Congestion Control for Interworking Wireless Systems

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ABSTRACT

New deployment concepts for next generation networks use fixed wireless routers to provide high capacity and high radio coverage. These fixed wireless routers might be based on heterogeneous interworking standards, e.g. by a dual standard delivery of HiperMAN and HiperLAN/2. Simulations have shown that when either interworking system is running into congestion, capacity is wasted. To align the capacity of an interworking connection to the capacity of the corresponding bottleneck link, a congestion control mechanism is introduced in this paper. It has been designed and specified based on the existing HiperMAN standard and the additional requirements of two interworking wireless systems. Simulation results show that the mechanism can handle the addressed congestion situations. It reduces the unnecessary transmissions and temporarily permits low priority connections to be scheduled. Thus, the overall system performance is optimized.

I. INTRODUCTION

Next generation networks aims at proposing a spectrally efficient broadband access by using interworking networks [1]. In [2] an optimal interworking/bridging mechanism between HiperMAN (HM) and HiperLAN/2 (H/2) has been studied. Several scenarios focusing on an Ethernet-based interworking approach have been configured. The interworking of HM and H/2 has been evaluated by means of traffic performance measures like throughput and delay. It turned out that whenever an interworking HM-H/2 system is running into congestion, capacity is wasted. It does not make a difference if it is the HM or the H/2 system which is facing the congestion situation. If the link capacity in one system is temporarily degraded due to a high traffic load in the system or due to interference, two effects could occur:

1. Loss of data due to buffer overflow and therewith unnecessary retransmissions
2. Waste of bandwidth due to unused reservations

The capacity of the corresponding interworking connection should be aligned with the capacity of the bottleneck link. There is no method defined in neither standard which temporarily adapts the Quality of Service (QoS) parameters dynamically during the connection runtime. In HM the existing MAC dynamic service change (MAC_DSC) mechanism is based on a 3-way message exchange and is therefore slow. In the standard there is no difference between the creation of a connection and the change of the parameters, thus all parameters involved have to be signalled and negotiated by the MAC_DSC mechanism. It is not designed to adapt QoS parameters on a short term basis [3]. The same applies for the H/2 standard. The existing DLC user connection modify (DUC_MODIFY) mechanism is also based on a 3-way exchange. The modification resets data buffers and ARQ respectively flow control states of the access point (AP) and the mobile terminal (MT). It is again like setting up a new connection [4]. In this paper a new congestion control mechanism is proposed to dynamically adapt the QoS demands of a certain connection during runtime. In the HM standard the QoS parameter set which is assigned to a connection is called service flow. It is negotiated by the management system or it is pre-provisioned, i.e. the service flow is downloaded from a management information base. Due to the temporary nature of congestion/interference situations, the mechanism is working on a temporary basis, i.e. an automatic recovery is included. The congestion control mechanism is working on the DLC/MAC layer. Four different congestion situations are imaginable [2]. By means of the proposed service primitives and MAC management messages all four situations can be handled.

The following section II describes the congestion control mechanism like it has been designed and specified. Section III gives a short overview of the simulation environment. Section IV outlines simulation results obtained with the implemented interworking HM-H/2 simulator. It evaluates performance results of different interworking scenarios.

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II. CONGESTION CONTROL MECHANISM

The proposed congestion control mechanism handles interference and congestion situations by means of a fast, dynamic and temporary reduction of a connection's transmission capability. Although such a mechanism is useful in both systems, the presented mechanism has been designed to fit into the HiperMAN standard. The mechanism is invoked by the new MAC service primitive MAC_DSC_TEMP.request. This primitive is generated by the convergence sublayer (CS) to request a temporary reduction of traffic for a downlink or uplink transport connection. Within an interworking scenario the primitive might be invoked directly by the interworking bridge. The parameters of the primitive are as follows:

MAC_DSC_TEMP.request(

SFID	**(mandatory),**
Maximum sustained traffic rate	**(optional),**
Maximum traffic burst	**(optional),**
Minimum reserved traffic rate	**(optional),**
Time indicator	**(mandatory))**

