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Optimized Header Compression for Real-time Communication in 6G Networks

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Abstract—With the advancement of 5G, many communication protocols for data transmission have been developed and put into practice. However, alongside these innovations, the issue of redundancy in packet headers has arisen, leading to concerns such as increased resource utilization, diminished transmission efficiency, and elevated latency in the context of real-time communications like voice-over-IP (VoIP). The existing header compression algorithms, such as robust header compression (RoHC), have fallen short in addressing these contemporary header compression demands, as they are primarily designed for specific headers such as RTP, UDP and IP. Therefore, it's necessary to achieve header optimization in the transfer of packets across various protocol layers and multiple flows, with scalability that can be applied to future 6G communications. This paper introduces optimized header compression (OHC) based on RoHC. OHC efficiently compresses headers over the 5G protocol stack and GPRS tunneling protocol user plane (GTP-U), catering to the requirements of real-time data transmission. Furthermore, OHC also integrates protocol headers from multiple quality-of-service (QoS) flows and multi-layer to perform better. The simulation results show that OHC provides a notable increase in header compression, with a minimum improvement of 45%, resulting in reduced resource demands and lower latency. Additionally, the combination of protocol headers from multiple flows and multiple layers yields further enhanced compression performance.

Index Terms—6G, Header Compression, RoHC, Real-time Communication, GTP-U

I. INTRODUCTION

The International Telecommunication Union (ITU) has identified three key characteristics of the 5G system, encompassing enhanced mobile broadband (EMBB), massive machine-type communication (MTC) and ultra-reliable low-latency communications (URLLC) [1]. In the context of URLLC, there is a growing demand for efficient packet transmission with small payloads within packet-switched communication networks. Furthermore, the advent of the Internet of Things (IoT) paradigm has amplified the need for timely transmission of substantial volumes of discrete small-data sensor readings [2], [3], [4].

Over the past two decades, VoIP and its associated applications have witnessed widespread adoption due to their real-time transmission capabilities, cost-effectiveness and scalabil-

ity. VoIP services rely on the transmission of multimedia data over IP networks. Presently, VoIP has become exceedingly popular in both residential and business settings, with well-known platforms such as Skype, WhatsApp, Apple's FaceTime and WeChat [5]. Fig. 1 illustrates two scenarios of a VoIP application. Firstly, the call service is provided through the base station (BS), routers and the server.

Secondly, a time-sensitive IP-based service is also depicted in Fig. 1. A patient with a heart condition wears a medical watch monitor to collect the heartbeat data and to send the data to the smartphone based on Bluetooth low energy (BLE). The monitoring data is transmitted to the healthcare provider's server via the IP-based service for further services like heart attack alert.

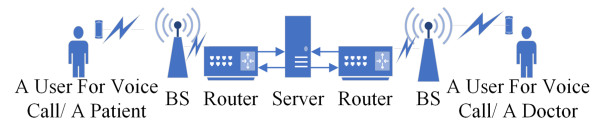


Fig. 1. IP-based service via mobile phone.

For low-latency transmission as mentioned above, the payload size of the packet can be as small as 20 bytes. In comparison, the size of the protocol header can be relatively substantial. For instance, when utilizing RTP/ UDP/ IPv4 protocols for real-time transmission, the summed header size is 40 bytes. Furthermore, in the context of the 5G network, with the inclusion of 5G-specific protocols, the summed header size can expand to approximately 100 bytes. Consequently, there arises a compelling need to employ header compression algorithms to mitigate the impact of these sizable headers on data transmission efficiency.

