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Subject

PERFORMANCE ANALYSIS OF A NEW HEADER COMPRESSION SCHEME FOR TCP STREAMS IN IP BASED WIRELESS NETWORKS

Authors: *Prof. Pietro Camarda, Ing. Sandro Petrizzelli*

Politecnico di Bari – Italy

Speaker: *Prof. Pietro Camarda*

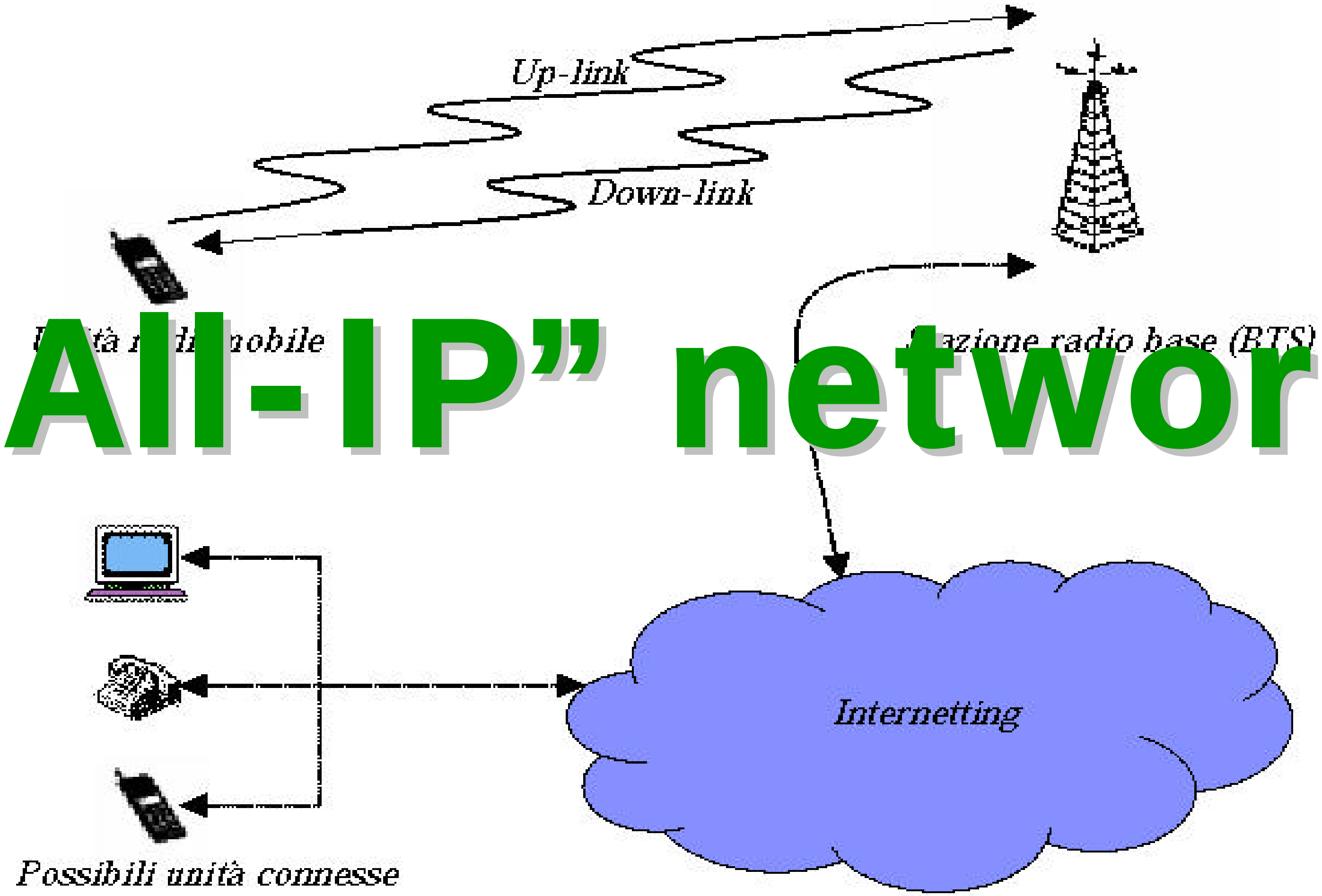
Introduction

- New telecommunication systems will be surely characterized by:
  - convergence between mobile telephony and data transmission
  - network platform totally based on a TCP/IP architecture (all-ip networks)

- It is necessary to optimize the use of the wireless bandwidth, since it is generally the most expensive and limited resource for networks

- In this paper, a new header compression scheme for TCP streams, as a specific header compression profile within the IETF ROHC platform, is proposed and analyzed through simulations by the Network Simulator.

Typical scenery: wireless/wired network



“All-IP” network

Why header compression?

1. The reduction of the overhead is equivalent to the reduction of the consumed bandwidth

$$\mathrm{BW_{TOT}} \;?\; \frac{\mathrm{H ? P}}{\mathrm{T}} \;?\; (\mathrm{H ? P}) ? f_{\mathrm{r}} \;?\; \mathrm{H} ? f_{\mathrm{r}} \;?\; \mathrm{P} ? f_{\mathrm{r}} \;?\; \mathrm{BW_{Header}} \;?\; \mathrm{BW_{Payload}}$$

$$\mathrm{OVERHEAD\,\%} \;?\; \frac{\mathrm{H}}{\mathrm{H ? P}} ?100 \;?\; \frac{\mathrm{H}}{\mathrm{H ? P}} ?100 ?\frac{f_{\mathrm{r}}}{f_{\mathrm{r}}} \;?\; \frac{\mathrm{BW_{Header}}}{\mathrm{BW_{TOT}}} ?100$$

