Cooperative IP Header Compression using Multiple Access Points in 4G Wireless Networks

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***Abstract*— In this paper we consider the usage of multiple base stations for IP streaming applications towards wireless terminals. The usage of multiple channels, coming from different base stations, increase the capacity and robustness at the price of an additional IP overhead. Therefore, we advocate to use a novel IP header compression scheme for efficient usage of spectrum resources. We propose the cooperative header compression scheme, referred to as COHC, that exploits cooperative behavior of multiple channels conveyed from different base stations. The proposed enhancement of header compression is simple which allows to keep the complexity of wireless terminals low. Furthermore, COHC does not require any feedback information, and thus it can be easily applied in multicast scenarios. We give an analytical comparison of our approach to the conventional solution and show that our approach can effectively cope with temporal bad channel conditions keeping the synchronization between the header compressor and decompressor. We further evaluate the maximum achievable bandwidth efficiency.**

I. INTRODUCTION

The wireless delivery of multimedia services is one of the goals of the next generations mobile communication systems. Users are expecting that the same services will be available in wireless networks as in wired ones. However, IP-based multimedia applications, including audio- and video-streaming and gaming, require more bandwidth than traditional voice services in circuit-switched networks. To overcome bandwidth constraints and high bit error rates of wireless environment, new technologies are developed. At the same time to use the limited resource, bandwidth, in the most efficient way, multimedia payload should be compressed and the IP header overhead should be reduced when possible. Compression of IP packet headers can result in significant reduction of overhead information [1].

IP header compression mechanisms have always been an important part of saving bandwidth over bandwidth-limited links. Many header compression schemes exists already, but they should be adopted to operation in the wireless environment and designed to withstand loss of packets due to severe propagation conditions. Recently, Robust Header Compression [2] was introduced especially developed for wireless multimedia delivery. This approach combines robustness for IP-based data streams and high compression gain due to connection-oriented approach in removing packet redundancies. The price to pay is high complexity of the scheme.

Generally, header compression (HC) is possible due to redundancy among the header fields of a packet flow. The main concept is as follows. On the sender side, the compressor removes redundancy from the incoming packet using information from the past packets, called the *context* (it is also sometimes called base). The decompressor maintain the context and uses it to reconstruct the header of the incoming packet. The inconsistencies in the contexts of compressor and decompressor lead to the loss in synchronization and failure of the decompression procedure. A context repair mechanism should be applied.

All existing header compression schemes are developed for single base station- single mobile terminal or single base station - multiple mobile terminals architectures. In this paper we advocate a new framework for header compression using multiple BSs serving one or several wireless terminals in a cooperative manner. We consider the following scenario. BSs are connected to an access controller (AC) and the streaming data intended to one or several recipients is split into several substreams by a controller. Each substream is forwarded to a BS for further wireless transmission to the wireless terminal (WT) (see Figure 1). Actually, splitting of one data stream into substreams can be dictated by an application. For example, downloading a web site, different TCP connections (for text, pictures etc) are established. Another example is usage of Multiple Description Coding (MDC) or Multi Layerd Coding (MLC) for coding of a video stream. Different substreams can be sent over different physical channels or over different logical channels. Thus, we consider a scenario when a wireless terminal has simultaneous connections to several BSs.

When multiple pathes are available between a source and a destination, Cooperative header compression (COHC) can be applied. One scenario is the usage of multiple base stations as given in Figure 1. The advantages of such an approach was already shown in [3, 4]. The base station are under control of the access controller (AC). The AC is the last IP end point before the wireless terminal. Therefore the header compressor and decompressor are place within the wireless terminal and the access controller. The base stations, or even access points, act only as a bridge. This architecture targets omnipresent WLAN such as IEEE 802.11 scenarios as well as future 4G wireless networks. Depending on the wireless condition the channels might differ in terms of quality.