The utilization of RoHC [6], [7] plays a pivotal role in compressing protocol headers. RoHC effectively reduces the volume of transmitted data without compromising the quality of communication. However, RoHC is designed primarily for specific headers such as higher-layer RTP/ UDP/ IP headers (shown in Fig. 2, RoHC is applied on the application protocol layers on top of SDAP (Service Data Adaptation Protocol)/

PDCP (Packet Data Convergence Protocol)). RoHC can not fully meet the contemporary demands of header compression. 5G-based packet transmission often involves multiple protocol layers, necessitating comprehensive header optimization across the stack. This optimization becomes imperative for real-time packet streams. To illustrate, compression for protocols like GTP-U (GTP User Plane), GTP-related lower-layer IP and UDP, and 5G-related PDCP and SDAP should be considered to address the requirement effectively.

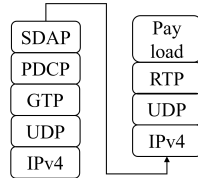


Fig. 2. Example of protocol stack in 5G.

Therefore, a novel optimized header compression (OHC) algorithm based on RoHC is proposed in this paper. OHC is specifically designed to optimize the headers of the real-time stream across the 5G protocol stacks. Besides, OHC is capable of integrating the headers from multiple QoS flows by multiple-flow OHC (M-OHC). Furthermore, OHC is also designed to optimize the cross-layer headers by vertical OHC (V-OHC). Unlike RoHC, OHC proposes a general approach to optimize the protocol headers in 5G, which is also scalable to future 6G applications. The main contributions of this paper are summarized as follows:

- We propose OHC based on RoHC to provide a general approach for optimizing protocol headers for 5G and future 6G networks, resulting in a higher header compression rate.
- For multiple-flow services, we integrate protocol headers to enable header-sharing among flows, further optimizing them through M-OHC.
- For single-flow applications, we achieve cross-layer header optimization with V-OHC to enhance the compression rate.

In this paper, the introduction to the 5G protocol stacks and RoHC is given in section II; the methodology of OHC is provided in section III; the simulation results and the analysis are demonstrated in section IV; the conclusion and further developments are provided in section V.

II. 5G PROTOCOL STACKS AND ROHC

A. 5G Protocol Stacks

The 5G system encompasses next-generation radio access network (NG-RAN), 5G core network (5GC), and user equipment (UE). The user plane (UP) is responsible for user data transmission, and the protocol stack in UP is shown in Fig. 3. The RLC (Radio Link Control), MAC (Medium Access Control) and PHY (Physical) layers serve as the foundation for data exchange between the UE and the gNB-DU (Distributed Unit).

To establish connectivity between the gNB-DU, gNB-CU-UP (Central Unit User Plane) and UPF (User Plane Function), GTP tunnels are utilized. Meanwhile, the SDAP and PDCP protocols are served between the UE and gNB-CU-UP, through the gNB-DU. Between the gNB and the UPF, the N3 interface comes into play. Finally, the UPF facilitates the delivery of e.g. RTP stream through the N6 interface.

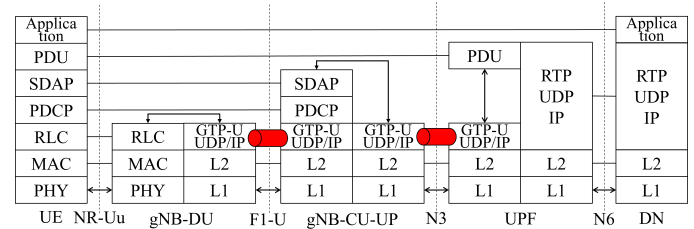


Fig. 3. User plane protocol stack. RTP/UDP/IP in the UPF is combined in the PDU.

The GTP tunnel through the F1-U reference point and the N3 point is marked red, meaning the optimization of the proposed OHC will be conducted here.

B. RoHC

RoHC is able to reduce the size of packets by compressing unnecessary information within protocol header fields. Protocol headers typically encompass various types of data. Within a stable transmission flow, these data can be categorized into three main types: STATIC field, DYNAMIC field and INFERRED field:

- **STATIC field:** It remains constant if the data flow transmission is stable. For example, the source address and the destination address in IPv4 are STATIC fields.
- **DYNAMIC field:** It will change dynamically in the data flow like the timestamp in IPv4. However, some DYNAMIC fields, such as sequence number (SN) in RTP, exhibit predictable behavior.
- **INFERRED field:** It can be calculated by the existing data like the packet length in IPv4.