The service flow ID (**SFID**) parameter specifies the transport connection for which the modification is meant. One or more of the traffic parameters specify the **reduced QoS parameter set**. The **time indicator** specifies the duration of the period during which the traffic is reduced. Having received the primitive, the MAC entity reduces the capacity of the indicated connection by changing the corresponding QoS parameters temporarily for the specified duration. The requestor MAC sends the management message DSC-TEMP to the corresponding MAC entity. The requestor MAC can directly invoke the mechanism by sending the DSC-TEMP message without being triggered by the CS if it detects the congestion situation itself. Since only the base station (BS) is the controlling device which is able to allocate bandwidth, two cases have to be considered. If the DSC-TEMP management message is sent by a subscriber station (SS) to a BS, it requests the temporary traffic reduction of a transport connection. If the message is sent by a BS to an SS, it indicates the temporary reduction. The format of the message is shown in Table 1.

Management Message Type	8 bit	set to 19
SFID	32 bit	
Reduction duration	16 bit	in ms
TLV encoded information	variable	TLV specific

Table 1: DSC_TEMP management message format

The connection identifier (**CID**) in the MAC header is set to the SS's CID. The service flow identifier (**SFID**) which uniquely specifies the concerned service flow (address of the connection) is mandatory. Finally the **reduction duration** (0…65535ms) of the requested downgrade is given. When the duration ends the service flow is upgraded without signalling. By sending a duration of 0 ms, the traffic reduction can be cancelled ahead of schedule. All service flow parameters are coded as type length value (**TLV**) tuples formatted according to ITU-T X.690. These parameters specify the service flow's temporary, i.e. downgraded traffic characteristics.

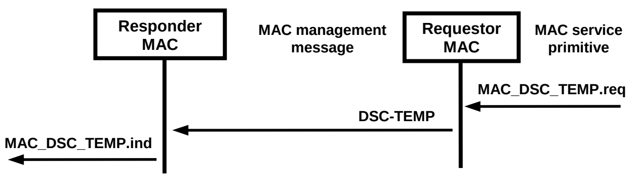

Figure 1: MAC event sequence stimulated by CS

The primitive MAC_DSC_TEMP.indication indicates the temporary reduction of the corresponding downlink or uplink transport connection by the MAC layer to the CS. The parameters and the format of the primitive are the same as in MAC_DSC_TEMP.request. The message is generated when the MAC entity receives a DSC-TEMP message. Assuming the MAC entity itself has detected the congestion, it sends out the DSC-TEMP message to the partner MAC instance and informs its CS with the indication primitive. The sequence of logical MAC service access point events and the associated actual MAC events effecting a CS stimulated temporary traffic reduction are shown in Figure 1. The state transition diagram for the proposed congestion control mechanism can be seen in Figure 2.

