Impacts of IPv6 on Robust Header Compression in LTE Mobile Networks

Daniel Philip VENMANI [*†]
Marion DUPREZ
*Orange Labs-
France Telecom R&D,
Issy les Moulineaux, France
danielphilip.venmani@orange.com
marion.duprez@orange.com

Houmed IBRAHIM
Yvon GOURHANT
Orange Labs-
France Telecom R&D
Lannion, France
houmed.ibrahim@orange.com
yvon.gourhant@orange.com

Marie-Laure BOUCHERET
†INP - ENSEEIHT Toulouse
Toulouse Cedex 7, FRANCE
marie-Laure.boucheret@enseeiht.fr

*Abstract***— LTE is an all-IP based 3GPP architecture, meaning that the transport in the network is based on IP, as post-Release 5 UMTS, unlike the former 3GPP architectures like GSM, Release 5 UMTS whose transport is based on ATM. Hence, fore-runners in this field have deployed with IPv4 as the basic protocol for addressing and transport, although the deployment of LTE is still in its initial phase and trial runs are executed by various operators. But findings and results prove that the exhaustion of IPv4 will not make it possible anymore IPv4 addresses for this new technology to take its full fledge. Hence, this led to the necessity of considering IPv6 as the protocol for addressing and transport. The primary reason to perceive IPv6 is its scalability feature meaning that it supports large address spacing. Now, with this in mind, when IPv6 is considered in the LTE architecture, the possible impacts on the network are investigated in depth in this paper. This is began by considering IPv6 in transport and application level in the different network entities in the LTE architecture like e-Node B, Serving-GW, PDN-GW and the transition impacts from IPv4 to IPv6 is analyzed. Based on preliminary empirical evaluation, our conclusion is that despite the fact that IPv6 offers large address spacing, the fact that the size of the IPv6 header is 20 bytes more than the header of IPv4, leads to complications as well.**

Keywords- IPv4, IPv6, LTE, ROHC.

I. INTRODUCTION

Next generation mobile communication systems are driven by demands that are expected to provide higher data rates and better link quality with the ability to support real-time and non-real time applications compared to the existing systems. The User Equipments (UE) nowadays are able to provide various internet applications and services that raise the demand for high speed data transfer and Quality of Service (QoS) and the dependency on Internet Protocol (IP) addresses [1] becomes a vital ingredient to rolling out services. Orthogonal Frequency Division Multiple Access (OFDMA) [2] and Single Carrier Frequency Division Multiple Access (SC-FDMA) [2] are strong multiple access candidates for the uplink of the International Mobile Telecommunications-Advanced (IMT-Advanced). These multiple access techniques in combination with the rise of the Mobile Internet will be utilized to reach the targeted IMT-Advanced system performance. Thus, IP capabilities are coming front and center for many operators. 3GPP [3] has responded to this trend with an all-IP core network called the Evolved Packet Core (EPC) and new packet-optimized access technologies like Evolved UMTS Terrestrial Radio Access Network (E-UTRAN), otherwise known as Long Term Evolution (LTE) [4]. LTE, whose radio access is called E-UTRAN, is expected to substantially bring improved user experience with full mobility. With the emergence of IP as the protocol of choice for carrying all types of traffic, LTE is scheduled to provide support for IP-based traffic with end-to-end QoS. With IP being the basic protocol for transport, the issue of Internet Protocol version 4 (IPv4) [5] exhaustion is considered to be pit-stop towards the implementation of LTE networks widely. Hence, the choice of adapting to another version of IP, which is Internet Protocol version 6 (IPv6) [6], [7], is deliberated to be the need of the hour.

With IPv6 in mind, in this paper, we analyze into various impacts on the LTE networks from a mobile network operators' point of view. The particularity of this paper is to analyze the impacts of IPv6 on the Radio Access Networks, i.e., to look into the impacts on the e-Node B in the LTE architecture. It gets deeper into the topic discussion where the analysis takes its root into the concepts of analyzing the impacts of IPv6 focusing on Robust Header Compression (ROHC) [8]-[12] comparing it with the existing IPv4 addressing scheme and looking into the possible changes that could occur when IPv6 comes into existence. The main conclusion of this paper is that, IPv6 besides its various numerous advantages also brings side effects that have to be taken care of. The issue of incompatibility between the existing IPv4 protocol and the IPv6 protocol could be one of the major problems that should be dealt with great care, besides considering the ways to handle the 20 extra header bytes of IPv6. Therefore, it must be considered in all phases of the development and deployment process by network operators and equipment vendors.