The header compression is conducted based on the classification of the fields. More specifically, STATIC field and INFERRED field can be removed directly, and DYNAMIC field can be removed partially based on some mechanisms. The components of RTP (Real-time Transport Protocol) header and its field classification are shown in Table I.

TABLE I
RTP HEADER FIELDS [6]

4 Octets			
0-3	4-7	8-15	16-31
Version, Extension	CSRC Counter	Payload Type	Sequence Number
Timestamp			
SSRC			

- **STATIC fields:** Version, Extension, CSRC counter, Payload Type, SSRC

- DYNAMIC fields: Timestamp
- INFERRED fields: Sequence Number

For a packet with RTP/ UDP/ IP headers, the corresponding RoHC header is shown in Table II. SN_RTP is the sequence number of RTP, UDP_Checksum is a field in UDP. Cyclic redundancy check (CRC) is calculated in RoHC generation.

TABLE II
STRUCTURE OF U-0 HEADER IN ROHC [6]

Octet							
0	1	2	3	4	5	6	7
0	SN_RTP				CRC		
UDP Checksum_1							
UDP Checksum_2							

As illustrated in Fig. 4, the compressor compresses the header before data transmission, while the decompressor is applied to recover the compressed protocol header. Before header compression, the parameters that indicate the compression rule are shared between two points and stored in the “context.”

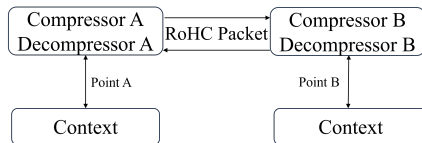


Fig. 4. Visualization of RoHC.

III. METHODOLOGY OF OHC

A. Comparison Between OHC and RoHC

As discussed above, RoHC is primarily designed to compress the headers of RTP, UDP and IP, classifying the header fields and removing redundant header fields. However, in present 5G and future 6G communications, numerous new protocols have their own headers that RoHC cannot handle. Furthermore, there is potential for integrating headers from different flows/ layers, which RoHC cannot explore.

Inheriting the principle of RoHC, OHC is proposed to expand the compression capabilities to 5G-specific protocol headers. Additionally, OHC achieves header integration from multiple flows and layers. Most importantly, the proposed OHC demonstrates scalability to accommodate any new protocol headers, showcasing its potential for application in future 6G communications.

B. Overview of Optimized Header Compression Algorithm

The implementation of OHC is described in Fig. 5. Three pairs of compressors and decompressors are applied, represented by OH_1, OH_2 and OH_3 respectively.

The RTP/ UDP/ IP headers are compressed by OH_1 and replaced by the OH1 header. OH_1 uses the same principle of RoHC for IP/ UDP/ RTP compression. Similarly, PDCP/ SDAP headers are replaced by the OH2 header, and GTP-U/ UDP/ IP headers are replaced by the OH3 header in OHC.

Fig. 6 provides a visual representation of the related data flow. OH2 and OH3 will be discussed later.

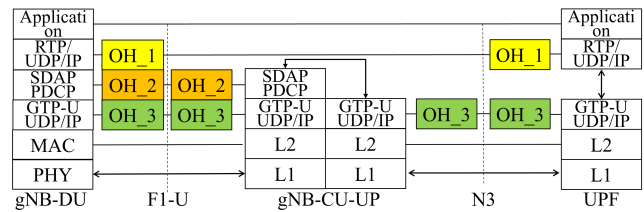


Fig. 5. Implementation of OHC in 5G user plane protocol stack.

C. Profile Analysis of OHC

1) *OHC for New Protocol Headers:* The fields of GTP-U header and extension header (PDU session container) are detailed in Table III.