2. For a fixed BER (Bit Error Rate), compression let us transmit less bits and this reduces FER (Frame Error Rate)

$$BER ? x$$

$$FER ? (P ? H) \cdot 8 \cdot BER$$

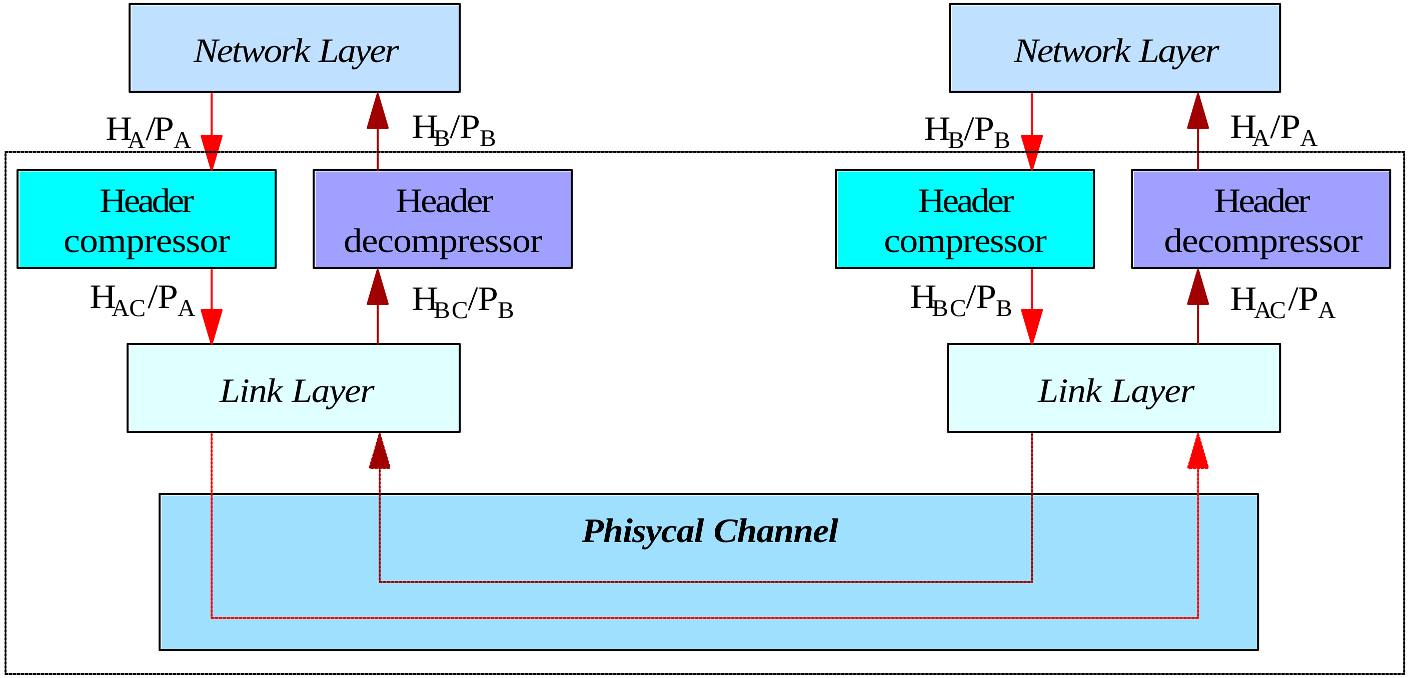
$$FER_C ? (P ? C) \cdot 8 \cdot BER$$

$$?FER\% ? \frac{FER ? FER_C}{FER} ? \frac{H ? C}{H ? P}$$

P	payload (byte)
H	header (byte)
C	compressed header (byte)
FER	$?\ (\mathrm{P ? H})\ ?8\ ?\mathrm{BER}$
$\mathrm{FER_C}$	FER with compressed headers
? FER%	improvement of FER

TCP/IP architecture with header compression module

Two couple of new functional units, the header compressor and the header decompressor, are needed in the TCP/IP architecture: they are positioned just under the network layer of mobile units and network nodes and they are transparent to upper layers



ROHC (Robust Header Compression) RFC 3095/3096

- **Actually, the most important proposal for header compression in wireless systems based on TCP/IP architecture seems to be the ROHC scheme (RObust Header Compression) proposed by IETF.**

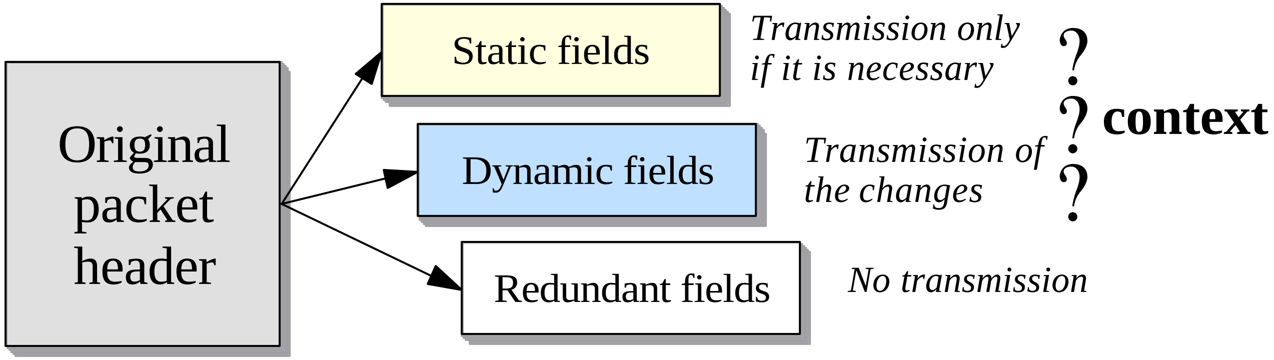
- **ROHC guidelines**
  - **RFC 3095** (July 2001)
    - Compression Profiles 0,1,2,3
    - Guidelines for header compression through ROHC scheme
  - **RFC 3096** (July 2001)
    - Requirements for robust IP/UDP/RTP header compression
  - **Lower Layer Guidelines** for RTP/UDP/IP (draft, Dec 2001)
  - **ROHC Implementer's guide** (draft, Febr 2002)

- **TCP/IP Compression with ROHC**
  - **Requirements for IP/TCP Header Compression** (draft, Febr 2002)
  - **TCP/IP Header Compression** (draft, Jan 2002)
  - **EPIC** (draft, Nov 2001)
  - **TAROC** (draft, Nov 2001)

ROHC: basical concepts (1)

- ROHC scheme uses the redundancy of header fields either within the same packet or between consecutive packets of the same stream

- Header fields are classified in three different classes: static, dynamic, redundant



- The set of static and dynamic fields constitutes the context. Every context is identified by a number called CID

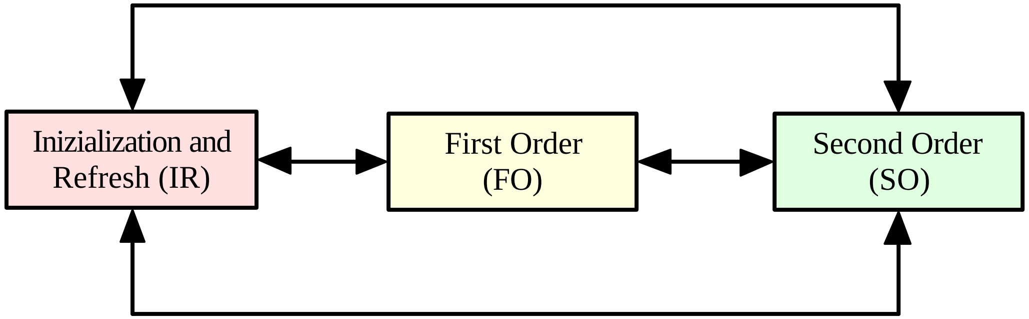
- If compressor and decompressor have the same context (synchronization) and there are no transmission errors, all packets are correctly decompressed

ROHC: basical concepts (2)

- **"Leader" field and "regular" flow**
  - When all the variations of header fields are fully predictable by the knowledge of the **leader field**, the stream is called **regular** and the compressor sends only the variation of the leader field, encoded W-LSB, with high benefit on the overhead and on the robustness level
  - Since TCP header doesn't have such a regular field, we introduce a new *ad hoc* field: **SNR** (Sequence Number ROHC, 2 byte)
- **Encoding methods**
  - The methods for encoding dynamic header fields are a fundamental tool for achieving either a high compression ratio or a good robustness against packet losses and transmission errors
    - **W-LSB encoding**: SNR, TCP SN, ACK SN, IPv4 ID, TCP Window Size
    - **Scaled encoding**: TCP Sequence Number o ACK Sequence Number
    - **Offset encoding**: IPv4 Identification
- **Feedback channel**
  - When it is possible to use a **feedback channel**, the decompressor can use it to send feedback information to the compressor, with the aim of either maintaining the synchronization or increasing the compression ratio

States machines

ROHC header compression can be seen as the interaction between two states machine (compressor and decompressor):

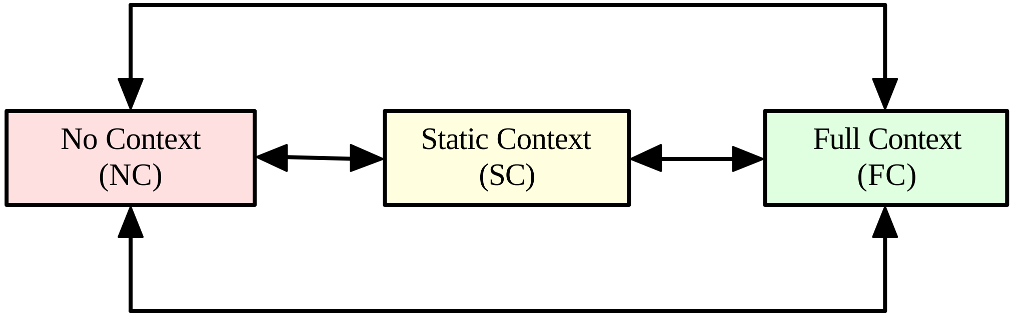


Inizialization and Refresh (IR)

