte). After a scheduling using different policies, a dynamic allocation of the DPDUs inside the MAC frame is realized. The dynamic scheduling policy is the main part of the protocol in the combined DLC and PHY layer approach.

Delay, delay jitter, reliability and throughput are the QoS requirements, which should be satisfied for real time transmission services. To guarantee a limited packet error rate (reliability), a so-called link adaptation technique can be applied. It means that the PHY mode (a combination of modulation scheme and coding rate), chosen for the transmission to the WT, is adapted to the current radio link quality between the AP and this WT, according to the HIPERLAN/2 standard [5] (see Fig. 2). The maximal allowed Packet Error Rate (PER) for MPEG-4 encoded real time video (10^{-2}) is taken as a criterion for the link adaptation. Video segments should be discarded if they cannot be transmitted completely within 40 ms in order to satisfy the delay requirement. In the scheduling policies introduced below, delay jitter and throughput of the WTs are guaranteed in different ways.

For the OFDM-TDMA system, two different scheduling policies are analyzed compared with the reference scheduling policy, **R**ound-**R**obin (*RR*) [6]. In RR, the Round-Robin-Principle is taken as the scheduling method. Data for the WTs are transmitted in a fixed sequence (such as WT 1, WT 2, ...). The AP does not care about the QoS requirements of the WTs and needs no channel state information. The Round-Robin-Principle is the oldest scheduling principle. The disadvantages of this principle are that on the one hand the QoS requirements of the WTs cannot be satisfied and on the other hand the system throughput cannot be optimized either. Two novel scheduling policies are introduced in the following subsections: Shortest-Queue (*SQ*) and Shortest-Transmission-Time (*STT*).

A. Protocal without joint layer design: SQ

The general design goals for the scheduling policies are clear: a low segment discarding rate, a low delay jitter and a high system throughput. In the first introduced scheduling policy, namely SQ policy, these design goals are realized as follows. The input queues of all WTs are checked for each MAC frame, the WT with the shortest queue length will get the preference to transmit its data, because this WT has the smallest amount of data and it is expected that it needs the smallest portion of the MAC frame, so that the delays for other WTs can be kept small. The mathematical expression for this scheduling policy is shown in the following:

$$\begin{aligned} if\ \ l_i < l_j < l_g, &\qquad i,\ j,\ g \in [1, N] \\ sendingsequencing: &\qquad WT\ i, WT\ j\ and\ WT\ g, \end{aligned} \tag{1}$$

where l_i denotes the input queue length of WT i in terms of number of DPDUs and N active WTs exist in this wireless