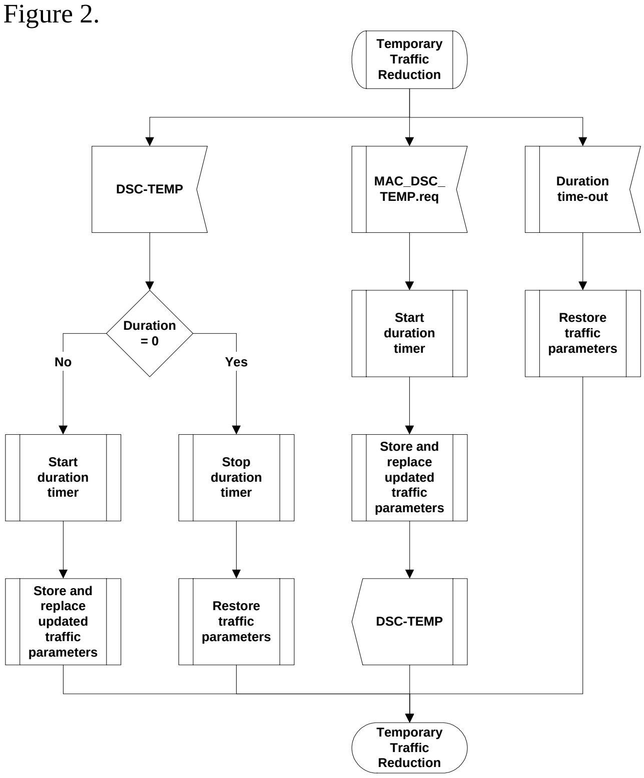

Figure 2: State transition diagram DSC_TEMP

Although the mechanism has been designed to fulfil the specific demands of an interworking system, it is also quite useful in stand alone HM systems. In congestion situations the proposed mechanism can be seen as a first step towards a cross-layer optimization. By means of that mechanism, the MAC and the PHY layer are sharing knowledge of the wireless medium with higher layers. As an example one could think of the TCP Explicit Congestion Notification (ECN) mechanism which notifies the receiving TCP entity whenever congestion occurs in the network. The so called ECN bit is set to one by routers (HM stations respectively) if congestion is detected. When the marked packet reaches the destination, it implicitly informs the source about the current situation [5]. The TCP entities could react with an adaptation of its transmission rate by reducing the *congestion window* and an automatic transition to the *congestion avoidance* phase instead of the *slow start* phase. A special treatment of the internal timer values, e.g. TCP's retransmission timeout (RTO) might also be possible [6]. Another enhancement could be to directly address the application layer to reduce the generated data rate, e.g. a video codec might reduce the quality according to the congestion situation. The coded video stream could have a reduced frame rate (pictures per second) or a higher compression ratio of the frame [7]. Beside cross-layer communication, the congestion control mechanism is also useful if an uplink connection with an unsolicited grant scheduling service (UGS) is handled. Bandwidth is reserved for that particular UGS connection on a strictly periodic basis. This kind of scheduling service might be used for VoIP, video or machine-to-machine communication. But even these services might be interrupted by accident or on purpose. Thus, if there is currently no data to be transmitted and there is no other connection to take over that bandwidth, the reserved bandwidth will be unused. The proposed control mechanism is able to temporarily reduce the reserved bandwidth. When the data source recovers, the connection's original QoS parameters are recovered automatically. In the meantime the system capacity can be used by other connections.

III. SIMULATION ENVIRONMENT

The simulation results have been obtained by an event-driven, stochastic simulator based on the specification and description language (SDL) and C++ [2]. Within this simulator standard-compliant HM as well as H/2 protocol stacks are implemented. A validation of the simulator and initial performance results of a stand alone HM system can be found in [8]. The simulator has been enhanced with interworking functionalities. The proposed congestion control algorithm has been implemented in the HM as well as in the H/2 protocol stack. To be able to compare performance results, the scenarios have been aligned with the IST-STRIKE demonstration scenarios defined in [9].

IV. SIMULATION RESULTS

All interworking scenarios contain an H/2 system including two MTs, which AP is connected to an HM SS via an interworking bridge. The HM SS is served by its BS (see Figure 3 and Figure 6). The parameters of the congestion control mechanism are kept fixed during simulations. The reduction duration is set to 1 s and the reduced data rate is always fixed to 0 Mbps, i.e. the connection is being shut down for 1 s. The reduced data rate could be further optimized. It could be adapted to the current transmission rate during the congestion situation instead of reducing it to 0. For the reduction duration an exponential back off algorithm instead of the fixed duration of 1 s is possible. The algorithm could start with a reduction duration of several MAC frames and increase it exponentially when congestion is still present.

The mechanism is triggered whenever the fill level of the buffer within a MAC entity reaches a certain threshold. The threshold of each connection is adapted individually based on the scenario and the traffic requirements. Both systems perform priority queuing and the priority parameter is exchanged between both systems. ARQ was disabled within both systems. Basic system parameters and a detailed description of all scenarios can be found in [9].