TABLE III
GTP-U HEADER AND EXTENSION HEADER FIELDS

4 Octets			
0-7	8-15	16-23	24-31
Version and Flag	Message Type	Length	
TEID			
SN		N-PDU Number	Extension Header
Header Length	PDU Type	PDU QFI	SN_UL_QFI
SN_UL_QFI		Padding	

The classification of GTP-U and extension is shown below:

- STATIC fields: Version and Flag, TEID, Extension Header, PDU Type, PDU QFI, Padding
- DYNAMIC fields: SN, N-PDU Number, SN_UL_QFI
- INFERRED fields: Length, Header Length

The GTP-U/ UDP/ IP headers are replaced by the OH3 header in OHC. The OH3 header is shown in Table IV. The first three bytes hold UDP/ IP header information, which is the same as RoHC, except for SN_RTP. The following two bytes hold the GTP-U header and extension header information. They include SN, N-PDU Num (Network PDU Number), SN_UL_QFI (SN for Uplink QFI in PDU session container) and CRC_GTP.

TABLE IV
STRUCTURE OF OH3 FOR REPLACING GTP-U/ UDP/ IP HEADER

Octet							
0	1	2	3	4	5	6	7
0	Padding				CRC		
UDP Checksum_1							
UDP Checksum_2							
SN				N-PDU Num			
SN_UL_QFI				CRC_GTP			

The PDCP and SDAP headers are shown in Table V and Table VI, respectively. The classification for PDCP/ SDAP is:

- STATIC fields: D/C, R and QFI
- DYNAMIC fields: PDCP SN

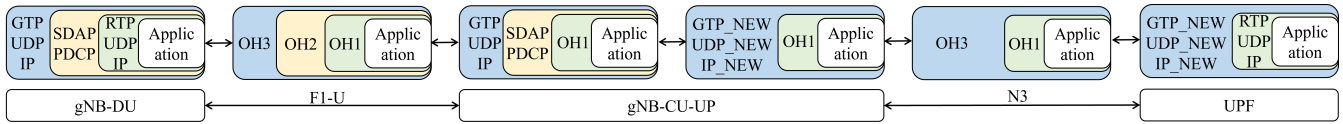


Fig. 6. Data flow in OHC.

The PDCP/SDAP headers are replaced by the OH2 in OHC. The structure of the OH2 header is shown in Table VII. The structure of OH1 for replacing RTP/UDP/IP headers in OHC is the same as in RoHC.

 TABLE V
PDCP HEADER FIELDS

Octet							
0	1	2	3	4	5	6	7
D/C	R	R	R		PDCP SN		
PDCP SN							

 TABLE VI
SDAP HEADER FIELDS

Octet							
0	1	2	3	4	5	6	7
D/C	R				QFI		

 TABLE VII
STRUCTURE OF OH2 FOR REPLACING SDAP/ PDCP HEADERS

Octet							
0	1	2	3	4	5	6	7
0		SN_PDCP			CRC		

Therefore, the 5G protocol stack as shown in Fig. 2 is replaced by OH1/ OH2/ OH3 headers. The same compression scheme will be used over the N3 reference point except for the OH_2 pair.

2) *M-OHC for Multiple Flows Header Integration*: When transmitting the QoS flows in the same protocol data unit (PDU) session, part of the information in the header is the same. M-OHC is used to optimize the header from multiple flows. As illustrated in Fig. 7, the OH3 is shared between a video flow and an audio flow, since the GTP-U-related header will be largely the same between two QoS flows in the same PDU session.

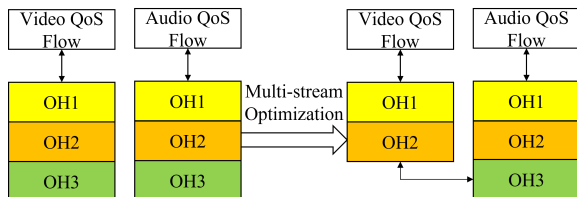


Fig. 7. Multi-stream optimization for QoS flows.