First Order (FO)

Second Order (SO)

Compressor



No Context (NC)

Static Context (SC)

Full Context (FC)

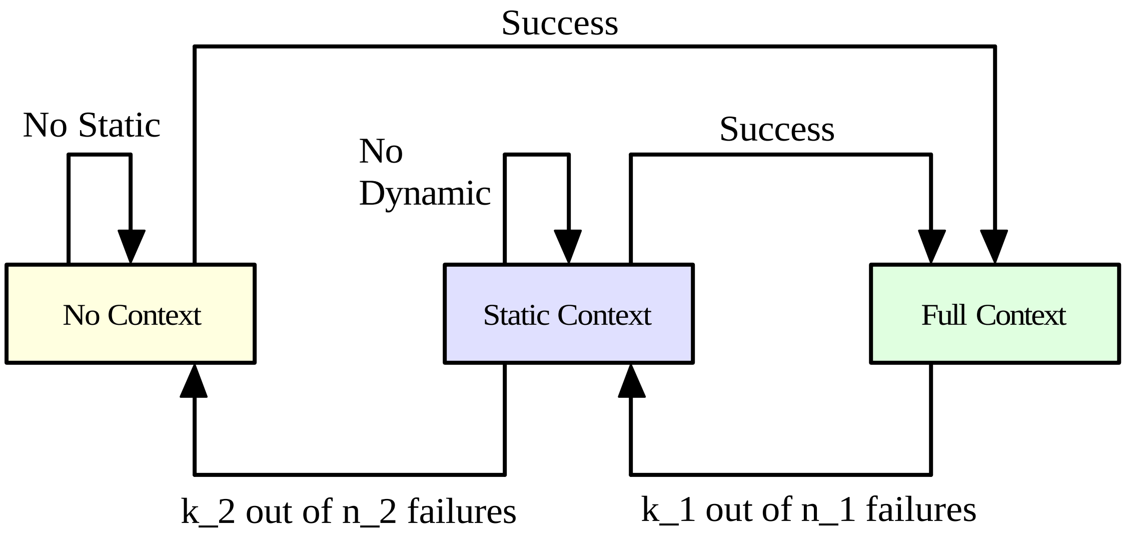
Decompressor

Operative modes

- ROHC compression mechanism is based on three different operative modes:
  - **Unidirectional Mode**
  - **Bidirectional Optimistic Mode**
  - **Bidirectional Reliable Mode**

- Every mode controls the state transitions logic and the actions to perform in each state.
- The state machine for the decompressor is the same in all modes.
- The state machine of the compressor depends on the operative mode

Decompression states



The decompressor starts working always in No Context state.

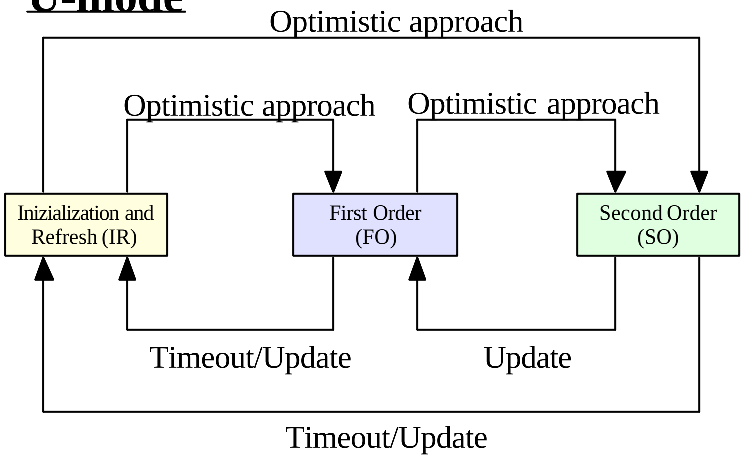
Once a packet has been decompressed correctly, the decompressor can transit to the Full Context state.

After repeated failures, the decompressor first transits back to the Static Context state: there, the reception of any packet sent in the FO state is normally sufficient to enable transition to the Full Context state again.

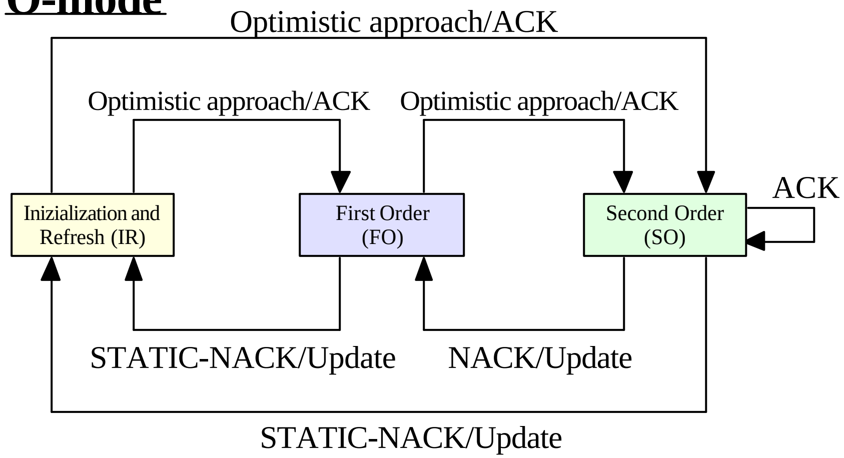
Only when decompression of several packets sent in the FO state fails in the Static Context state, the decompressor will go all the way back to the No Context state, waiting for another initialization packet.

Compression states

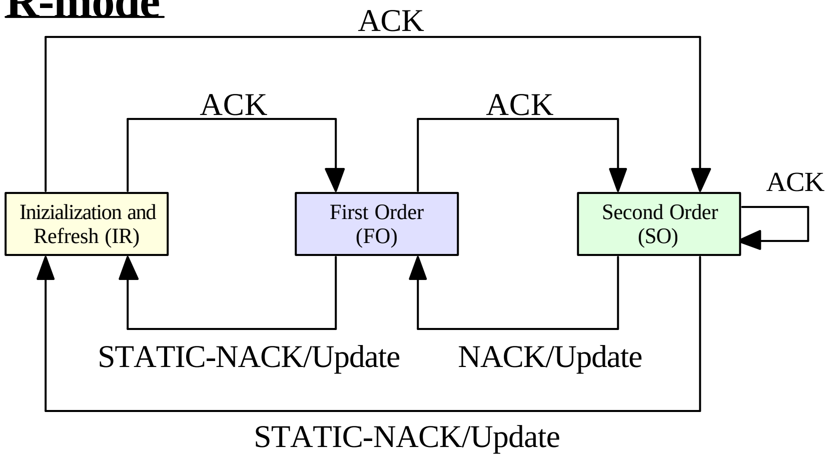
U-mode



O-mode



R-mode

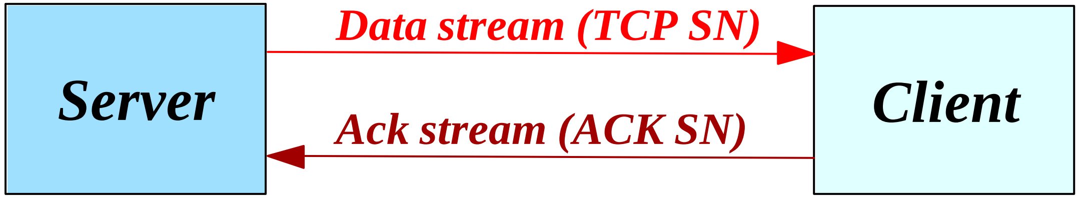


Principal mechanisms:

- Optimistic Approach
- Feedback information (ACK, NACK, STATIC-NACK)
- Updates (stream evolution)

TCP / IP connections

- TCP/IP protocol implements bi-directional reliable connections, that can be described by the combination of two streams:



- Our scheme performs the separate compression of these two streams.
- Every stream is characterized by the presence of a "key field": **TCP Sequence Number** (TCP SN) for the data stream and **ACK Number** (ACK SN) for the ACK stream. The compressor monitors this fields with the aim of establish whether the stream is *regular* or not.
- The evolution of these fields, during the same flow, strongly affects the compression ratio

Errors management

- **Our compression scheme uses five tools for the prevention and the managements of *errors situation*:**

a) **W-LSB** encoding of dynamic fields: this encoding method minimizes the probability of synchronization’s loss in presence of packets losses

b) **Feedback packets**, **timeout mechanism** and **optimistical approach** for the recovery and the maintenance of synchronization

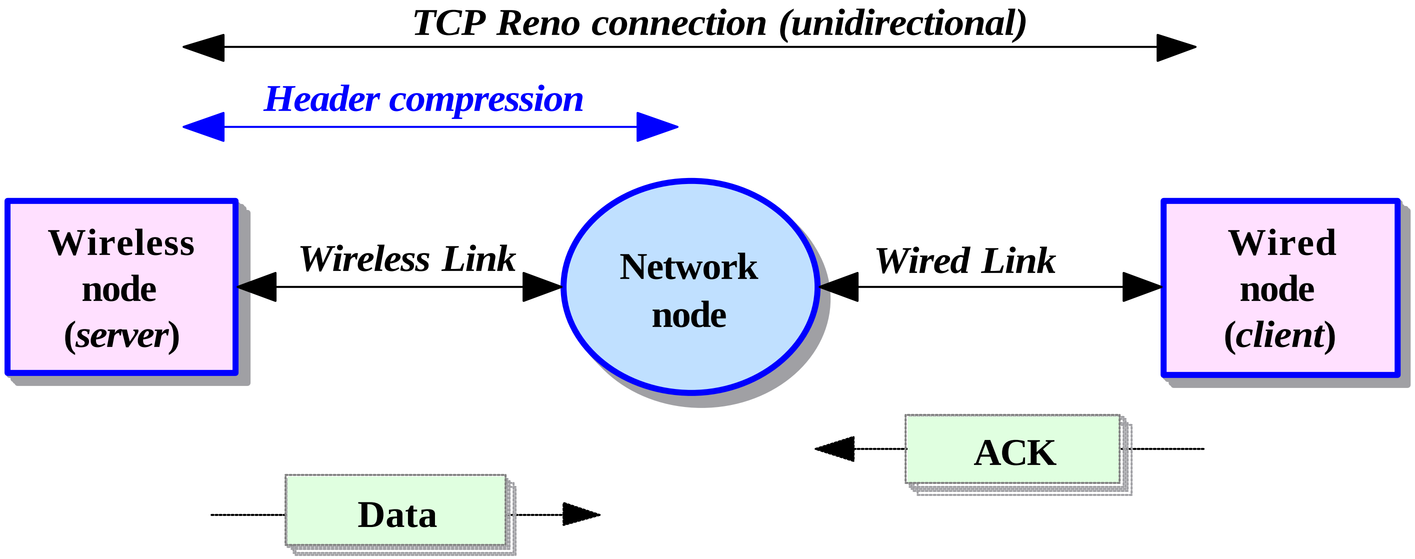
c) **CRC** protection for discovering incorrect decompressions

d) **Local mechanism of context repair** at the decompressor

e) “**Automatic context updates**” in presence of retransmission (data stream) and/or duplicated ACK (ACK stream)

- Only for reliable connections as TCP streams

Simulations



✍Scenery of Simulation (UMTS):

wireless link: bandwidth 9.6 - 384 kb/s, delay 30 ms, BER 10^{-6}-10^{-3}

wired link: bandwidth 2 Mb/s, delay 30 ms, reliable

Assumptions (1)

- *TCP version Reno* - *IP version 4*
- Sequential generation of IPv4 Identification field
- *Small CIDs* (1 byte of costant overhead)
- Virtual Feedback Channel with *piggybacking*
- Wireless Error Model with uniformly distributed errors
  - Variable BER (10^{-6} – 10^{-3})
  - No residual errors over packets delivered to the decompressor

Assumptions (2): TCP header fields management

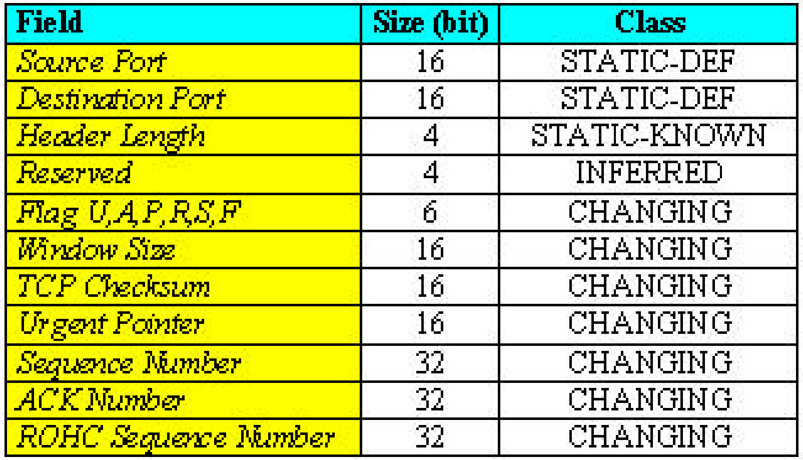
Redundant fields (8 bits):
Header Length, Reserved

Static fields (32 bits):
Source Port, Destination Port

Dyamic Fields (140 bits):
Flags, Window Size, Checksum, Urgent Pointer, SN, ACK SN, SNR

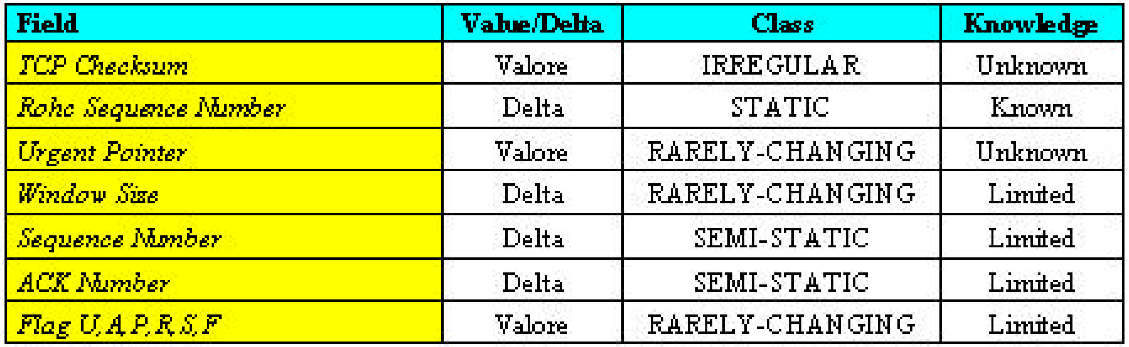
Extra Fields: *Sequence Number ROHC (2 byte), Delta SN (1-2 byte)*

No optional fields



Field	Size (bit)	Class
Source Port	16	STATIC-DEF
Destination Port	16	STATIC-DEF
Header Length	4	STATIC-KNOWN
Reserved	4	INFERRED
Flag U,A,P,R,S,F	6	CHANGING
Window Size	16	CHANGING
TCP Checksum	16	CHANGING
Urgent Pointer	16	CHANGING
Sequence Number	32	CHANGING
ACK Number	32	CHANGING
ROHC Sequence Number	32	CHANGING