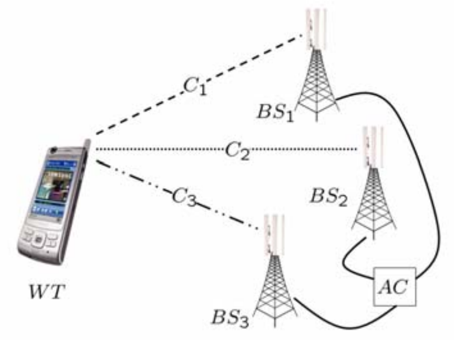

Fig. 1. Example of a network with one WT connected to several BSs

COHC approach is based on the concept of additional information container (AIC). One of the important points in general header compression design is ensuring that the contexts of the compressor and decompressor are the same and thus, the decompression process of a compressed header entity can be done successfully. The AIC is used to repair a corrupted current base of neighboring compression entities, and therefore, it is used to help the compressor and decompressor to stay synchronized. One should note that the usage of COHC does not need a feedback channel. In this paper we consider only IP/UDP/RTP traffic. COHC can be successfully applied for the case of multicasting, when a group of users get the same content delivered.

The paper is organized as follows. Section 2 introduces cooperative approach for IP header compression in presence of multiple streams. In Section 3 performance evaluation results are presented including estimation for maximum achievable bandwidth efficiency. Section 4 offers some concluding remarks and give the guidelines for the future work.

II. COOPERATIVE HEADER COMPRESSION

To prevent the context re–synchronization, a context repair mechanism should be applied. With the help of feedback from the decompressor, a compressor can learn that the base is lost and the full update of the header will be sent. However, providing feedback can be impractical, if not at all impossible, in some situations. For example, this is the case for multicast services and delay-sensitive applications. When the feedback is unavailable (like in Unidirectional mode of ROHC), the synchronization of the contents is achieved by periodic refreshes of the states. How often the updates should be done, depends a lot on the channel error rate and the propagation environment. Rare periodic updates can lead to a situation when a packet is received correctly but can not be decoded because of absence of the correct current base. Frequent updates keep the system robust, but compression gain is decreased. The main idea of Cooperative header compression is to have a robust and efficient scheme in case the feedback can not be provided from the decompressor. By using AICs, the updates can be sent less frequently that ensures high compression gain, at the same time maintaining robustness of the scheme. AICs introduce some additional overhead, but the overall bandwidth efficiency of the method is improved significantly.

In this paper we consider header compression scheme based on delta coding and enhance it in the case of multiple channels between access points and a wireless terminal. Delta coding is a simple and efficient scheme: one uncompressed header is sent and followed by a row of compressed headers that carry only the differential information referring to the previous header. The drawback of this scheme is that it is very sensitive to the loss of the packets: if one packet is lost, the base at the decompressor is updated and all the subsequent packets, even if received correctly, can not be decompressed. We refer to this situation as *loss propagation*.

Loss propagation can be reduced if each of the packet carries some additional information as in case of COHC. It is possible to rebuild a current base (even if the current packet is lost due to channel conditions) by using the AIC information in combination with any given base. The AIC for a given channel does not necessarily refer to the base of this given channel. This is up to the designing process. Obviously, the size of the AIC is smaller if it refers to the base of the channel to which it is dedicated to support. One possible solution would be that the AIC is just a copy of a compressed header and send over different channels. In this case the AICs are sent on parallel channels and refer to the base of the current channel. We note that this approach is less complex, but not the most efficient one. To make it more efficient, the amount of data has to be reduced. In comparison to a compressed header the AIC do not have to carry any information that belongs to the packet itself, but only everything that is needed to retrieve the base. An example is the UDP checksum, which should not be part of the AIC. The UDP checksum is needed to check whether the packet is received correctly. This would decrease the amount of data for each AIC.

Figure 2 shows one possible way of AICs construction. Each compressor generates its own compressed header and the related AIC, which is passed to the neighboring compression entities. The neighboring entities in turn send their AICs such that the compressor is able to compose the payload, the compressed header and the AICs for the neighboring channels. Here the AICs of one compression entity are the same.

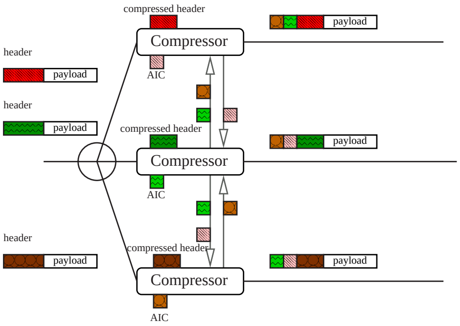

Fig. 2. AICs construction for three cooperative channels.