The rest of the paper is structured as follows. Section II elaborates our motivation to carry out research within this area stating briefly the impacts of IPv4 address exhaustion. It then describes the role of IP within the context of LTE/EPC networks, extending further identifying the role of IPv6 within LTE/EPC networks. Continuing further is section III which presents a brief state of the art on ROHC mechanisms, then the impact of IPv6 address on ROHC and finally the performance of ROHC with IPv4 and IPv6 packets are evaluated empirically, concluding the paper.

ISBN: 978-1-61208-186-1

II. NECESSITY FOR IPV6 IN LTE

An address goes through a number of stages on the path to deployment. Originally the address block is a parameter set of the underlying protocol, and the intended purpose of segments of the address space is described in an address architecture. The number of IPv4 addresses, while vast, is finite. The '/8' IANA blocks for Regional Internet Registries (RIRs) is 0% as of February 03, 2011 [13]. Subsequently, the addressing pool available to RIRs for assignment to Internet Service Providers is anticipated to run-out in the following 2-3 years. Most of the IPv4 address exhaustion mitigation strategies rely on network service providers to act as gatekeepers to selectively issue temporary IPv4 addresses to users. Allocating temporary addresses has technical problems, such as limiting users to existing applications. The impact of IPv4 address exhaustion includes policy issues, where it can be used in a predatory manner to keep competitive services out of the reach of a service provider's customer base. The third generation (3G) mobile network on its own easily consumed a majority of the available addresses. Running out of addresses does not mean the IPv4-based Internet will suddenly stop working. Nevertheless, it does mean it will be difficult, if not impossible, to distribute new IP addresses to new or expanding enterprises. Such a limitation will have clear impacts on commerce and innovation.

A. *Impacts of IPv4 Address Exhaustion*

There are two simultaneous approaches to addressing the run-out problem: delaying the IPv4 address exhaustion, and introducing IPv6 in operational networks. Delaying the public IPv4 address exhaustion involves assigning private IPv4 addressing for end-users, as well as extending an IPv4 address (with the use of extended port ranges). Mechanisms such as a Network Address Translator (NAT) and "A+P" [14] are used at the provider premises (as opposed to customer premises in the existing deployments) to manage IP address assignment and access to the Internet. In a mobile network, the IPv4 address assignment for a Mobile Node (MN) is performed by the Mobile Network Gateway [15]. In the 3GPP network architecture, this assignment is performed in conjunction with the Packet Data Network (PDN) connectivity establishment. A PDN can be understood to be the end-to-end link from the MN to the MNG. There can be one or more PDN connections active at any given time for each MN. A PDN connection may support both IPv4 and IPv6 traffic (as in a dual-stack PDN in 4G LTE networks) or it may support either one only (as in the existing 3G UMTS networks). The IPv4 address is assigned at the time of PDN connectivity establishment, or is assigned using the Dynamic Host Configuration Protocol (DHCP) after the PDN connectivity is established. This IP address needs to be a private IPv4 address which is translated into a shared public IPv4 address in order to delay the exhaustion of public IPv4 addresses as IPv6 is being deployed. Hence, there is a need for private - public IPv4 translation mechanism in the mobile network. In the Long-Term Evolution (LTE) 4G network, there is a requirement for an always-on PDN connection in order to reliably reach a mobile user in the All-IP network. If this PDN connection were to use IPv4 addressing, a private IPv4 address is needed for every MN that attaches to the network. This could significantly affect the availability and usage of private IPv4 addresses. Alternatively, the always-on PDN connection may be assigned with an IPv6 prefix (typically a /64) at the time of connection establishment, and an IPv4 address is assigned only on-demand (e.g., when an application binds to an IPv4 socket interface). This is feasible on the same (dual-stack) PDN in LTE networks (with short DHCP lease times), or with on-demand IPv4 PDNs. On-demand IPv4 PDN and address management can be effective in conserving IPv4 addresses; however, such a management could have some implications to how the PDN and addresses are managed at the MN. On the other hand, in the existing 3G UMTS networks, there is no requirement for an always-on connection (a 'link' from the MN to the MNG in 3G UMTS is referred to as a Packet Data Protocol (PDP) context/connection) even though many Smart Phones seldom relinquish an established PDP context. And, the existing (so-called pre-Release-8) deployments do not support the dual-stack PDP connection. Hence two separate PDP connections are necessary to support IPv4 and IPv6 traffic. Even though some MNs (especially the Smart Phones) in use today may have IPv6 stack, such a capability is not tested extensively and deployed in operational networks. Given this, it is reasonable to expect that IPv6 can only be introduced in the newer MNs, and that such newer MNs still need to be able to access the (predominantly IPv4) Internet.