A. Downlink scenario, H/2 system congested

The first scenario contains two interworking downlink connections (refer to Figure 3). All connections in the HM system are running with 64 QAM ¾ which leads to an approximate MAC system throughput of 19 Mbps. H/2 system uses QPSK ¾ which results in an effective data rate of approximate 14 Mbps.

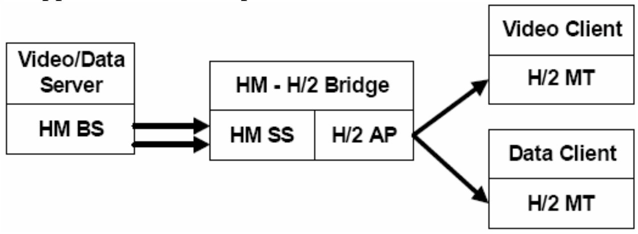

Figure 3: Configuration of downlink scenarios

The downlink video connection is configured as 9 Mbps constant bit rate (CBR) source with high priority. The traffic generator of the low priority data connection also generates CBR traffic with a rate of 5 Mbps. Due to an overload situation the usable data rate of the H/2 system drops to approx. 10 Mbps and rises again to 14 Mbps after the congestion has disappeared. The congestion control algorithm is triggered by the MAC entity of the H/2 AP.

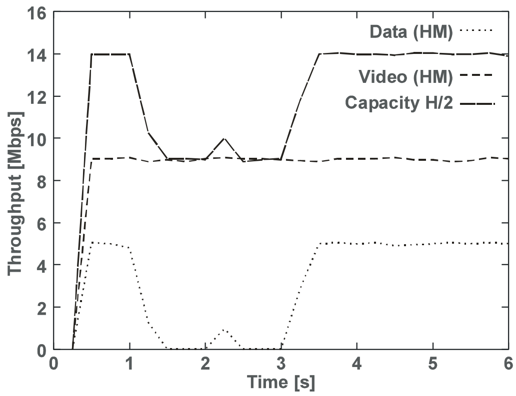

Figure 4: DL scenario, H/2 system congested

The transmission is split in two phases, a regular and a congested one. In Figure 4 the measured throughput rates are drawn over the simulation time. Delay measures are not shown, because they are known for the regular transmission [2] and during the congested phase no packets are transmitted at all. Packet loss has also been discarded because in regular operation no packets are lost while during congestion, buffers are overflowing.

In the beginning both, the video and the data connection can be handled. After a simulation time of 1 s the available data rate in the H/2 system is reduced, e.g. by interference. This causes an overload situation in H/2 and the data rate of the lowest priority connection is automatically reduced. The HM system is not aware of that and continues to transmit. Since transmission's direction is downlink, the buffer fill level in the H/2 AP is increasing. When the level reaches a certain threshold, the congestion control algorithm is triggered. The mechanism signals the congestion situation of the corresponding connection via the HM SS to the HM BS. The BS reduces the capacity of the connection for 1 s. The throughput reduction of the data connection in the HM system can be seen in Figure 4.

After the reduction duration of one second, HM tries to recover the original rate of the data connection. A small peak occurs right after a simulation time of 2 s. But the H/2 system is still congested and cannot deliver the packets which have to be stored in the buffer. This triggers the mechanism a second time. The transmission rate of the data connection is again reduced for another second. When the second reduction duration is over, the automatic recovery is successful, because the congestion situation in the H/2 system disappeared. The available H/2 capacity recovered and is again sufficient to handle both interworking connections. During the whole simulation, the available capacity of the H/2 system stays sufficient to handle the video connection, which does not run into congestion. Since the congestion control mechanism is based on the connection identifier, the video transmission is not affected. In Figure 4 it stays constant during the whole simulation.