In this paper we consider the following approach to construct the AICs: a header compression entity includes one AIC for each neighboring channel in the same time domain. In this approach only AICs with the same time instants can be used to repair the base in case of packet errors. Figure 3 shows the base repair process. As one can notice, this scheme requires that the parallel flows are synchronized, that is all channels between a sender and a receiver have the same delay characteristics within the granularity of IP packets. The synchronization of the substreams can be achieved in the considered scenario with the help of the access controller. In case IP datagrams are segmented into smaller data link packets, jitter can be expected between IP packets and therefore. a buffer should be introduced at the receiver side. In case there is a limited number of retransmissions on the link layer or no retransmission at all (e.g. broadcasting), the jitter is bounded and will not have a significant impact on the performance of the scheme.

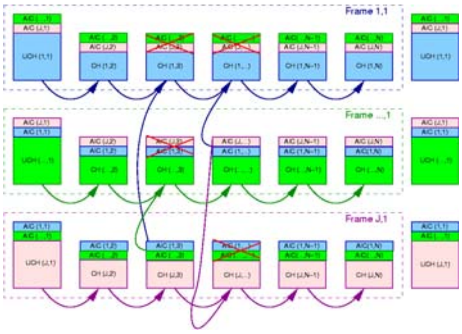

Fig. 3. One possible implementation of piggy–backed information (AIC) for neighboring channels with packet errors.

Detailed description of the Cooperative Header Compression an interested reader can find in [5].

III. PERFORMANCE EVALUATION

A. *Considered scenario*

In Section I we have already introduced the scenario when a wireless terminal has several simultaneous connections to the access points. Due to propagation characteristics of wireless medium, the receipt quality of one link can be higher compared with other links. In the case when a direct line of sight (LOS) exists between a WT and a BS, we expect a low bit error rate (BER) of order 10^{-5}. When a path is obstructed by a person (indoor) or building (outdoor), the probability to loose a packet increases. In this section we focus on the situation when pathes between the WT and APs have different channel error rate and show that COHC can help to 'survive' a temporal increase in BER without loosing synchronization between the compressor and decompressor.

B. *Packet error probability and bandwidth efficiency*

As a measure of robustness of HC schemes we are using packet error probability (PEP). One should note that a packet can be lost either because of the error due to bad channel condition or because a receiver does not have a base to decompress the header and therefore a packet is of no use. Both cases lead to loss of a packet on IP layer, and therefore they should be both taken into account estimating PEP. Another important parameter is *bandwidth efficiency* defined as a ration of correctly received payload to the total amount of information sent. Low PEP is an indication of robustness of a scheme. Bandwidth efficiency reflects both compression gain and error rate.

We assume that the behavior of the channels is uncorrelated. What is more, we make an assumption that the packets of one channel are lost randomly, with probability p. If interleaving is used, this assumption is natural. We evaluate the impact of different channel error probability (CEP) on the performance of HC schemes.

First, we consider the case of two base stations. Let p be the CEP (i.e. the probability to loose a packet due to the bad channel conditions) of one channel, and q be the CEP of another channel. N is the refreshing rate (i.e. the number of packets in a frame consisted of the first uncompressed header and the following compressed entities). To find the PEP of the whole stream, we find PEPs of two substreams and average them.

Considering delta coding compression, a loss of one packet results in the loss of all subsequent packets in the frame. Therefore, the analytical expression for PEP has the form:

$$PEP_{delta} = 1 - \frac{(1-p)(1-(1-p)^N)}{2Np} - \frac{(1-q)(1-(1-q)^N)}{2Nq}$$

Deriving formula for PEP in COHC case, we should take into account that the loss propagation can be stopped and the only case when it can occur is when both packets from two different channels are lost at the same time stamp. Omitting the detailed derivations, we present the final formula:

$$PEP_{COHC} = 1 - \frac{(1-(1-pq)^N)(1-(p+q)/2)}{Npq}$$

In Figures 4 and 5 dependence between PEP and CEP is shown for delta coding and COHC approaches. First of all, one can notice that the cooperative scheme results in much lower probability to loose a packet. It is interesting to observe the behavior on the edges of the 3D plots, when CEP of one channel is low (meaning a WT finds itself in a good position relative to the BS, e.g. very close to BS). From the figures we see that PEP for COHC stays low even though the conditions of another channel are bad (high CEP values for the second connection). In the case of delta coding the average PEP increases significantly even though one of the channels is good. It shows that in this situation COHC keeps the context for the second channel synchronized, even though the e.g. every second packet is lost when $q = 0.5$. Then wherever a packet is received, it can be also decompressed - this helps to bring PEP as low as possible. The price for this to pay is the increase of header compression size. Therefore, we have also chooser to evaluate the bandwidth efficiency of the schemes.