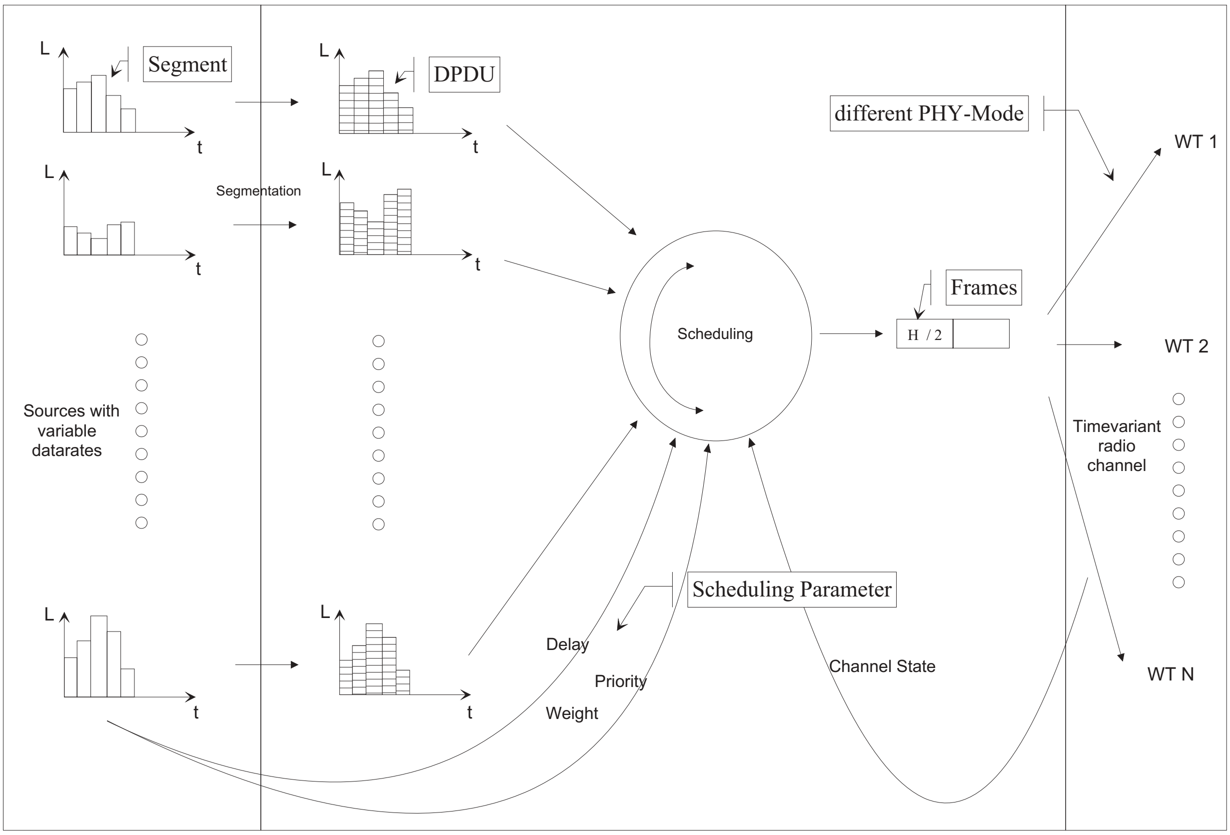

Fig. 3. Radio resource scheduler structure

transmission system.

The principle of this scheduling policy is illustrated in Fig. 4, where clear to see is that the joint layer design is not applied for this scheduling policy and for this protocol.

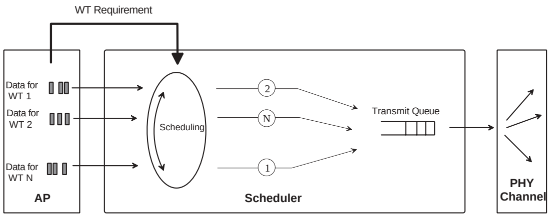

Fig. 4. Concept of the Shortest-Queue policy

In Fig. 5, the scheduling of DPDUs is shown. The first row “input queue” denotes the input queue length of the WTs in terms of number of DPDUs, where the rows below show the transmitted number of DPDUs for each WT in a MAC frame. The shortest queue principle described above is applied for the scheduling of DPDUs. Compared with this figure, Fig. 6 depicts the occupied percentage of a MAC frame for each WT as a consequence of the applied physical modes. From these two figures, it becomes clear, that WTs with a shorter queue length (e.g. $l_2 < l_1$) sometimes need a higher percentage of the MAC frame than WTs with much more data to transmit (e.g. WT 1).

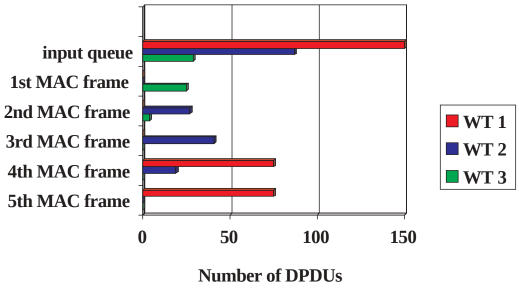

Fig. 5. Example for the scheduling of DPDUs for three different users with the SQ policy

B. *Protocol with joint layer design: STT*

According to the fact that the radio channel is time variant and the link adaptation technique is applied, the actually realized data throughput of the WTs is different. This will be denoted

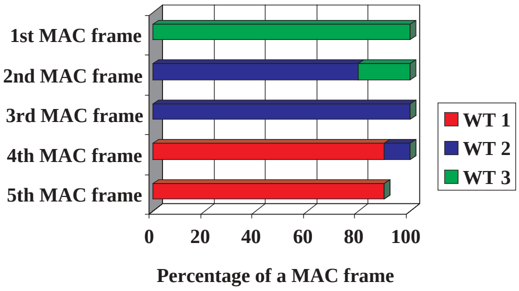

Fig. 6. Example for the occupation of the MAC frames by three different users with SQ policy

in Eqn. 2 as phy_i for the WT i. In this equation, t_i indicates the needed transmission time for the WT i in the current transmission situation and L_{DPDU} denotes the DPDU length in bits. In accordance with the name of this second proposed policy, **S**hortest-**T**ransmission-**T**ime (*STT*) policy, the DLC layer scheduler checks the input queues of all of the active WTs and also the current channel state for each WT, calculates the needed transmission time for the remaining data of the WTs and then gives the preference for transmitting data to the WT with the shortest transmission time. The sending sequence in this scheduling policy cannot be the same as the one in the first introduced scheduling policy due to the different data throughput that can be realized for each WT. This policy should be more efficient than the SQ policy, which can be proven with the simulation results in the next section.