3) *V-OHC for Cross-layer Optimization*: The OHC algorithm mentioned above implements three parallel compression flows for different protocol headers. In some cases, it's also

applicable to achieve the cross-layer compression by V-OHC, as illustrated in Fig. 8.

In OHC, CRC is independently calculated in OH1/ OH2/ OH3, while it will be calculated once in VOH. Besides, only the UDP checksum in OH3 will be kept in V-OHC, since it covers the calculation of the UDP checksum in OH1. The structure of the VOH header is presented in Table VIII. It achieves a reduction in header size from 9 to 5 bytes while retaining essential data. Additionally, the calculation latency is expected to decrease significantly due to the simplified nature of V-OHC. In this case, OH1, OH2 and OH3 header are integrated by VOH header, achieving cross-layer header optimization.

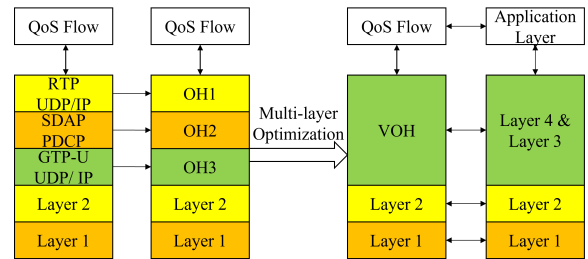


Fig. 8. Multi-layer Optimization for a QoS Flow

 TABLE VIII
STRUCTURE OF VOH FOR CROSS-LAYER OPTIMIZATION

Octet							
0	1	2	3	4	5	6	7
0	SN_RTP			N-PDU Num			
SN_GTP-U				SN_PDCP			
SN_UL_QFI				CRC			
GTP-related UDP Checksum_1				GTP-related UDP Checksum_2			

D. Evaluation Metrics

The average header compression rate \bar{S}_H for a sequence of N packets is shown as:

$$\bar{S}_H = \frac{1}{N} \sum_{i=1}^N S_H(i) = \frac{1}{N} \sum_{i=1}^N \frac{UH(i) - CH(i)}{UH(i)}, \quad (1)$$

where $S_H(i)$ indicates the header compression rate for i -th packet, $UH(i)$ denotes the i -th uncompressed header size, $CH(i)$ denotes the i -th compressed header size by applying the compression algorithm.

Besides, the paper measures the transmitted bits per second under the same packet-sending rate, a metric referred to as

“required data rate.” Higher required data rate values indicate that the tested algorithm occupies more transmission resources.

Furthermore, the performance of the algorithm can be evaluated based on the algorithm delay, which can be calculated using CPU timestamping by comparing the time it takes to complete the compression (or decompression) of the i -th packet in the stream to the timestamp recorded at the beginning of the process [8].

E. Simulation Environment and Approaches

The 5G simulation environment is constructed using NS-3. Packet generation is facilitated within this software environment, including the creation of Opus-coded 50-byte voice payloads, H.264-coded 300-byte video payloads. The simulation is configured with a data link rate limit of up to 1Gbps, and transmission latency in the channel is disregarded.

RoHC is implemented utilizing the open-source RoHC_v1 library [9], inheriting essential definitions, concepts, and mechanisms from this library. Wireshark and Matlab are used for data collection, analysis and visualization.

IV. SIMULATION RESULTS AND ANALYSIS

In this section, simulation results over the F1-U and N3 reference points are shown, implementing uncompressed communication, RoHC, OHC, M-OHC and V-OHC. The simulation results over the N3 reference point are only presented briefly since they exhibit substantial similarity to the F1-U simulation results. Separate conclusion tables will be provided for both N3 and F1-U point simulations.

A. Header Optimization by OHC and V-OHC

The simulation results for single flow header optimization are depicted in Fig. 9.