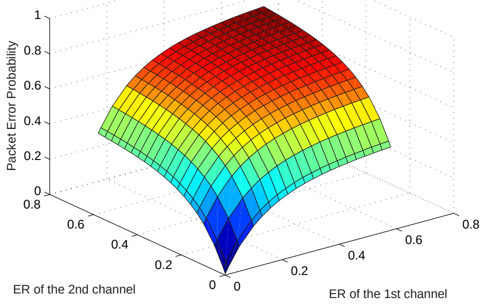

Fig. 4. Packet error probability as a function of channel error rates for delta coding compression. $N = 12$, $D = 40$, $B_u = 40$, $B_c = 4$, $B_a = 2$ bytes.

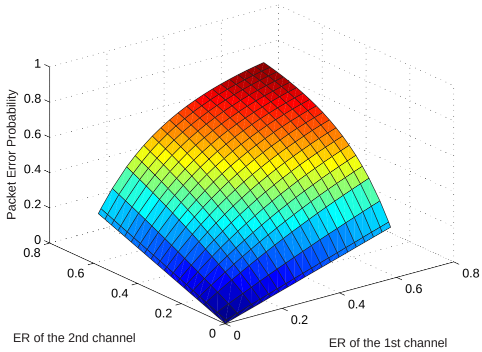

Fig. 5. Packet error probability as a function of channel error rates for cooperative compression. $N = 12$, $D = 40$, $B_u = 40$, $B_c = 4$, $B_a = 2$ bytes.

Bandwidth efficiency can be found as follows:

$$BE = \frac{ND(1 - PEP)}{(ND + B_u + B_c(N-1) + NB_a)}$$

where D is payload in bytes (we assume all packets have the same payload size), B_u and B_c are size of uncompressed and compressed header respectively. B_a is a size of one AIC.

Figures 6 and 7 shows the efficiency for two approached. Again, we observe that cooperative behavior brings the efficiency much higher. To make the results more visual, Figure 8 shows the efficiency gain, that we define as a difference of BE for COHC and BE for delta coding:

$$Gain = BE_{COHC} - BE_{delta}$$

From Figure 8 it is clear that cooperative behavior results in significant efficiency gain, except of the situations when CEP is very low. When the communication channels are almost error-free (the case of wired connections), unmodified delta coding should be preferred.

The presented results are calculated for 40 bytes of payload and a frame size of $N = 12$. We have evaluated the schemes

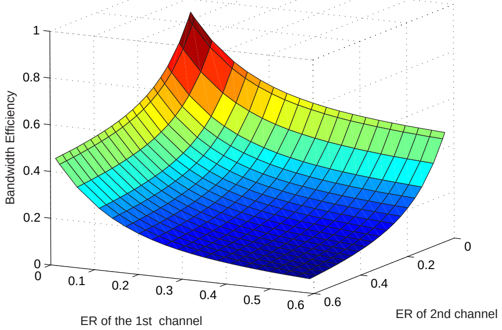

Fig. 6. Bandwidth efficiency as a function of channel error rates for delta coding compression. $N = 12$, $D = 40$, $B_u = 40$, $B_c = 4$, $B_a = 2$ bytes.

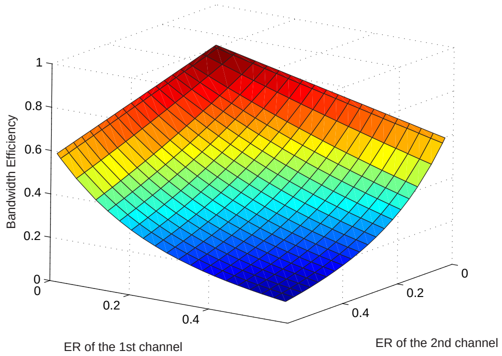

Fig. 7. Bandwidth efficiency as a function of channel error rates for cooperative compression. $N = 12$, $D = 40$, $B_u = 40$, $B_c = 4$, $B_a = 2$ bytes.

