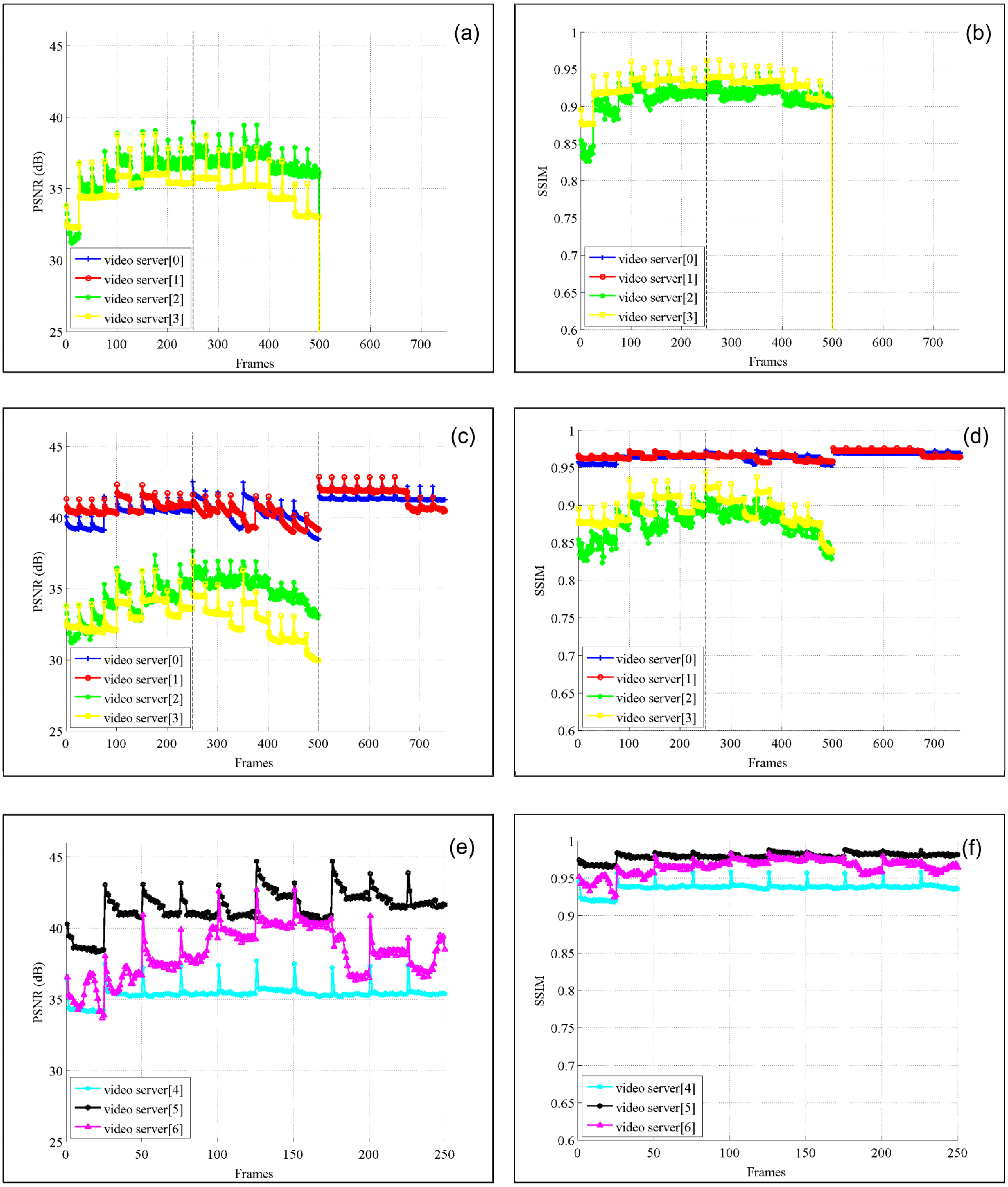
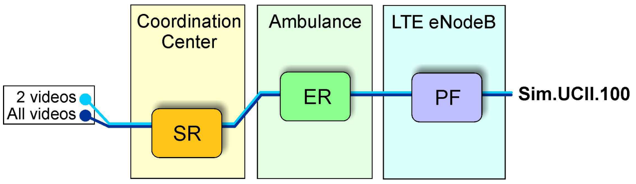


Figure 33 - Sim.UCII.001, GBR = 4.5Mbps at the LTE eNodeB. Video quality at the doctor's UE within the remote hospital. PSNR values are reported on the left, while SSIM are on the right. Plots (a)-(d) refer to Phase 1, while plots (e) and (f) to Phase 2. The curves reported in (a) and (b) correspond to the case of 2 videos in Phase 1, while (c) and (d) to the case of 4 transmitted videos.

Some Remarks:

In the Sim.UCII.001 case, the system intelligence is mainly concentrated in the radio management performed by the LTE eNodeB. As it can be noted from Figure 30 and Figure 31, the delay is considerably lower than with the PF policy and more suitable to real-time or quasi real-time communications. However, also in this case the quality spread among the sequences is considerable, as no quality fairness is guaranteed within the ambulance. In particular, in Phase 2, the ultrasound video has a SSIM still lower than 0.95, considered a target quality level to achieve a good diagnostic service.