B. Downlink scenario, H/2 link congested

Again two downlink connections are interworking like it is outlined in Figure 3. The HM connections are running with 16 QAM ¾ which leads to an approximate data rate of 12.8 Mbps provided by the MAC layer. On the H/2 links, data is modulated and coded with QPSK ½ which results in an effective overall rate of approx. 10 Mbps. The traffic characteristics of the high priority video and the low priority data connections stay the same as in section II.*A*.

Now the particular link carrying the high priority video connection suffers from an interference situation. This may be caused by the MT moving out of range. Thus, the H/2 video transmission between 1 s and 3 s is stopped. This information is signalled to the HM BS, causing a change in scheduling.

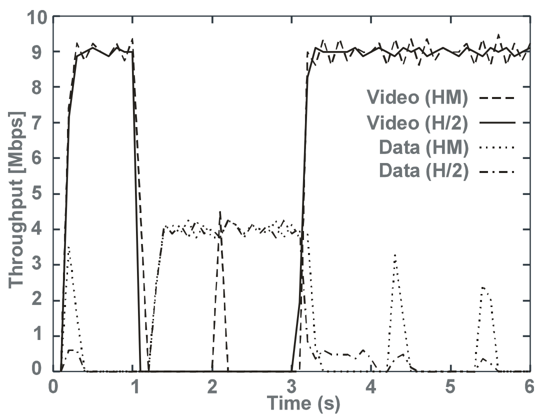

Figure 5: Downlink scenario, H/2 link congested

In the beginning the 9 Mbps video connection can be handled, but after a simulation time of 1 s the downlink video transmission is stopped in the H/2 system. This causes a buffer overflow in the H/2 AP which invokes the congestion control algorithm. Via the HM SS, the congestion control mechanism triggers the HM BS to reduce the capacity of the corresponding connection. The reduction of the video connection in the HM system is slightly delayed compared to the H/2 system which can be seen in Figure 5. The data connection can take over the freed capacity. Although the data connection has a lower priority it is now scheduled by the HM BS. Thus, the unnecessary transmission of video data, which would anyway be discarded at the H/2 AP, has been stopped. In return, the low priority data connection can take over the capacity during that phase. The first unsuccessful try of the automatic recovery is indicated by the peak in throughput of the HM video connection right after a simulation time of 2 s. The mechanism is triggered a second time. Having reached the end of the second reduction duration, the recovery is successful. The H/2 MT came back into the coverage area and the link to the receiving terminal has been set up again. The video connection is recovered in both systems and is transmitting with its original data rate of 9 Mbps. Since the data source is configured to transmit 5 Mbps best effort (BE) traffic and the H/2 system has an overall capacity of approximately 10 Mbps it is congested from the very beginning of the simulation. In the beginning of the simulation the HM throughput of the data connection rises much faster than the H/2 throughput which stays down at 1 Mbps. The data connection runs into congestion and the congestion control mechanism is triggered. The same happens at the end of the simulation. Thus, the mechanism also reduces the BE traffic, although it is not designed for that. In reality, BE traffic is adapting itself to the available transmission rate on a long run. Its capacity is being controlled by end-to-end flow control mechanisms like e.g. TCP. Since CBR traffic sources are applied during simulation, TCP is not enabled. In this context, the influence of end-to-end flow control algorithms and the proposed congestion control mechanism might be interesting, especially a possible cooperation with the TCP ECN bit.

C. Uplink scenario, HM link congested

This scenario includes two H/2 MTs, but only the uplink video connection is interworking. The HM system is running with 16 QAM ¾ which leads to an approximate MAC data rate of 12.8 Mbps. H/2 uses QPSK ¾ which results in an effective overall rate of approx. 14 Mbps. The CBR video connection carries 9 Mbps. The data connection is not interworking, both client and server are located within the H/2 system (see Figure 6). The data server generates BE CBR traffic. The priority of the video connection is higher than the one of the data connection.