B. *IP in LTE/EPC Mobile Networks*

The concept of Fixed-Mobile convergence is already on its verge of deployment. The primary reason for this is the use of the IP transport layer for both wired and wireless networks. These converged networks will be the building blocks for “All-IP Networks”. As stated previously, LTE evolution calls for a transition to a “flat”, all-IP core network with open interfaces, called the Evolved Packet Core or EPC. While the EPC has been defined in conjunction with LTE, it is an open next generation packet core for all networks, including 2.5G, 3G, 4G, non-3GPP, and even fixed networks. LTE network, slightly differing from the traditional architectures, with the base station controller (BSC) or radio network controller (RNC) integrated into the access or core layers in a dual network structure. Base stations which are e-Node B are connected to the EPC through IP, and services are accessed through gateways. The traditional circuit switched domain is removed and service access, bearing, switching, coordination, charging and control are packet domain and IP-based. Therefore, this leads to the so-called mobile network IP transformation to enable the traditional technologies to co-exist with the emerging IP-based LTE technologies. This IP transformation can be realized through three steps as follows:

- First comes the IP transformation of interfaces. IP transmission can be used between 3G base stations and BSCs. In this case, lease and construction costs are reduced in traditional time division multiplexer

(TDM) transmission, and sufficient bandwidth is provided for high-speed data services. In the GSM system, the IP transformation of A interfaces can reduce TransCoder (TC) and network costs, enabling TransCoder Free Operation (TrFO) and enhanced voice quality. Interface IP transformation has less impact on the entire network architecture and is easy to achieve.

- The second stage involves the IP transformation of the kernel. As the keys for mobile network IP transformation, prerequisites to avoid failure are strong network capabilities and a thorough knowledge of transmission and data communications. Data sent from a base station to the BSC through IP is not switched or decoded, but is transmitted to the core network directly through an IP switch. Highly-integrated digital signal processing (DSP) and multi-kernels can be applied to enhance equipment performance, reduce power consumption and save resources.
- The final stage describes the IP transformation of services. When network entities and the entire network are transformed to IP, service access can be simplified to a connection between servers and gateways. With the help of an OSS/BSS system, mobile network operators can deploy and manage telecom services just as Internet service providers run their Web services. The IP transformation of the mobile network is an important step for LTE All-IP and flat network architecture, and also a preparation for LTE network architecture.

C. IPv6 in LTE/EPC mobile networks

The considerations from the preceding paragraphs thus led to the following observations. First, there is a need to support private IPv4 addressing in mobile networks in order to address the public IPv4 run-out problem. This means there is a need for private - public IPv4 translation in the mobile network. Second, there is support for IPv6 in both 3G and 4G LTE networks already in the form of PDP context and PDN connections. Also, mobile Internet access from smart phones and other mobile devices is accelerating the exhaustion of IPv4 addresses. It goes without saying that to realize LTE, it needs IPv6.

III. IMPACTS OF IPV6 ON ROHC

As the networks evolve to provide more bandwidth, the applications, services and the consumers of those applications and services, all compete for that bandwidth. For network operators it is important to offer a high QoS in order to attract more customers and encourage them to use their network as much as possible. Hence among many, one of the advantages could be achieving higher average revenue per user (ARPU).