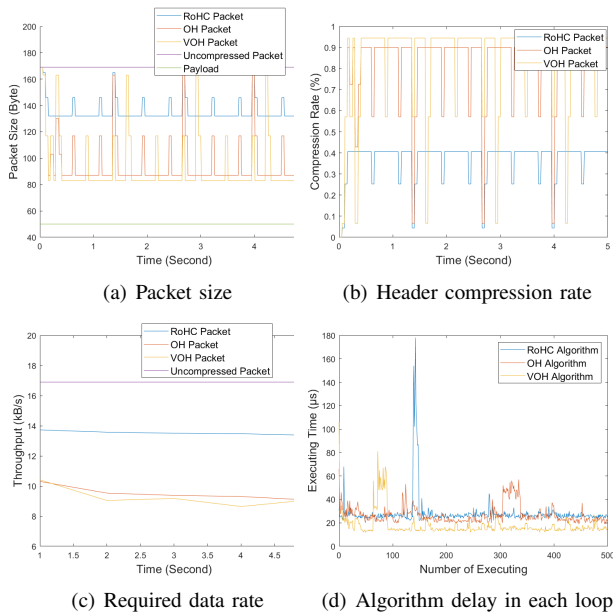


Fig. 9. Simulation results of the algorithms.

The statistics of the simulation results are concluded later. Fig. 9(a) provides the packet size over time for uncompressed packets, RoHC packets, OHC packets and V-OHC packets.

As a result of periodic refreshing for robustness, the flow for the header compression packet (Fig. 9(a)) experiences variations in size. This fluctuation occurs because the algorithm is required to transmit the original header periodically to verify the correctness of compression. Fig. 9(b) depicts the header compression rate of the algorithms. The curve exhibits a periodic pattern due to the recurring refreshing mechanism as discussed above.

The required data rate is shown in Fig. 9(c). The required data rate for OHC algorithm is much smaller than RoHC algorithm, and V-OHC algorithm needs a lower data rate than OHC algorithm.

The algorithm delay for implementing in each loop (header compression and recover once) is shown in Fig. 9(d). The delay for V-OHC algorithm is lower than OHC algorithm since V-OHC achieves cross-layer optimization with a simplified structure. Only one compressor/ decompressor pair is required in V-OHC. The spiking is due to the decompression error. The algorithm needs to retransmit the original header for parameter adaptation.

B. Header Integration for Multiple Flows by M-OHC

The simulation results of a video and an audio flow in the same PDU session are shown in Fig. 10.

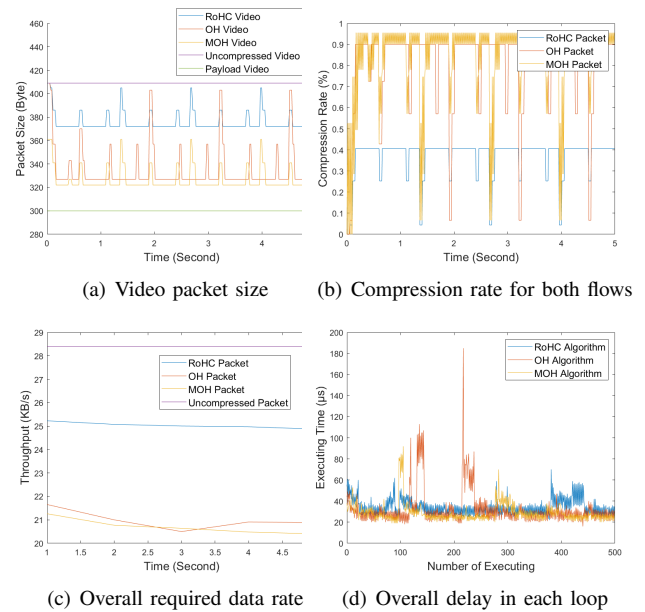


Fig. 10. Simulation results for multiple flows.

Fig. 10(a) illustrates the video packet size over time. The audio packet size curve in this scenario is the same as shown in Fig. 9(a). The curves for RoHC, OHC and M-OHC show periodic ups and downs for the same reason mentioned above. Compared with OHC, the M-OHC curve becomes lower since the OH3 header is not added to the video packet.