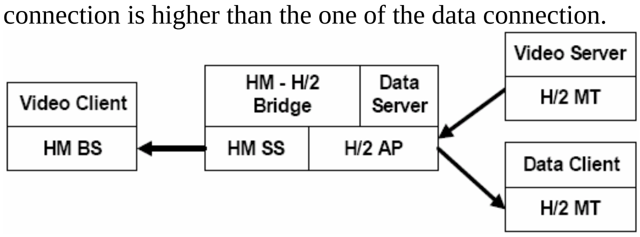

Figure 6: Configuration of uplink scenario

The connection carrying the high priority video stream will be stopped in the HM system, indicating an interference situation for the particular link. The HM BS will no longer allocate any bandwidth for this connection in the uplink.

Thus, the HM uplink connection is congested. This information is signalled to the H/2 AP where it causes a reduction of the connection's capacity. The proposed congestion control mechanism is now running within the H/2 system. Right from the start of the simulation, the 9 Mbps video stream can be handled by both systems. At 1 s the video transmission is stopped in the HM system. The H/2 system continues the transmission and causes a buffer overflow in the HM SS which triggers the congestion control mechanism. The signal is passed to the H/2 AP which reduces the capacity of the corresponding uplink connection. The different throughput rates of HM and H/2 can be seen in Figure 7.

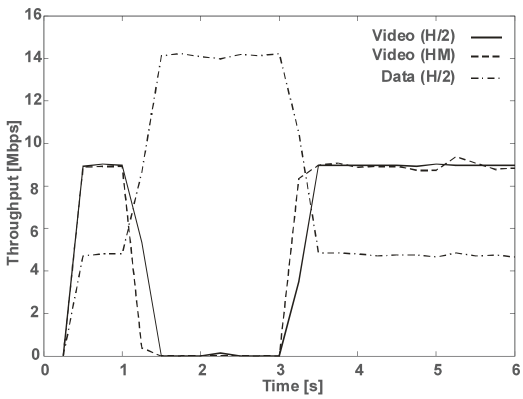

Figure 7: Throughput of STRIKE scenario 3

The data which cannot be transmitted is indicated by the area between the two curves representing the video connection. It has to be buffered in the H/2 AP and in the end this data triggers the mechanism. The small peak at a simulation time of 2 s is the first attempt to recover the connection. But the recovery is not successful until the congestion in the HM system has disappeared. The low priority data connection is utilizing the remaining H/2 bandwidth which is 5 Mbps in the beginning. Once the mechanism is triggered, and the video stream is shut down, the data connection takes over the whole capacity of the H/2 system, i.e. 14 Mbps. Since the data connection is not interworking but located in the H/2 system only, its throughput rate grows higher than the maximum capacity of the HM system, which is 12.8 Mbps in this scenario.

V. Conclusion

The capacity of an interworking HiperMAN HiperLAN/2 connection can be aligned with the capacity of the corresponding bottleneck link by means of the proposed congestion control mechanism. It has been designed and specified based on the existing HiperMAN standard and the additional requirements of two interworking wireless systems. The mechanism can also be used in a stand alone HM or H/2 system for cross-layer optimization and improved utilization of UGS connections, i.e. reserved bandwidth in UL direction.
The congestion control mechanism has been implemented into a HM-H/2 simulator. Results show that the mechanism can handle the addressed congestion situations. It reduces unnecessary transmissions and temporarily permits low priority connections to be scheduled. Thus, the overall system performance is optimized. The presented results will be compared to the measurements gained with the STRIKE interworking demonstrator.
The proposed mechanism is based only on a single (wireless) link. In contrary to end-to-end methods like TCP or higher level connection admission control it can be seen as a more decentralized or distributed approach to handle congestion. Each part (or hop) of the overall transmission chain is signalling a congestion situation to its neighbours. Like this the bottleneck link (which is most likely a wireless one) is determining the end-to-end transmission rate. Which approach performs better in certain scenarios could be investigated in the future. The interaction between end-to-end flow control algorithms like e.g. TCP Explicit Congestion Notification and the proposed congestion control mechanism is another interesting point for further analysis.

VI. ACKNOWLEDGEMENTS

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