A. Introduction to IP Header Compression

In many services and applications like Voice over IP (VoIP), interactive games, multimedia messaging etc, the payload of the IP packets is almost of the same size or even smaller than the header. Over the end-to-end connection, comprised of multiple hops, these protocol headers are extremely important but over just one link (hop-to-hop) these headers can be compressed and must be uncompressed at the other end of the link. It is possible to compress those headers, providing in many cases more than 90% savings (described in Section IV), and thus save the bandwidth and use the expensive resource efficiently. Thus, IP header compression is the process of compressing excess protocol headers before transmitting them on a link and uncompressing them to their original state on reception at the other end of the link [16]. It is possible to compress the protocol headers due to the redundancy in header fields of the same packet as well as consecutive packets of the same packet stream. IP header compression thus provides a reduction in packet loss and improved interactive response time by compressing the IP headers. On low bandwidth networks, using header compression results in better response times due to smaller packet sizes, i.e., improved RTT values can be observed. A small packet also reduces the probability of packet loss due to bit errors on wireless links resulting in better utilization of the radio spectrum. It has been observed that in applications such as video transmission on wireless links, when using header compression the quality does not change in spite of lower bandwidth usage. For voice transmission, the quality increases while utilizing lower bandwidth.

B. ROHC Scheme

The compression mechanism for IP headers described in the previous section for IP are not considered robust because they do not perform well on links with high error rates and long round trip times like the wireless links and do not take into account that some applications may actually benefit that delivering packets with errors. Therefore, Robust Header Compression emerged from the need to standardize a single, solid and extendable header compression protocol that performed well over links with high error rates and long link round trip times, taking into account the problems shown by its predecessors. ROHC scheme uses window based least significant bits encoding for the compression of dynamic fields in the protocol headers. Due to its feedback mechanism, ROHC is robust on wireless links with high BER and long RTT. It can achieve compression up to 1 byte and thus it is more efficient than other compression schemes. Even though it is complex compared to earlier schemes, it is suitable for wireless networks, which use the very expensive radio spectrum resource.

C. ROHC mechanism

The fundamental challenge in header compression for transmission over wireless links is to maintain the correct context at the decompressor in the face of quite frequent bit errors in the received packets. ROHC supports three different modes for maintaining the context in different wireless systems [9]. The unidirectional mode is designed for systems without a feedback channel from the decompressor to the compressor, i.e., where the decompressor can not acknowledge the correct receipt of context information. To overcome this limitation, the compressor periodically retransmits the context information. The bidirectional optimistic mode and the bidirectional reliable mode are designed for systems with a feedback channel from the decompressor to the compressor, i.e., where the decompressor can acknowledge the correct receipt of context information and/or send negative acknowledgements to request the retransmission of context information. With the bidirectional optimistic mode, bit errors in the compressed header are detected with a 3-bit cyclic redundancy check (CRC) code. When the CRC check fails the decompressor generally discards the affected packet and attempts to repair its context either locally or by requesting a context update from the compressor. The reliable mode extends the optimistic mode by a more complex error detection and correction which uses a larger number of coding bits. Fig. 1 illustrates ROHC mechanism.