$$\begin{aligned} t_i &= \frac{l_i * L_{DPDU}}{phy_i} \\ if \;\; t_i < t_j < t_g, & \quad i,\ j,\ g \in [1, N] \\ sendingsequencing: & \quad WT\ i, WT\ j\ and\ WT\ g. \end{aligned} \qquad (2)$$

In Fig. 7, it becomes clear that this DLC layer scheduler does not only needs information from the application side (i.e. from the upper layers, as in a conventional DLC scheduler), but also from the physical layer, as it should be in the joint layer approach.

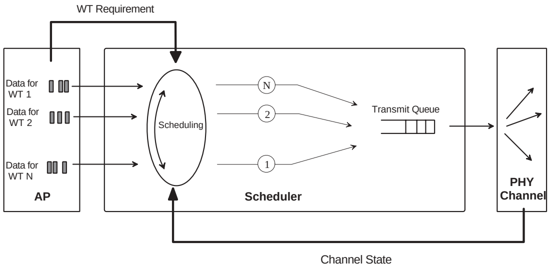

Fig. 7. Concept of the Shortest-Transmission-Time policy

Fig. 8 and 9 show an example of the STT policy for the same three WTs and under the same mobile channel conditions as in the SQ policy. Compared with the Fig. 5 and 6, it is clear to see that a different scheduling is applied in this example. No longer will the data for the WT with the shortest queue length (the WT 3) be transmitted first, but the data for the WT with the shortest transmission time (= shortest MAC frame occupation, WT 2). 70% of one MAC frame channel capacity can be saved for this example with the joint layer approach STT.

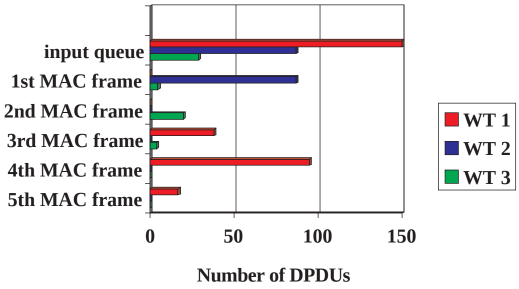

Fig. 8. Example for the scheduling of DPDUs for three different users with the STT policy

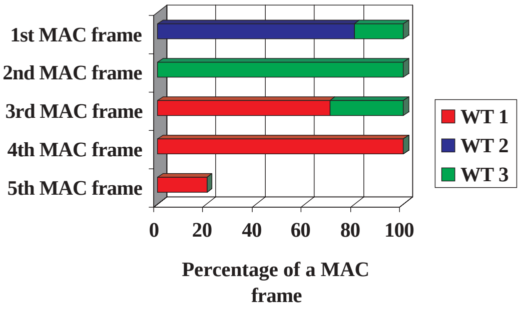

Fig. 9. Example for the occupation of the MAC frames by three different users with STT policy

IV. PERFORMANCE EVALUATION AND COMPARISON OF THE PROTOCOLS

A large open space environment with a cell size of $100\ m$ is investigated for the computer simulations. The AP is placed in the middle of the cell and a **n**on **l**ine **o**f **s**ight (*NLOS*) condition for all WTs is assumed. For each WT, a starting point and an end point are randomly generated. WTs move directly from the starting point to the end point with a fixed velocity of $50\ km/h$. If the end point is reached before the simulation is finished, the WT will remain stationary at the end point. For simulation of the **c**arrier to **N**oise ratio (*C/N*), channel characteristics like path loss, slow fading and fast fading are taken into consideration. For link adaptation purposes, the channel state information is sampled in each MAC frame. This channel state information is assumed here as perfect. Discarding time of the video segment is 40 ms.

For the real time video transmission, delay jitter is a very important QoS parameter beside the segment discarding rate and the data throughput. Delay jitter is defined as follows:

$$j_i = d_i - D_i, \tag{3}$$

where j_i denotes the delay jitter of WT i, d_i is the actual delay of WT i and D_i represents the ideal delay for WT i.