Case Sim.UCII.100

Video Encoding Performance:

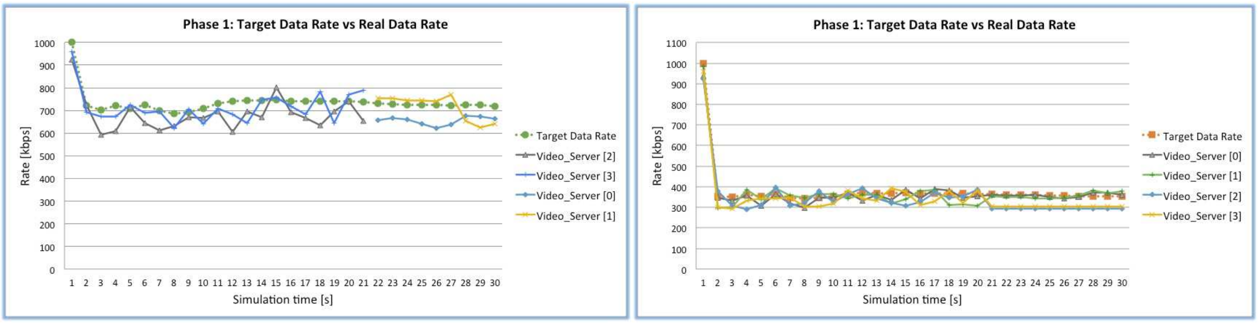


Figure 34 - Sim.UCII.100. Target source rate specified to the APP Controller and achieved rate during Phase 1. Case of 2 videos (left) and 4 videos (right).

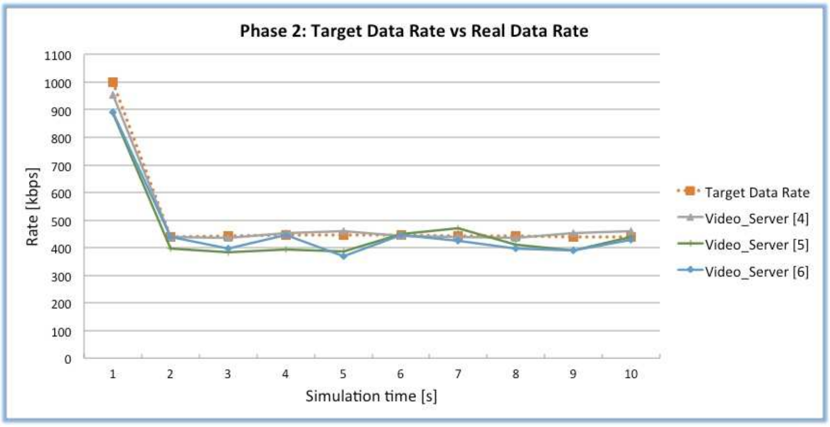


Figure 35 - Target source rate specified to the APP Controller and achieved rate during Phase 2.

LTE Uplink Performance:

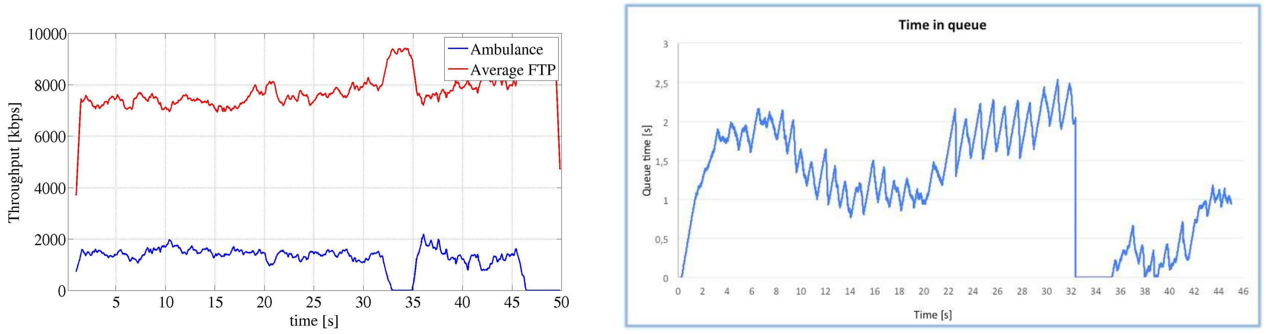


Figure 36 – Sim.UCII.100. Rate allocated by the LTE eNodeB to the ambulance and to the additional users in the cell (left) and time spent in TX queue at the LTE MAC layer (right). Transmission of 2 videos during Phase 1 (the case with 4 videos provides similar results).