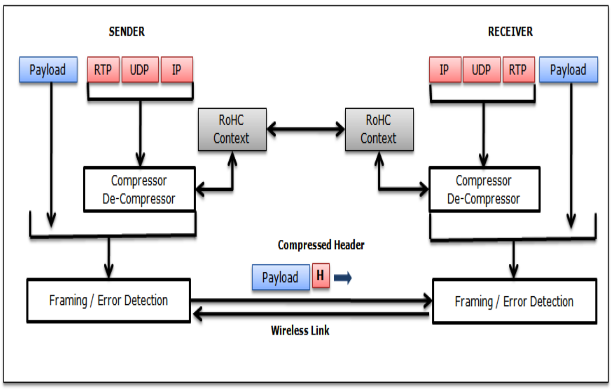

Figure 1. ROHC mechanism

The ROHC compressor replaces the RTP/UDP/IP headers by its own, much smaller header. On the receiver side the decompressor transforms the ROHC header into the original protocol layer headers. A step by step illustration of header compression using ROHC is shown in Fig. 2. A multimedia stream packet composed for an IP network transmission typically consists of a 20 byte IP header (considering it to be an IPv4 address), an 8 byte UDP header, and a 12 byte RTP header. The IPv6 version requires a 40 byte IP header, so the total RTP/UDP/IP header size can sum up to 60 bytes. When voice frame is an audio AMR codec of 12.2 Kbps, it travels on RTP protocol over UDP, besides themselves being very small. Payload is 20 to 60 bytes with a RTP/UDP/IP header of 40 bytes (IPv4=20 bytes; UDP=12 bytes; RTP=8 bytes). Then due to the high relation between header size and payload size, the transmission of VoIP packets is not an efficient process. Being VoIP a protocol to service a playback application (voice playback) its maximum end to end delay should be less that 150-200ms; where 150ms is considered to be the best optimal value. This is to guarantee the good quality of the sound to be transmitted. The efficiency of transmission is low. For transmitting 20-60 bytes, a header of 40 bytes is needed, that results in a relation of 200% to 26.67%. It must be noticed that, because of this significant header's size, the necessary throughput for a VoIP call would be 28.8 kbps (with IPv4) or 36.8kbps (with IPv6) whereas the current service of voice call in circuit switch domain needs a throughput of 12.2 kbps. Thus, the support of this type of packet corresponds to a waste of radio resources and implies the need of performing a compression of RTP/UDP/IP header to reduce the ratio between header and payload's sizes and consequently the necessary throughput, which is carried out by ROHC.

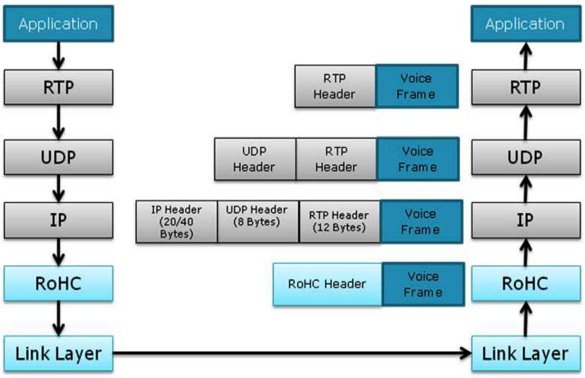

Figure 2. ROHC in a protocol stack

D. *Impact of IPv6 on ROHC in LTE*

While considering the different protocol layers and their functions in the LTE architecture, in the user-plane, the Packet Data Convergence Protocol (PDCP) layer is responsible for compressing and decompressing the headers of user plane IP packets using ROHC to enable efficient use of air interface bandwidth. PDCP specification applies header compression between the e-Node B and the UE in Release 8 onwards. This is depicted in Fig. 3.