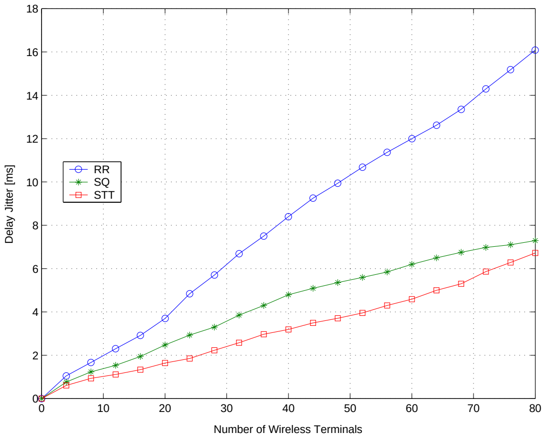

Fig. 10. Delay jitter increases with the increasing number of WTs

The advantages of the joint layer design are shown with the following simulation results. In Fig. 10, the delay jitter of SQ and STT policies is compared to each other and also to the reference policy RR. As expected, delay jitter for the both introduced scheduling policy is much smaller than the RR policy, and the STT policy is more efficient with regard to the delay jitter than the SQ policy. This is because sometimes a WT with a smaller queue length (few data are waiting for the transmission) requires more transmission time for these data due to its poor radio channel state than WT with a larger queue length. With the SQ policy, the data for this WT will be first transmitted, and therefore has a stronger impact on the other WTs. This leads to the fact that the overload situation is reached much earlier in the SQ policy, more data must then be discarded and only a smaller system throughput can be achieved. This effect can be seen in Fig. 11 and 12.

V. CONCLUSIONS

The focus of this paper has been directed towards the joint layer optimization in a wireless communication system. Joint design of DLC and PHY layer is taken as the example where the fully capacity and flexibility of the OFDM transmission technique is exploited and intelligent resource allocation policy is developed. It is proven with the simulation results that a better system performance with regard of the system throughput, delay jitter and segment discarding rate can be achieved. The end-user QoS can be guaranteed in this way.

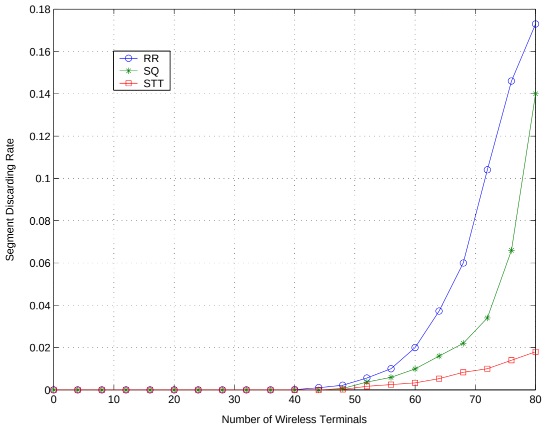

Fig. 11. Segment discarding rate increases with the increasing number of WTs

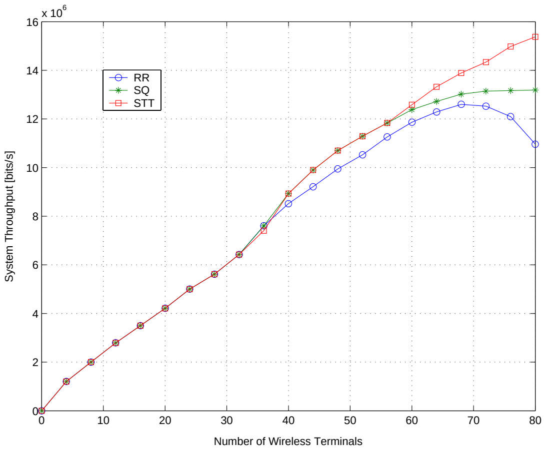

Fig. 12. System throughput increases with the increasing number of WTs

REFERENCES

[1] ISO, *ISO 7498, Basic reference model for Open System Interconnection*, 1983

[2] H. Rohling, T. May, K. Brüninghaus, R. Grünheid, *Broad-Band OFDM Radio Transmission for Multimedia Applications*, Proceedings of the IEEE, Vol. 87, No. 10, Oct 1999.

[3] Frank H.P. Fitzek and Martin Reisslein, *MPEG–4 and H.263 Video Traces for Network Performance Evaluation*, IEEE Network, October 2001.

[4] ETSI TS 101 761-1 V1.2.1, *Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Data Link Control (DLC) layer*, November 2000.

[5] ETSI TS 101 475 V1.1.1, *Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Physical (PHY) layer*, April 2000.

[6] Bing Chen, Frank Fitzek, James Gross, Rainer Grünheid, Hermann Rohling, Adam Wolisz, *Framework for Combined Optimization of DLC and Physical Layer in Mobile OFDM Systems*, 6th International OFDM-Workshop, 2001 Hamburg