Table 1 – Classification of TCP header's field



Field	Value/Delta	Class	Knowledge
TCP Checksum	Valore	IRREGULAR	Unknown
Rohc Sequence Number	Delta	STATIC	Known
Urgent Pointer	Valore	RARELY-CHANGING	Unknown
Window Size	Delta	RARELY-CHANGING	Limited
Sequence Number	Delta	SEMI-STATIC	Limited
ACK Number	Delta	SEMI-STATIC	Limited
Flag U,A,P,R,S,F	Valore	RARELY-CHANGING	Limited

Table 2 - Classification of CHANGING TCP header's fields on the basis of their expected change patterns

Performance criteria

- **Throughput** $$? \frac{P_{\text{recv}}}{\text{T}_{\text{conn}}} \frac{?byte?}{?\; s \;?}$$

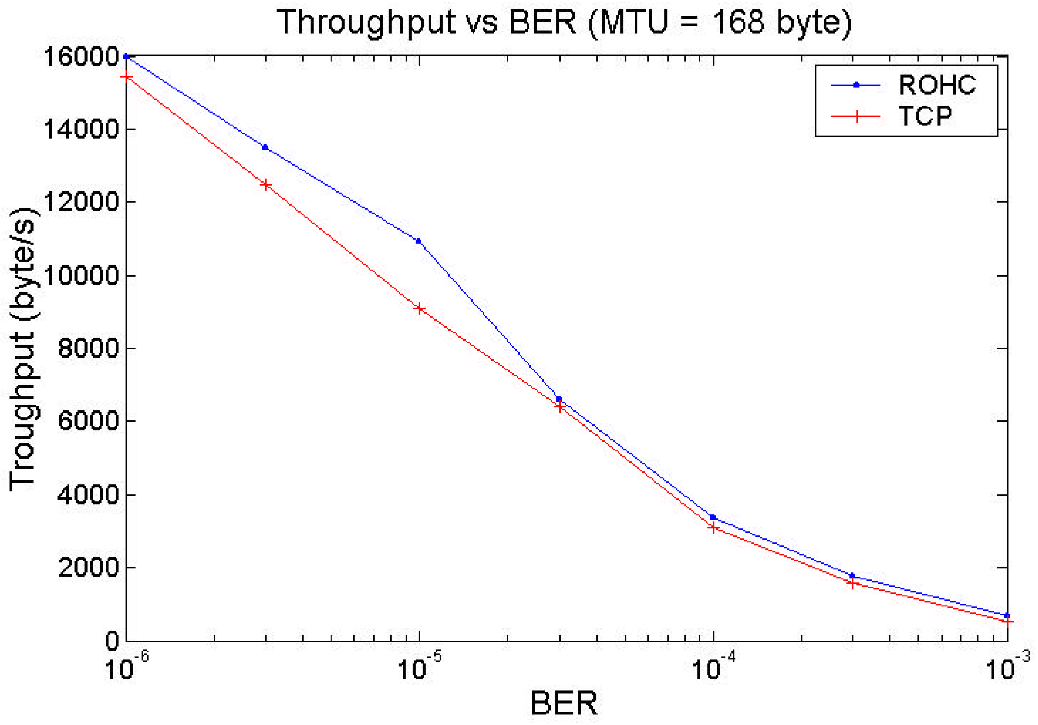
- **Overhead %** $$? \frac{H_{\text{fwd}}}{H_{\text{fwd}} ? P_{\text{fwd}}} ?100$$

- **Goodput %** $$? \frac{P_{\text{recv}}}{?H_{\text{fwd}} ? P_{\text{fwd}} ?? H_{\text{ack}}} ?100$$

Throughput in U-mode

The throughput is always better with compression than without it, even if the improvement is very small. This is a fundamental starting point for every compression scheme

Our scheme is robust with respect to bad wireless channel conditions

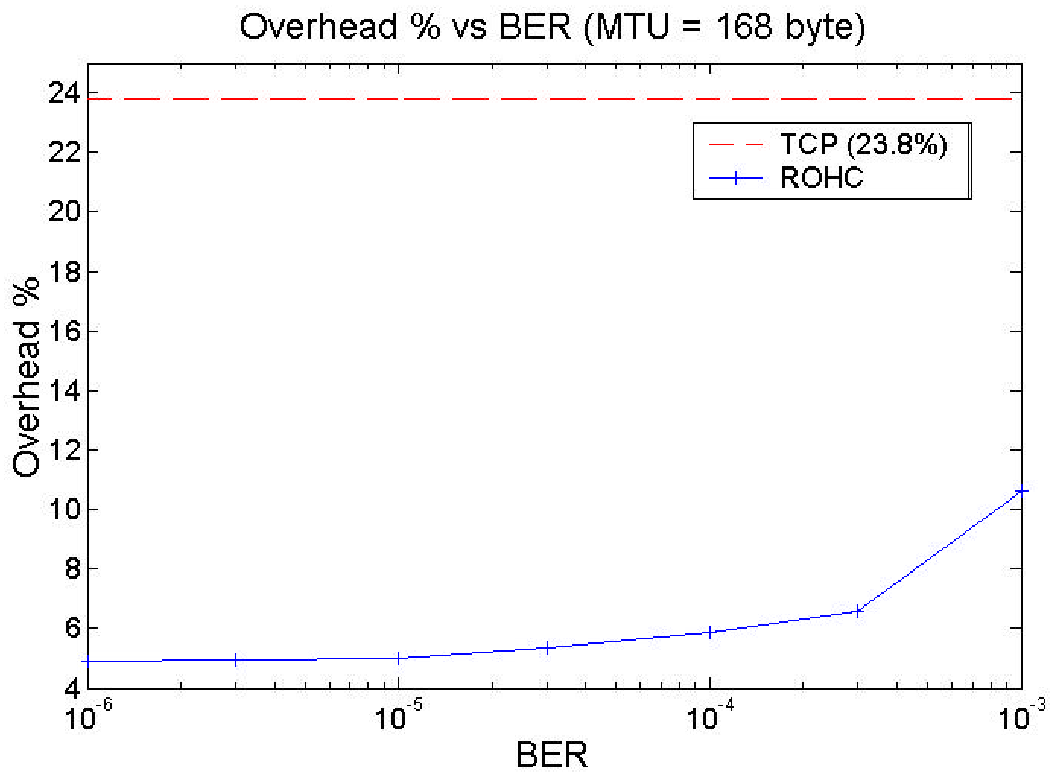


- Variable MTU, Variable BER
- Wireless: 384 kb/s, 30 ms

Overhead in U-mode

Our scheme assures good values of overhead and goodput for every value of BER, but it obtains the best performance when the BER is not excessively high (<10^{-4})