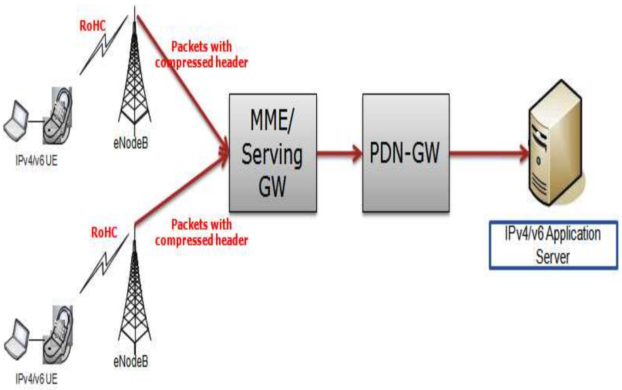

Figure 3. ROHC applied in LTE architecture

Incorporation of header compression between two nodes places restrictions on underlying link layer. IP payload length must be inferred from the underlying link layer. Decompressor must receive the packets in the same order that the compressor sends them. Packets are not duplicated by the link layer between the compressor and decompressor. Header Compression requires extra resources on nodes that instantiate the compression algorithms. This can include additional memory required on nodes for storage of context information and also additional processing required on nodes for compression and decompression of packets. As ROHC always resides above the link layer, the other Internet components do not notice the usage of a compression scheme, but the wireless service provider can take advantage of a significant reduction of the required bandwidth. ROHC requires from the link layer that the packets are sent in a strictly sequential order. Also the packets are not allowed to contain routing information (single hop restriction). As the current LTE architecture implements ROHC with IPv4, the implementation of IPv6 introduces concerns related to expanded packet headers as the size of packet header doubled from 20 Bytes (IPv4) to at least 40 Bytes (IPv6). In addition to the above mentioned case, the incorporation of network-layer encryption mechanism which includes Internet Protocol Security (IPSec) nearly doubles IP operational overhead. Hence, the methods that reduce this expanded overhead will increase user throughput and/or the number of users a network can support.

IV. PERFORMANCE EVALUATION

An empirical evaluation considering three different types of packets to analyze the effect of overhead and to illustrate clearly the use of Robust Header Compression is performed in this section. For the sake of illustrating the same, let us consider an uncompressed IPv4 packet, uncompressed IPv6 packet and another packet that is compressed using ROHC mechanism.

1) *Considering a Payload that could be the size of the maximum allowable MTU size of the network.*

a) Case 1: Uncompressed IPv4 packet with an IPv6 payload.

Here, the case deals with the scenario when the UE tries to send a packet with an IPv4 header and with an IPv6 payload of size of 1442 bytes (here 1442 bytes is considered as the MTU for the payload since the total payload of the whole packet should sum upto 1500 bytes). Also, the packet is encapsulated with a RTP and UDP header. Fig.4 below illustrates this pictorially.

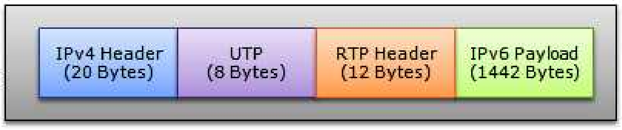

Figure 4. Uncompressed IPv4 packet with an IPv6 payload

Overhead = Total Header bytes / Total bytes transmitted = (40 / 1442) * 100 = 2.77%

b) Case 2: Uncompressed IPv6 packet with an IPv6 payload.

Here, the UE tries to transfer a packet with an IPv6 header with an IPv6 payload. Hence, the packet format and structure looks like in the Fig. 5.

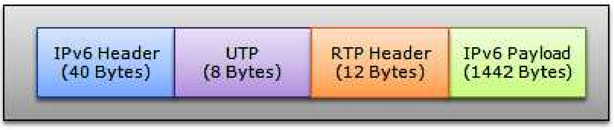

Figure 5. Uncompressed IPv6 packet with an IPv6 payload

Overhead = Total Header bytes / Total bytes transmitted = (60 / 1442) * 100 = 4.16%

c) Case 3: Packet compressed using ROHC mechanism with an IPv6 payload.

Assuming robust header compression algorithm is applied to the RTP/UDP/IP header, overhead calculations can be made:

Overhead = Total Header bytes / Total bytes transmitted = (2 / 1442) * 100 = 0.14%

2) *Considering a VoIP Payload*

Here, inorder to illustrate effect of ROHC in the voice packets, we consider VoIP payload with audio codecs. The chosen codec is AMR with the mode corresponding to a throughput of 12.2kbps. Each 20ms, a 32 bytes long packet is generated by the codec. After encapsulation by the protocols described before, the packet to transmit on radio interface is much bigger than the initial AMR payload packet. Hereafter is illustrated the overhead introduced with all these encapsulations.

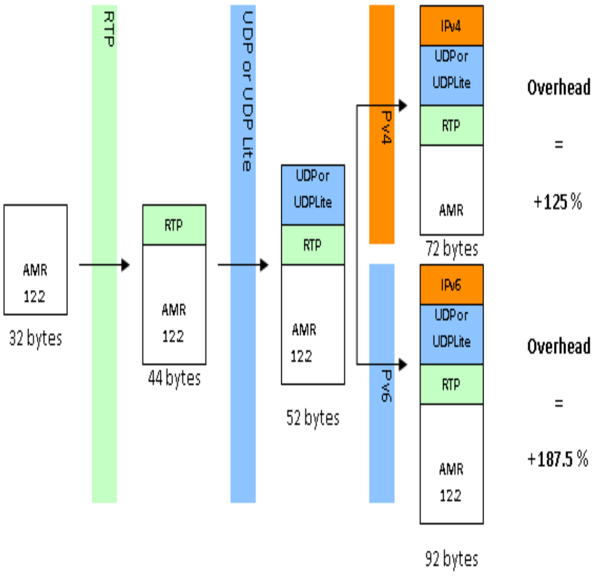

Figure 6. Overhead introduced with VoIP with AMR 12.2 Kbps

a) Case 1: Uncompressed IPv4 Header with an VoIP payload.