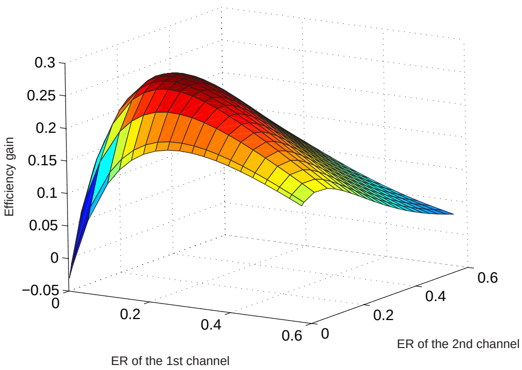

Fig. 8. Efficiency gain as a function of channel error rates. $N = 12$, $D = 40$, $B_u = 40$, $B_c = 4$, $B_a = 2$ bytes.

under the different range of parameters D and N and the same behavior was observed. Figures 4-8 are given for the range of CEP $0.001 - 0.8$. The high values like 0.8 are unrealistic, but they are included in the figures to show the tendency. Alteratively, one can view these high values for CEP as temporal channel degradation.

C. Maximum achievable bandwidth efficiency

One can notice that the optimal refresh rate depends on the channel conditions: if BER is low, update frequency should be made smaller in order to increase bandwidth efficiency and compression gain. On the contrary, when channel conditions are bad, the frequent updates are required to keep the robustness of the scheme. Therefore, for the fair comparison between the HC schemes, we adapt the number of the packets in a frame N to the CEP.

For example, when CEP is 10^{-2} (in this subsection the same error rate is assumed for parallel channels), the value of N that maximizes the efficiency is 13 for delta coding, 125 for COHC with two cooperative channels and 1224 for COHC with three cooperative channels. The complete set of the results is presented in Figure 9. Figure 10 shows the maximum achievable bandwidth efficiency when N is chosen adaptively. One can observe that the cooperative schemes with two cooperative channels always has higher maximum BE than the non-cooperative scheme. Though when channel error probability becomes high, it is more efficient to use three cooperative channels. When the channel conditions are almost error-free, COHC with three channels introduce unnecessary overhead. The conclusion to be made here is that the cooperative approach should be chosen operating in the environment with CEP higher than 0.01.

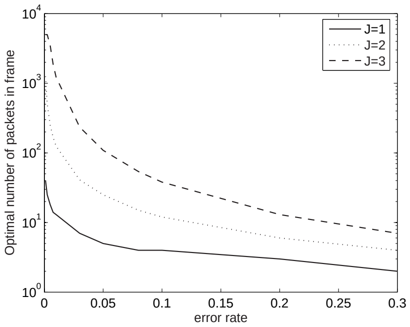

Fig. 9. Optimal number of packets in a frame as a function of channel error rate. $J = 1$ corresponds to the case of non-cooperative channels, $J = 2$ and $J = 3$ present the case of 2 and 3 cooperative channels.

IV. CONCLUSION AND FUTURE WORK

In this paper we advocate the usage of multiple base stations for IP streaming applications. the presented scenarios target omnipresent WLAN networks as well as future 4G wireless networks. We show how by introducing the cooperation between different streams, the performance of header compression schemes can be significantly improved. Without relying on the feedback from the decompressor, COHC can maintain synchronization of the context of the compressor and decompressor.

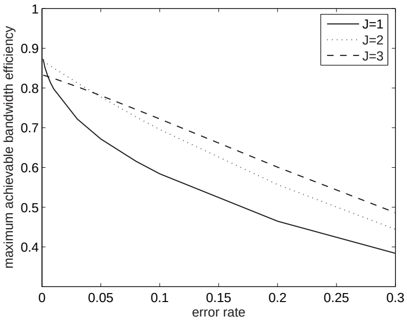

Fig. 10. Maximum achievable bandwidth efficiency when N is chosen adaptive to the channel error probability.

One of the characteristics of the wireless environment is the fluctuating link quality. The proposed cooperative approach can efficiently cope with channel errors. If one of the connections is good, it would help another connection to keep synchronization, preventing loss propagation. The advantage of this approach is it's simplicity that allows to keep the complexity of wireless terminals low. Another advantage is the no need of feedback information that is especially important in the multicast scenarios.

Currently, we are extending the performance evaluation results by simulation and measurements including realistic indoor and outdoor propagation environments. Furthermore, it is within the future work to consider the combination of header compression schemes with different error protection coding and efficient combination of COHC with TCP retransmission mechanisms.

V. ACKNOWLEDGEMENT

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