<u>End-to-end Performance:</u>

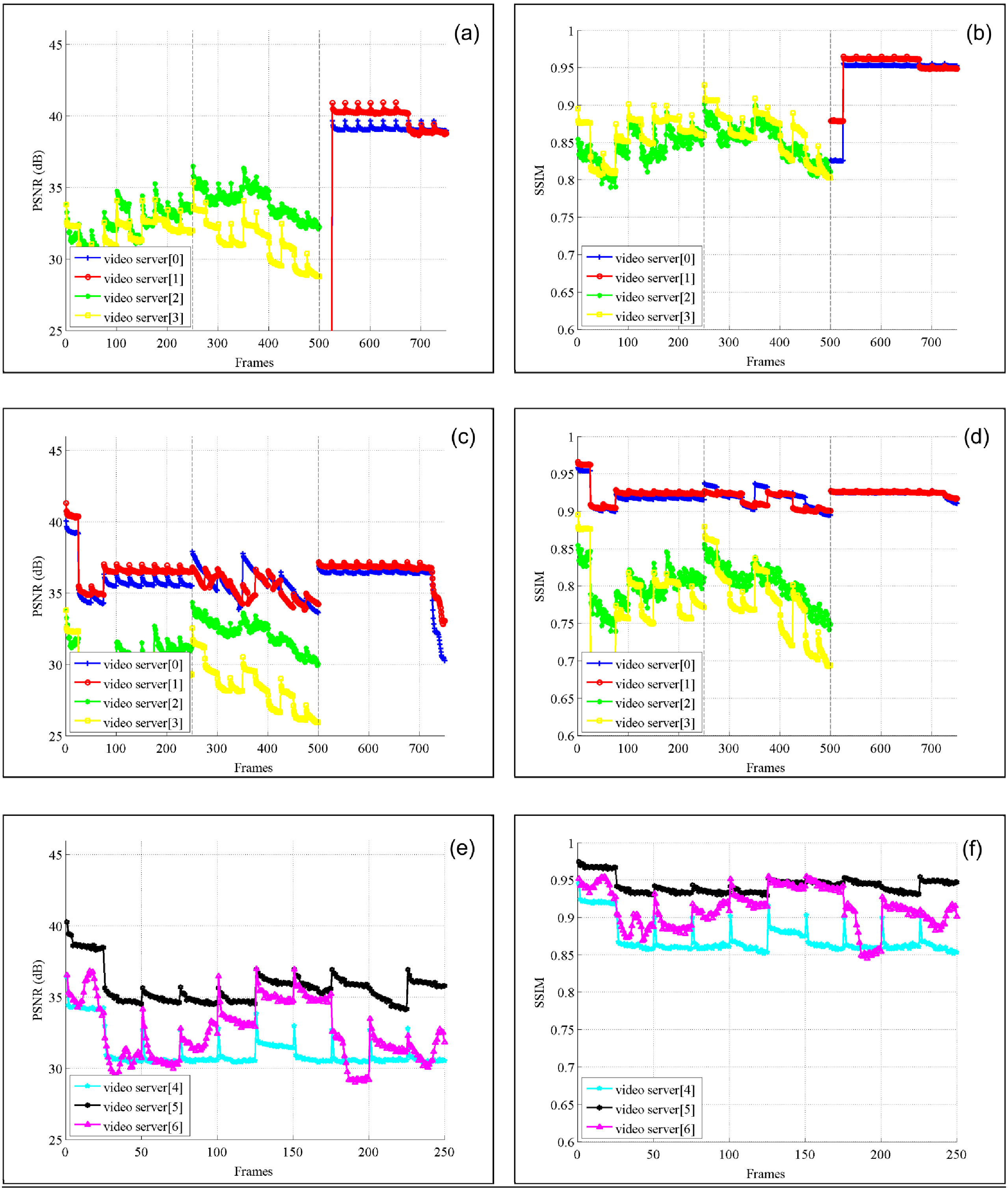


Figure 37 - Sim.UCII.100. Video quality at the doctor's UE within the remote hospital. PSNR values are reported on the left, while SSIM are on the right. Plots (a)-(d) refer to Phase 1, while plots (e) and (f) to Phase 2. The curves reported in (a) and (b) correspond to the case of 2 videos in Phase 1, while (c) and (d) to the case of 4 transmitted videos.