Our scheme is efficient also with bad wireless channel conditions

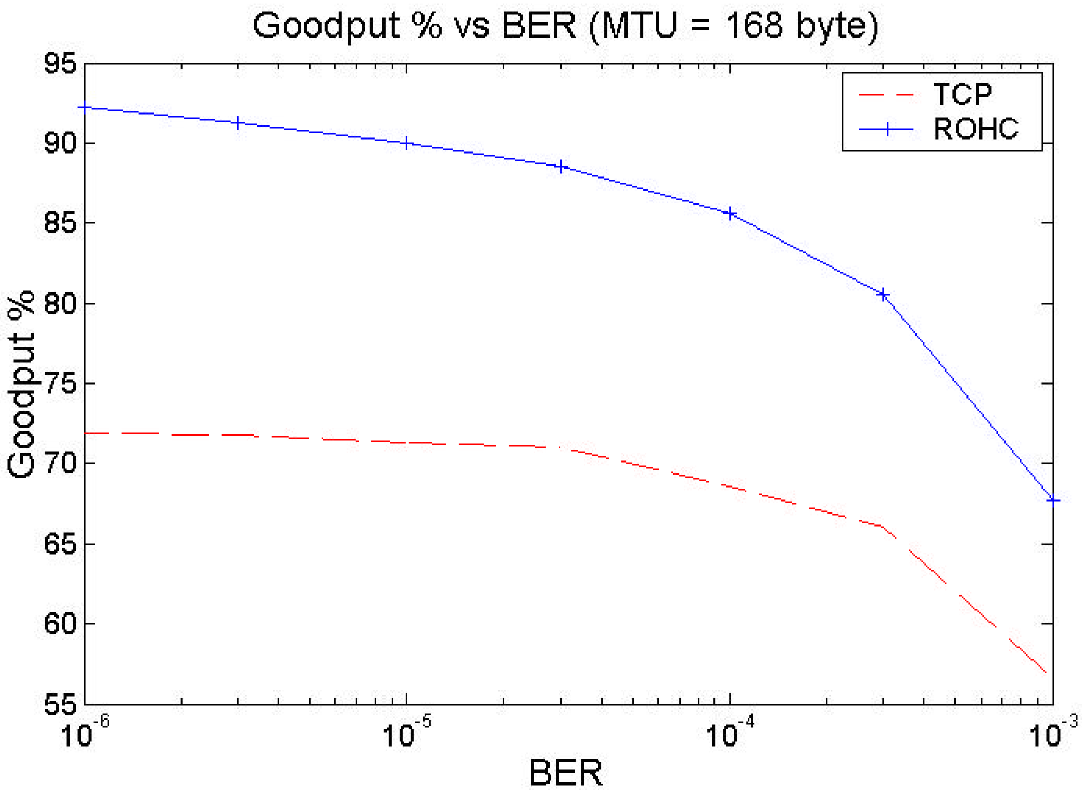


- Variable MTU, Variable BER
- Wireless: 384 kb/s, 30 ms

Goodput in U-mode

Header compression increases the goodput, with high variations also in presence of bad channel conditions

Our scheme is globally efficient for all kinds of wireless channel conditions



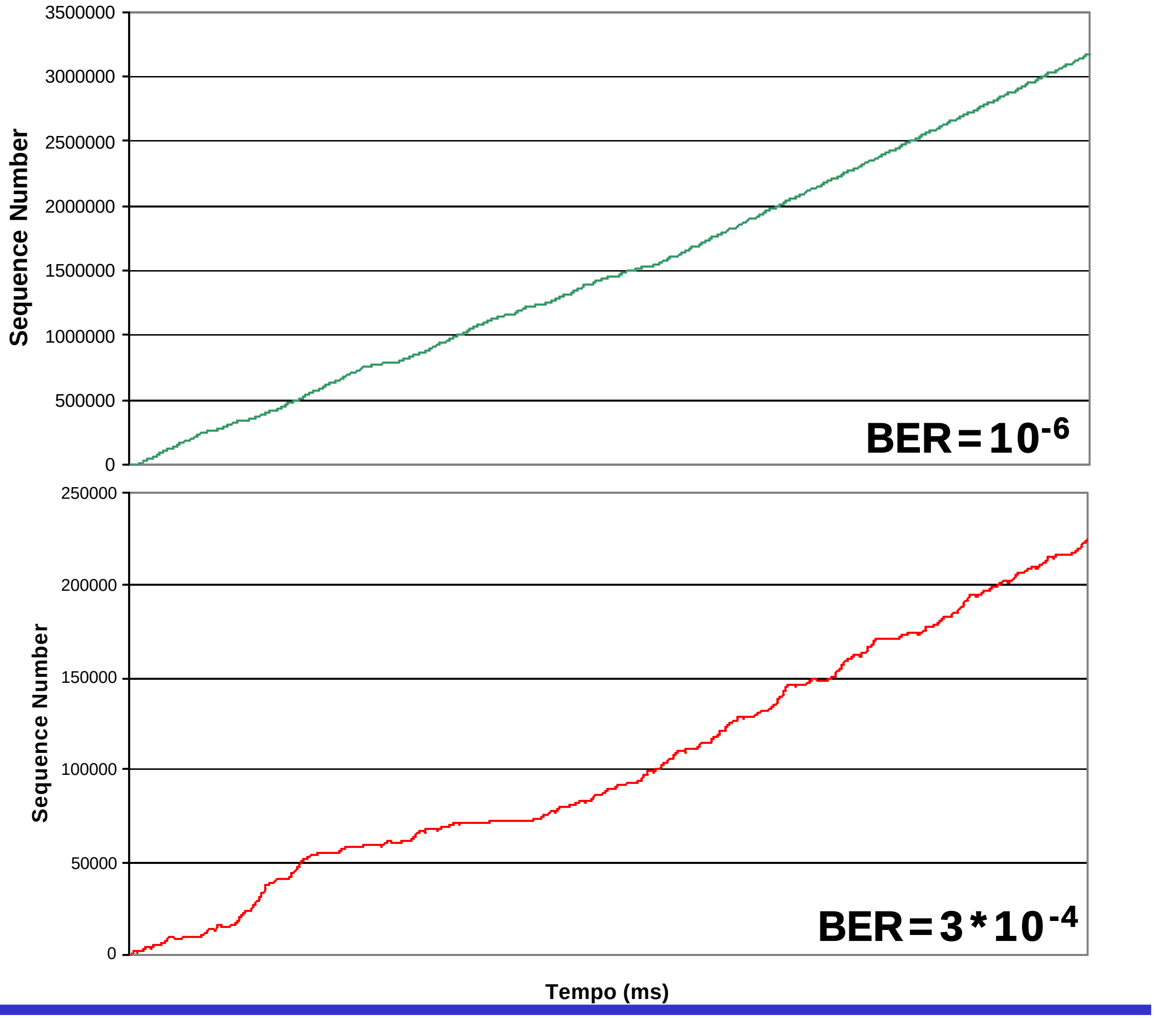
- Variable MTU, Variable BER
- Wireless: 384 kb/s, 30 ms

TCP SN evolution (U-mode)

TCP SN field (resp. ACK SN) has variations strictly influenced by channel conditions, since they affect the number of retransmission (resp. duplicated ACK).

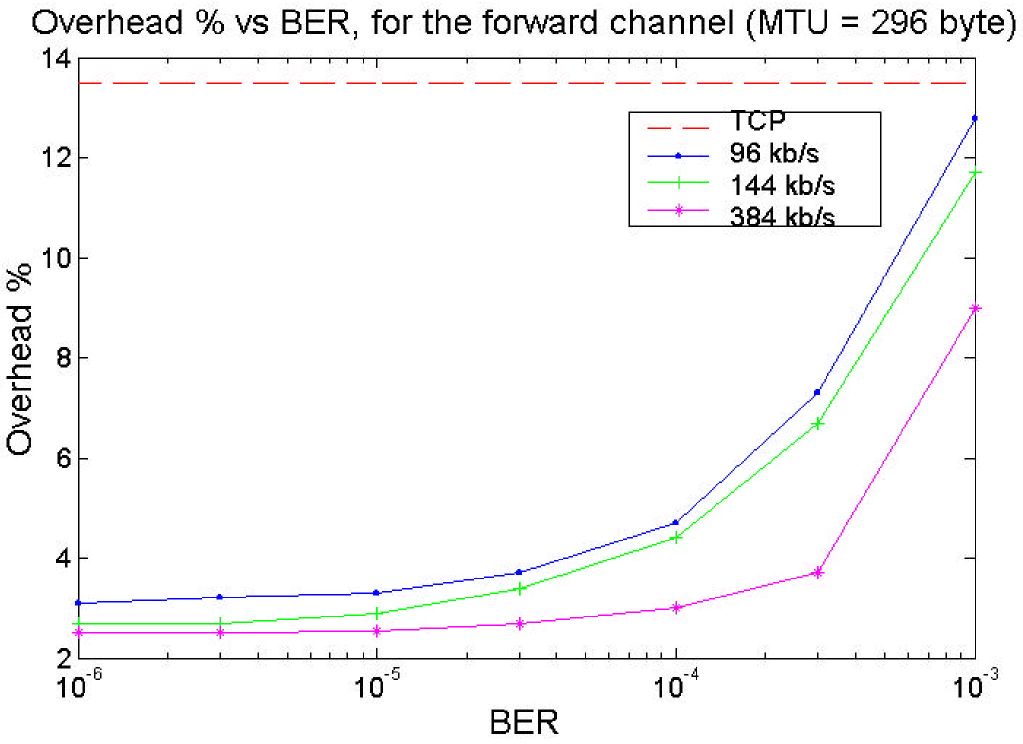
Under good conditions, the compressor can reach the SO state more frequently and for longer periods