Overhead = Total Header bytes / Total bytes transmitted = (40 /32) * 100 = 125%

b) Case2: Uncompressed IPv6 Header with an VoIP payload.

Overhead = Total Header bytes / Total bytes transmitted = (60 /32) * 100 = 187.5%

c) Case3: VoIP Packet Compression with ROHC.

Overhead = Total Header bytes / Total bytes transmitted = (3 /32) * 100 = 9.375%

Therefore, to meet the requirements in terms of delay, jitter and latency for interactive communication, like VoIP, where delay is also caused due to sampling and packetization, the transmission must be minimized. When using the Real-time Transport Protocol (RTP) and IP/UDP/RTP headers for encapsulating voice samples, the ratio between the IP/UDP/RTP header portion and payload size is typically 2:1 and 3:1 for IPv4 and IPv6 respectively. Using ROHC in such scenarios will increase the wireless capacity by the factor of 3 and 5 for IPv4 and IPv6 respectively. The table below summarizes the different possible compressed gain values that can be obtained from various combinations of the headers calculated empirically as above.

TABLE I. HEADER COMPRESSION GAINS

Protocol Headers	Total Header Size (Bytes)	Minimum Compressed Header Size (Bytes)	Compressed Gain %
IPv4/TCP	40	4	90
IPv4/UDP	20	1	96.4
IPv4/UDP/RTP	40	1	97.5
IPv6/TCP	60	4	93.3
IPv6/UDP	48	3	93.75
IPv4/UDP/RTP	60	3	95

Although, from the results above we can conclude that the percentage compressed gain for IPv4 header is greater when compared to the compressed gain of IPv6 header, ROHC yields benefits in both IPv6 and IPv4. Infact, there are greater benefits with IPv6 due to a fixed-size header and static fields leading to even better compression efficiency gains. For e.g., a typical RTP/UDP/IPv4 has static fields of 25 Octets and dynamic fields of 15 Octets and a typical RTP/UDP/IPv6 has a static fields of 49 Octets and dynamic fields of 11 Octets. Therefore, IPv6 compressed headers are smaller than IPv4 compressed headers, as only fewer octets are dynamic. Additionally, there is no fragmentation in the network with IPv6 in the presence of path MTU discovery in IPv6, making every datagram compressible in IPv6. It should be noted, however, that smaller packets offer a smaller target for bit errors. So the packet loss rate for any compression method should be lower than for uncompressed packets. So if ROHC has only a very small probability of loss of sync between compressor and/or decompressor state machines, there should be a small reduction in overall packet loss rate between applications. This is a minor effect. The main purpose of ROHC is just to not increase the packet loss rate between applications.

V. CONCLUSIONS

The evolution from existing networks to LTE should be a smooth and gradual process through mobile network IP transformation. The most interesting question to be addressed here is, is this shortage of IPv4 addresses, a problem or an opportunity? Hoarding IPv4 addresses and postponing IPv6 deployment means that the countries laying away IPv4 risks becoming an island in the global next-generation Internet. Our preliminary results here show that, inorder to facilitate quick prototyping and rapid implementation, it is very important to consider even small details such the impact of ROHC within LTE. Our evaluation identifies the global addressing problem in the context of efficient network utilization that helps network designers and vendors to carefully design their system. With IPv6 widely seen as crucial for the continued operation and growth of the Internet, it is critical in mobile networks in particular. It goes without saying that to realize this vision, LTE needs IPv6. IPv6 is a minor aspect in the big LTE scheme of things but is essential for its success as a truly global and pervasive means of communications.

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