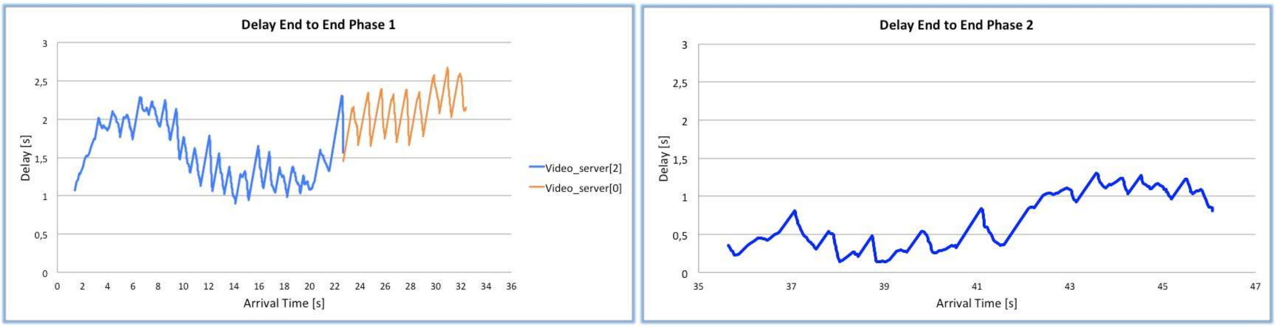
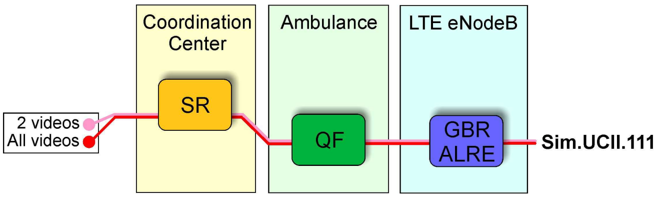


Figure 38 - Sim.UCII.100. End-to-end delay in Phase 1 (left) and Phase 2 (right). The case with 2 videos in Phase 1 has been reported, while similar results have been obtained also in the case with 4 videos.

Some Remarks:

Unlike the benchmark, in this case source prioritization is applied at the CC and the ranking is communicated to the ambulance through the DDE. In case of 2 transmitted videos in Phase 1, the transmitted sources are automatically changed after the first 20s, passing from *video_server[2]* and *video_server[3]* to *video_server[0]* and *video_server[1]*. In fact, in the interval between 20s and 30s (patient loading on the ambulance) the two cameras initially selected are less significant than the other two.



Case Sim.UCII.111

Video Encoding Performance:

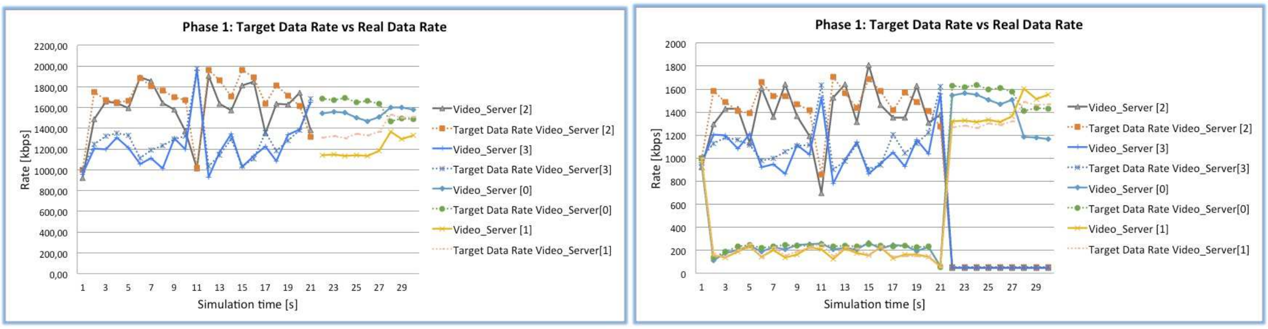


Figure 39 - Sim.UCII.111. Target source rate specified to the APP Controller and achieved rate during Phase 1. Case of 2 videos (left) and 4 videos (right), with GBR = 3Mbps at the LTE eNodeB.

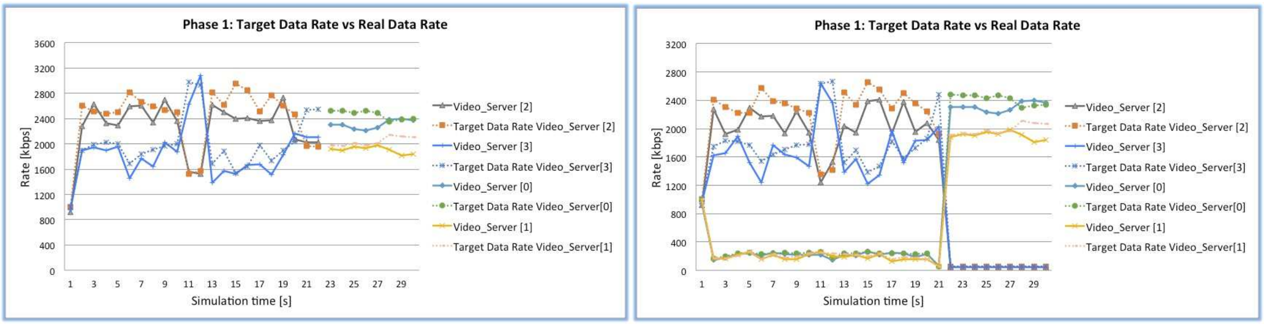


Figure 40 - Sim.UCII.111. Target source rate specified to the APP Controller and achieved rate during Phase 1. Case of 2 videos (left) and 4 videos (right), with GBR = 4.5Mbps at the LTE eNodeB.