- MTU=256 byte
- Wireless: 384 kb/s, 30 ms



The importance of wireless bandwidth (U-mode)

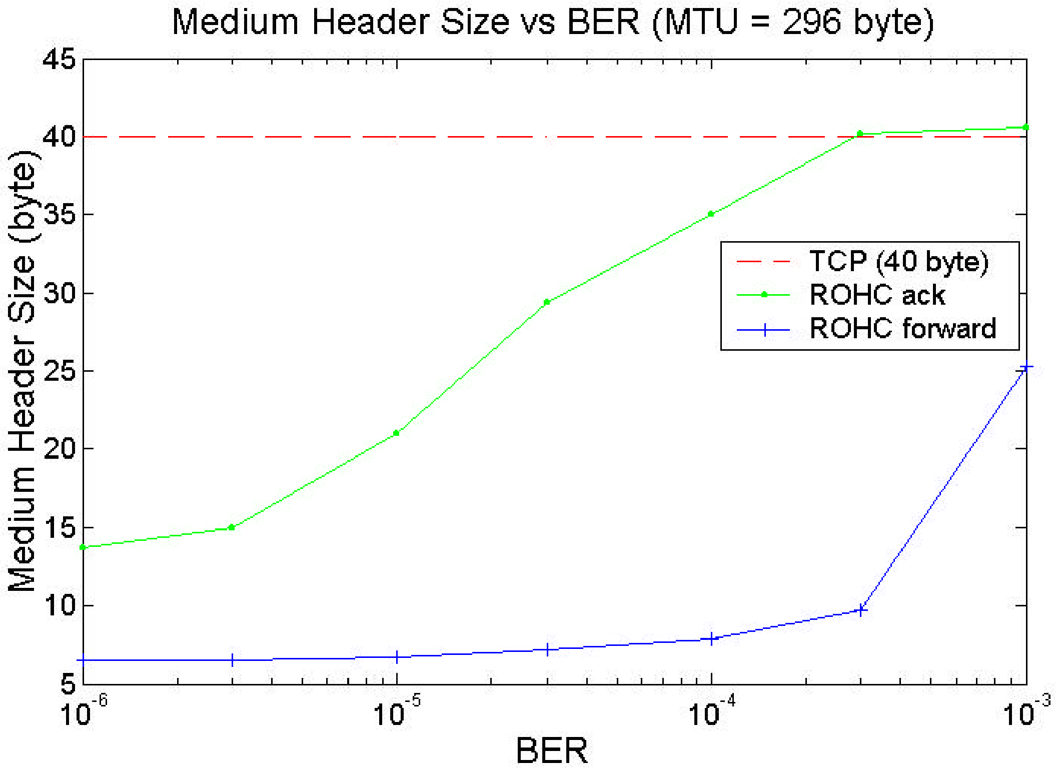
The compression ratio decreases with the bandwidth, because the number of packets generated by the TCP sender is proportional to the bandwidth and the compressor needs to receive packets in high number and with great frequency in order to exploit the periods in which the flow is regular



- MTU=296 byte, Variable BER
- Wireless: 384 kb/s, 30 ms

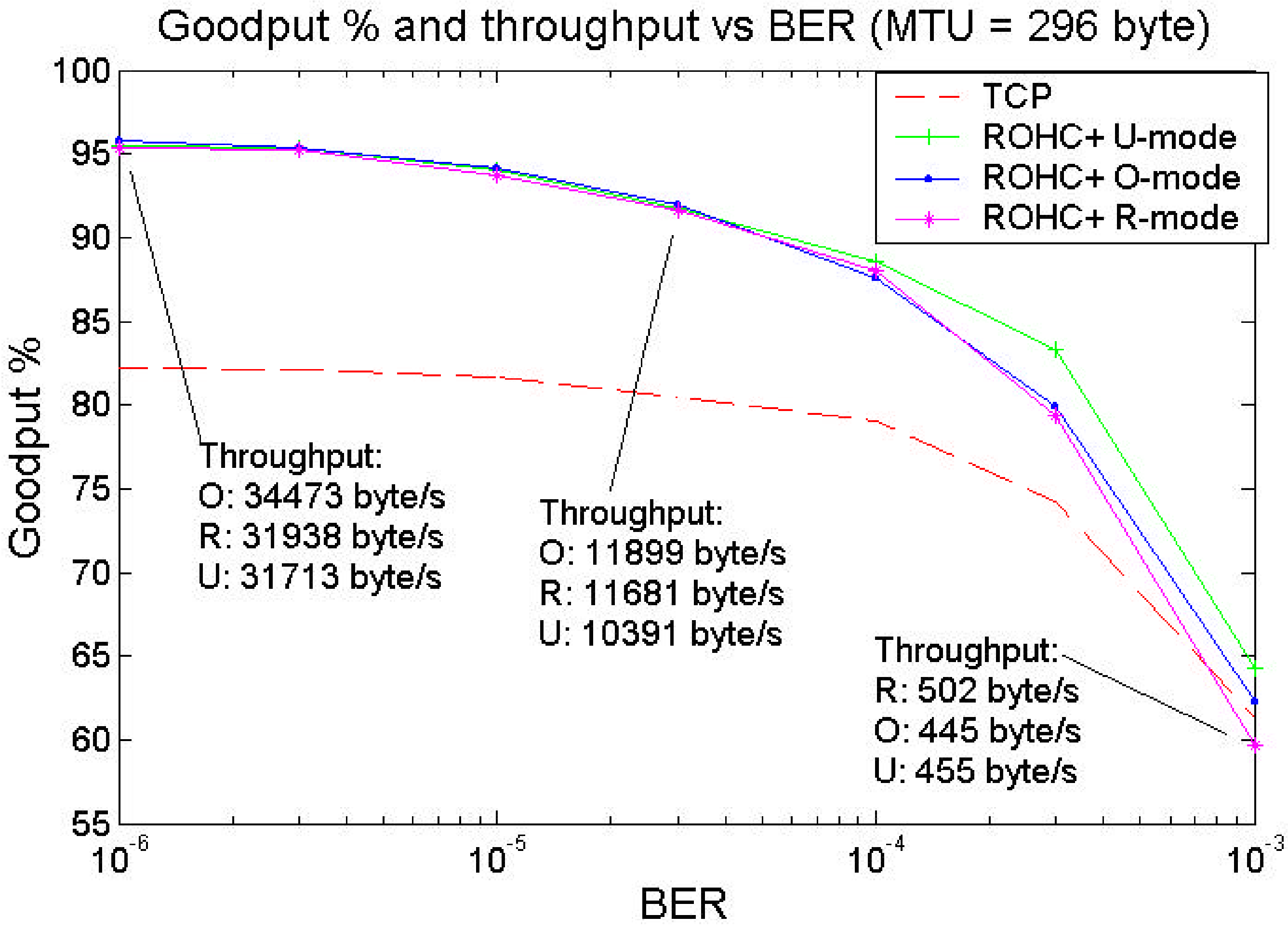
Compression over the reverse channel (U-mode)