Fig. 10(b) shows the overall header compression rate. The M-OHC curve fluctuates because of the round-robin mode transmission for voice-video packets. There are value differences in the compression rate between the video and the voice packet, causing fluctuations in the curve.

The overall required data rate of the algorithms is shown in Fig. 10(c). Compared to OHC, M-OHC gives a better performance since less header is transmitted. The algorithm delay is shown in Fig. 10(d). The spiking is also due to the error. Compared to OHC, the delay in M-OHC decreases a little.

C. Overall Results Analysis

The overall simulation results over F1-U and N3 are shown in Table IX and Table X. Compared with RoHC, OHC can increase the header compression rate by 45% in all scenarios in the F1-U reference point simulation. Two scenarios see a drop in required data rate of 26% and 15%, respectively. OHC reduces the algorithm delay by an average of 6% (2 μ s).

Compared to OHC, both M-OHC and V-OHC increase the header compression rate by 3%. For algorithm delay, M-OHC and V-OHC reduce by 10% and 35%, respectively.

TABLE IX
SIMULATION RESULTS STATISTICS FOR F1-U

Scenario	Evaluation Metric	RoHC	OHC	M-OHC	V-OHC
Single Flow VoIP	Header Compression Rate (%)	34.2	81.1	-	85.5
	Decrease in Required Data Rate (%)	22.1	48.9	-	51.5
	Average Algorithm Delay (μ s)	28.3	26.7	-	17.9
Double Flows Video-Voice	Header Compression Rate (%)	37.2	82.1	85.0	-
	Decrease in Required Data Rate (%)	12.7	28.1	29.1	-
	Average Algorithm Delay (μ s)	34.3	32.0	28.8	-

TABLE X
SIMULATION RESULTS STATISTICS FOR N3

Scenario	Evaluation Metric	RoHC	OHC	M-OHC	V-OHC
Single Flow VoIP	Header Compression Rate (%)	-	82.7	-	84.7
	Decrease in Required Data Rate (%)	-	49.2	-	50.3
	Average Algorithm Delay (μ s)	-	21.9	-	16.0
Double Flows Video-Voice	Header Compression Rate (%)	-	83.2	86.3	-
	Decrease in Required Data Rate (%)	-	27.8	28.8	-
	Average Algorithm Delay (μ s)	-	29.9	26.4	-

In N3, since RoHC is normally not applied over the N3 reference point, the improvement is much better. OHC consistently achieves a header compression rate of 82-83%. OHC reduces the required data rate by 50% and 28% in two scenarios, respectively.

Additionally, M-OHC and V-OHC increase the header compression rate by 2% compared to OHC. The execution time is optimized by 12% and 23% when applying M-OHC and V-OHC in scenarios 2 and 3.

In summary, OHC demonstrates significant improvements in header compression, achieving a minimum increase of 45%. This leads to substantial reductions in latency and resource requirements. Moreover, the application of M-OHC and V-OHC further enhances performance by increasing header compression rates and reducing algorithm delays.

The simulation results also show that OHC has the capability to manage new protocol headers once they have been properly categorized, indicating that it is scalable for future 6G communications.

V. CONCLUSION

To extend the header compression to 5G, OHC algorithm is proposed based on RoHC in this paper. Unlike RoHC, OHC gives a general approach to compressing the new header if it's well classified.

The simulation demonstrates that OHC outperforms RoHC for efficiently optimizing redundant header information in 5G networks. OHC achieves an average of 45% improvement for header compression, translating to significant reductions in data rate requirements. Moreover, cross-layer and multiple-flow header optimizations are achieved by V-OHC and M-OHC, respectively, to provide a better performance, especially in algorithm delay.

The simulation also illustrates the possibility of extending the header compression range, which shows the potential usage in future 6G communications

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