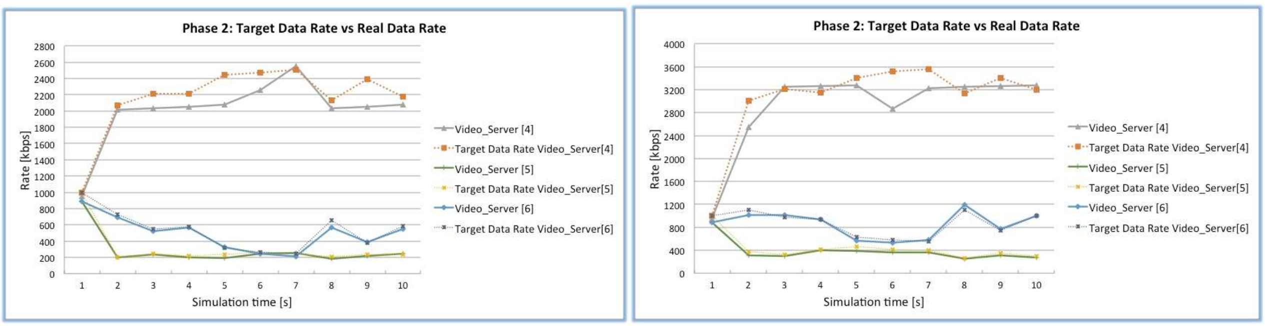


Figure 41 - Sim.UCII.111. Target source rate specified to the APP Controller and achieved rate during Phase 2, with GBR = 3Mbps (left) and GBR = 4.5Mbps (right) at the LTE eNodeB.

LTE Uplink Performance:

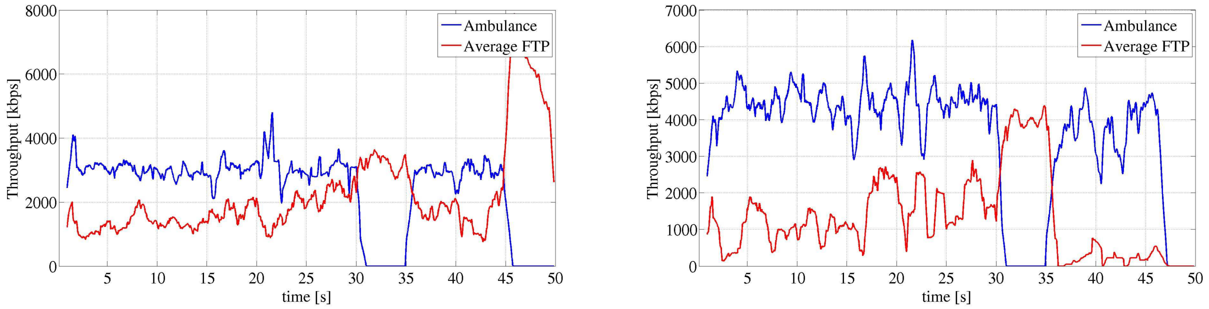


Figure 42 – Sim.UCII.111. Rate allocated by the LTE eNodeB to the ambulance and to the additional users in the cell. Transmission of 2 videos in Phase 1, GBR=3Mbps (left) and 4.5Mbps (right). Similar results have been obtained in the case with 4 videos in Phase 1.

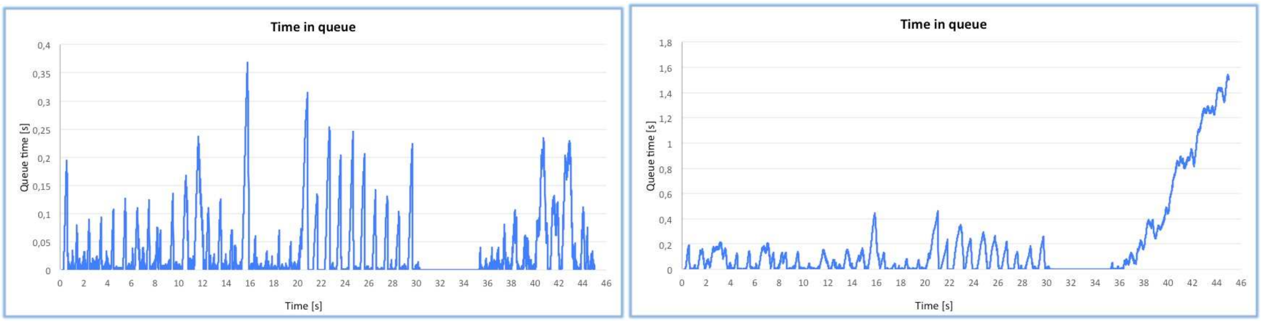


Figure 43 - Sim.UCII.111. Time spent in TX queue at the LTE MAC layer. The case of 2 videos in Phase 1 has been reported, with GBR=3Mbps (left) and GBR=4.5Mbps (right) . Similar results have been obtained in the case with 4 videos in Phase 1.