The compression ratio in reverse channel is rather worse than in the forward channel, because the behavior of ACK SN field in the ACK stream is always less regular than the one of TCP SN in the data stream , keeping the compressor more frequently in lower compression states



- MTU=296 byte, Variable BER
- Wireless: 384 kb/s, 30 ms

Bidirectional Modes

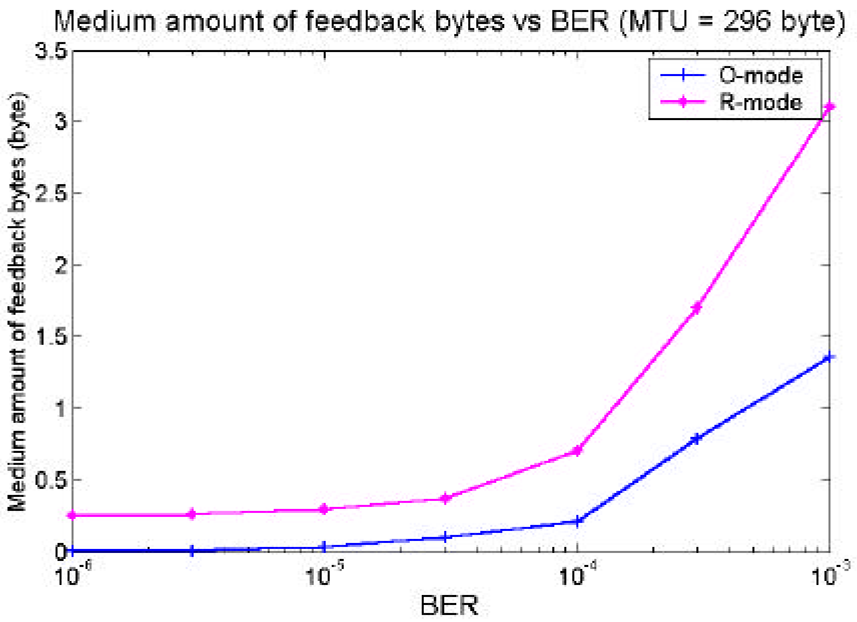


- MTU=296 byte
- Variable BER
- Wireless: 384 kb/s, 30 ms

Bidirectional Modes (2)

Under bad channel conditions (BER>10^{-4}), the performance of U-mode and O-mode are almost the same, while the R-mode produces a good improvement of throughput in consequence of the intensive use of feedback

Under good channel conditions, the O-mode produces an improvement of the compression ratio with respect to other operative mode, by utilizing the feedback in a "intelligent" way



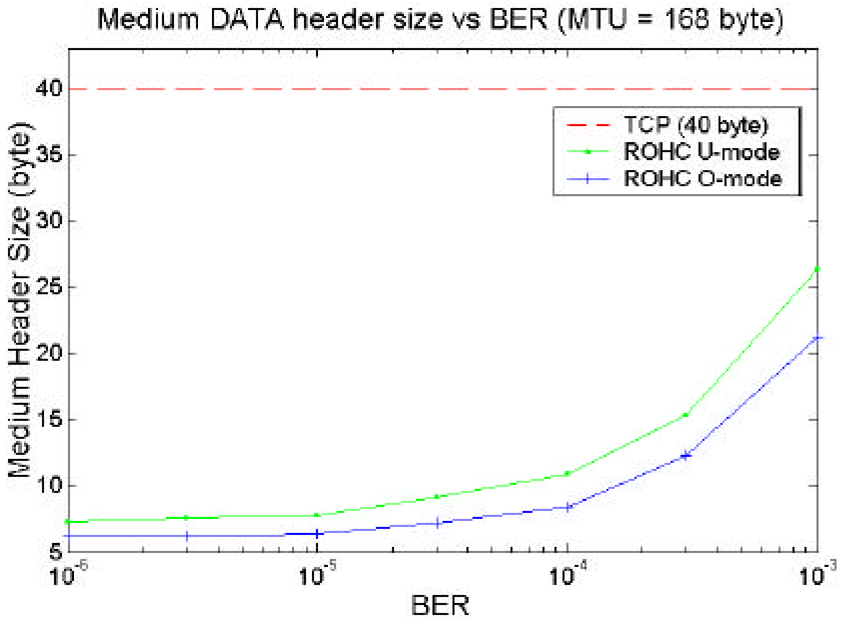
- MTU=296 byte, Variable BER
- Wireless: 384 kb/s, 30 ms

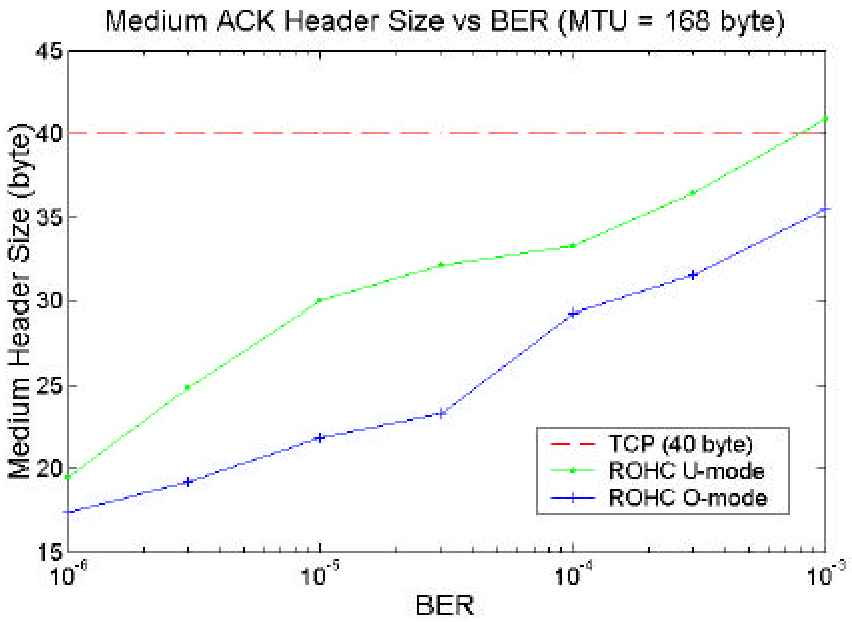
Optimistic Mode

(wireless: 64 kb/s, 100ms)

The Optimistic Mode produces its best performance when the weight of packets with low compression level is high.

Since the ACK stream is more "instable", the weight of packets with low compression level is greater for this stream and so the effect of O-mode appears to be more strong than the one in the forward direction.





Conclusions

This paper contains the performance analysis of a new scheme, perfectly integrable in the ROHC platform, for the header compression of a TCP/IPv4 stream in a wireless all-IP network.

- Results are directly dependent on the variations of TCP SN and ACK SN : it is important to well individualize the typical variation patterns of these fields in real networks;
- The performance of the compression scheme seems to be very "promising" in all considered cases:
  - With good channel conditions: minimum header size 5.3 bytes
  - Under bad channel conditions, the phenomenon of error propagation is minimized, especially through the W-LSB enconding
- The compression over the reverse channel is less efficient that the one over the forward channel, in consequence of the irregularity of ACK SN field
- We considered IPv4, but IPv6 has some features (the great size of static fields, the reduced size of dynamic fields and the absence of a "problematic" field like IPv4 Identification) that are particularly propitious for the compression with our profile.