<u>End-to-end Performance:</u>

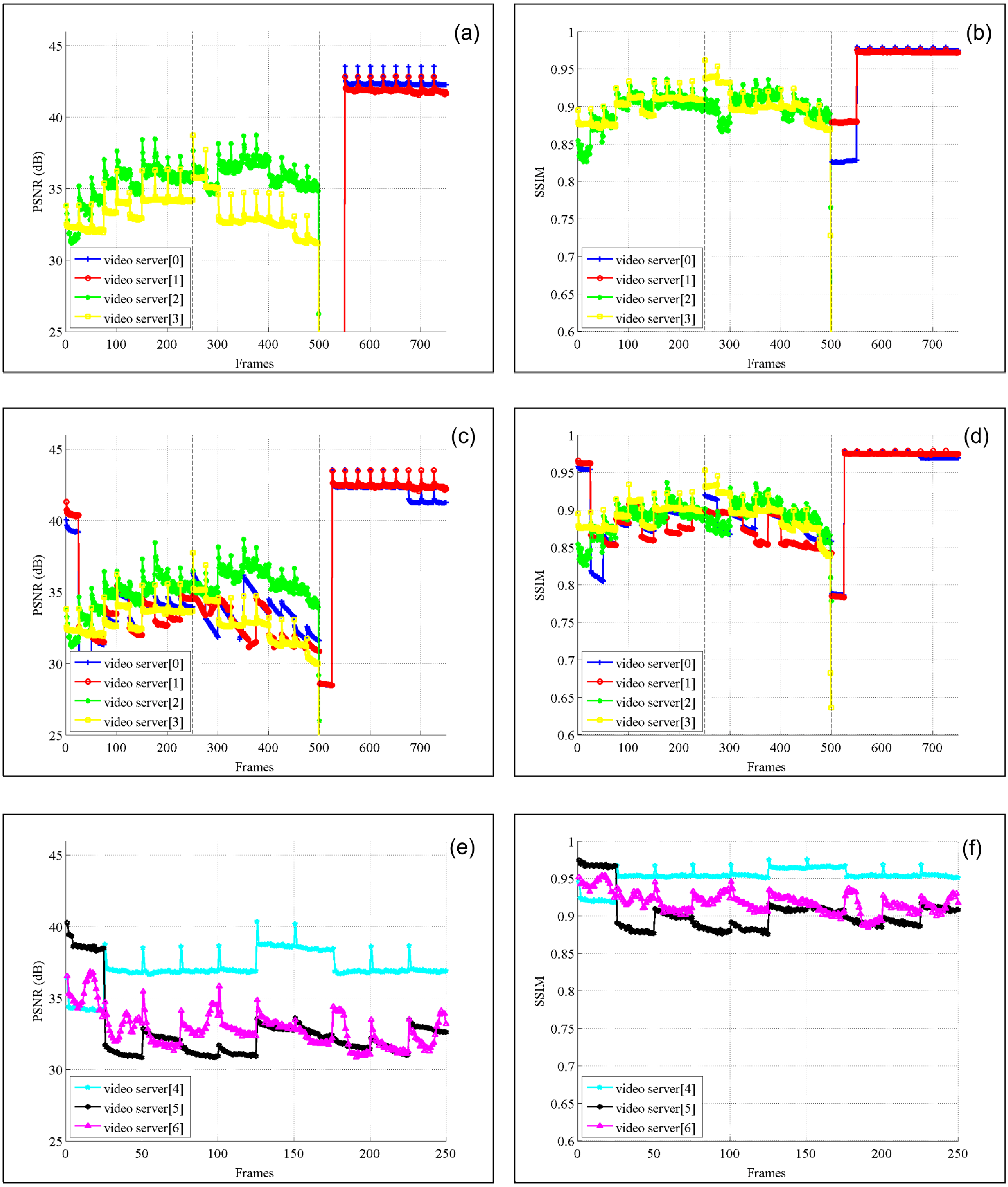


Figure 44 - Sim.UCII.111, GBR = 3Mbps at the LTE eNodeB. Video quality at the doctor's UE within the remote hospital. PSNR values are reported on the left, while SSIM are on the right. Plots (a)-(d) refer to Phase 1, while plots (e) and (f) to Phase 2. The curves reported in (a) and (b) correspond to the case of 2 videos in Phase 1, while (c) and (d) to the case of 4 transmitted videos.

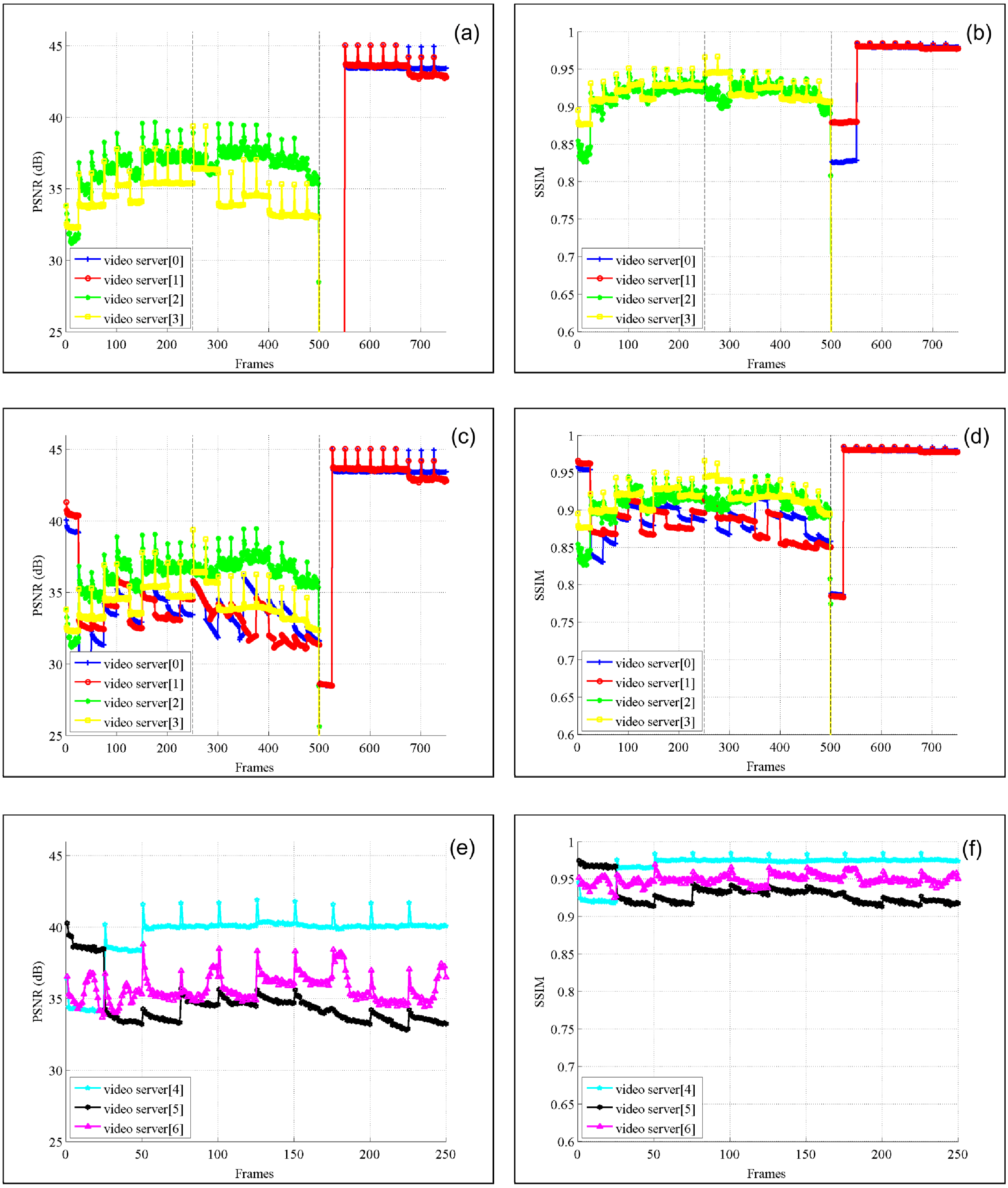


Figure 45 - Sim.UCII.111, GBR = 4.5Mbps at the LTE eNodeB. Video quality at the doctor's UE within the remote hospital. PSNR values are reported on the left, while SSIM are on the right. Plots (a)-(d) refer to Phase 1, while plots (e) and (f) to Phase 2. The curves reported in (a) and (b) correspond to the case of 2 videos in Phase 1, while (c) and (d) to the case of 4 transmitted videos.

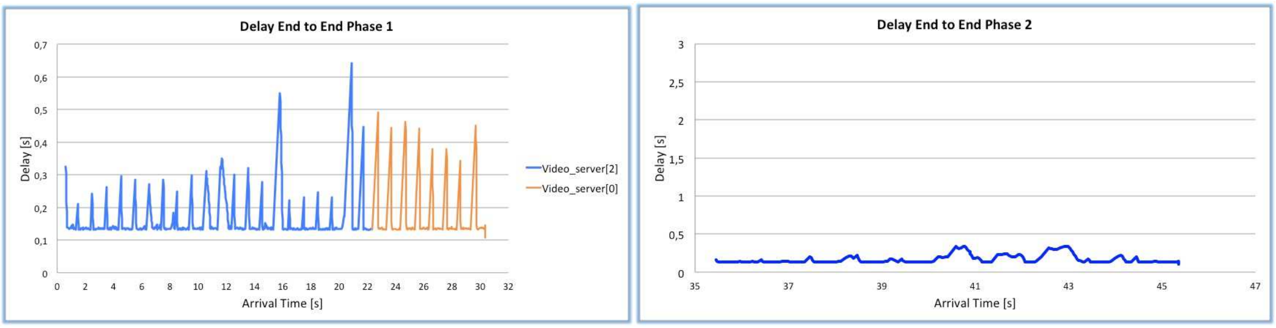


Figure 46 - Sim.UCII.111. End-to-end delay in Phase 1 (left) and Phase 2 (right). The 2 video case has been reported, with a GBR = 3Mbps at the LTE radio link. Similar results have been obtained in the case with 4 videos in Phase 1.

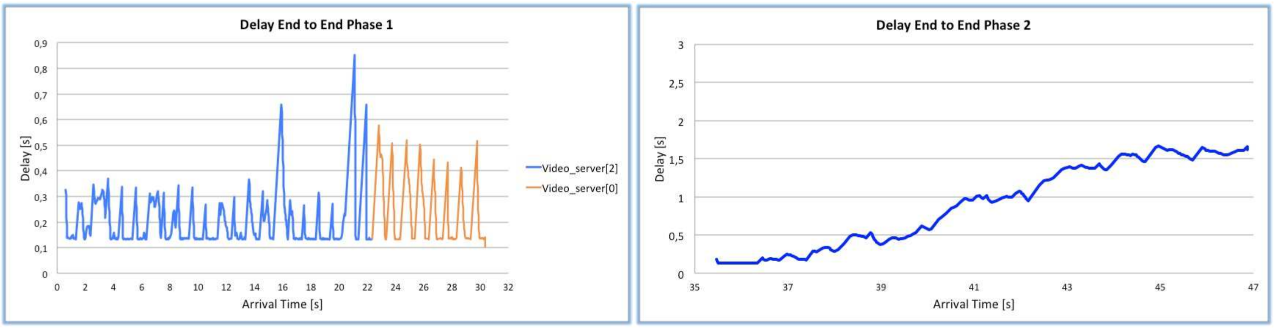


Figure 47 - Sim.UCII.111. End-to-end delay in Phase 1 (left) and Phase 2 (right). The 2 video case has been reported, with a GBR = 4.5Mbps at the LTE radio link. Similar results have been obtained in the case with 4 videos in Phase 1.

Some Remarks:

This case represents the fully optimized solution, including camera ranking at the CC, joint video coding adaptation based on quality fairness criteria and smart radio resource management at the LTE radio access network, capable to guarantee a fixed bitrate for the CONCERTO user. As it can be noted from the numerical results, the quality spread among the ambient videos is significantly lower than that achieved with a simple equal rate policy. At the same time, the end-to-end delay allows a real-time interaction between the on-site staff and the specialized personnel at the hospital. Finally, it is worth noting that the quality-based video coding adaptation allows to specify a higher quality for the medical video during phase 2, enabling accurate tele-diagnosis service.

4.2.2.3 Use Case 2: Numerical Result Comparison

In this paragraph, a comparison of the different schemes simulated for the Use Case 2 is reported, in terms of both end-to-end quality and LTE uplink performance. As in previous figures, the FTP label corresponds to non-Concerto traffic within the cell. In this paragraph we report some remarks about the average performance achieved with the different strategies considered for Use Case 2, as depicted in Figure 48-Figure 51.

End-to-end Performance:

The average PSNR and SSIM achieved with the different transmission schemes is reported in Figure 48 and Figure 49, respectively. First of all, we remark that in all the simulated situations the ambulance is able to estimate its available throughput across the 4G link and to adapt the source rates accordingly, by means of the application controller. Based on the reported comparative results, it is possible to make some observations:

- When a PF scheduling is applied within the eNodeB, the throughput provided to the ambulance is not always sufficient to guarantee good quality. When all videos are transmitted via PF in Phase 1, the corresponding SSIM is distributed between 0.77 and 0.92 (28.68dB and 36.62dB, in terms of PSNR). An even higher quality spread is observed when only 2 videos are selected through SR for transmission, due to the low motion of the scene capture by *video_server[0]* and *video_server[1]*. More important, with PF the medical ultrasound video (Phase 2) is not able to achieve a video quality sufficient to enable an accurate tele-diagnosis.

- When SR is employed to select and transmit 2 videos, the system is able to automatically track the Point of Interest, switching from *video_server[2]* and *video_server[3]* to *video_server[0]* and *video_server[1]* during Phase 1. Transmitting only two videos out of the four available in Phase 1 permits to allocate more bandwidth to the most significant sources, improving the corresponding end-to-end quality with respect to the transmission of all the available videos.

  The possibility to guarantee a given throughput to the CONCERTO user across the LTE link turns out to be very important to achieve a satisfactory quality, especially when more than 2 videos are contemporary transmitted. For example, if 4.5Mbps are guaranteed to the ambulance by the eNodeB, all videos are received with average SSIM higher than 0.88 and PSNR not lower than 32.8dB.

- When the QF mechanism is implemented within the ambulance, the quality spread between the ambient streams is effectively minimized. In particular, the QF rate allocation turns out to be fundamental when a medical stream is multiplexed with the others, in order to achieve the video quality required by the specialists at the hospital. In particular, with all the Sim,111 schemes the ultrasound video (*video_server[4]*) is received with SSIM higher than 0.95 and PSNR above 37dB. On the contrary, when the ER policy is applied, the medical video is always received with a quality lower than the ambient videos, due to a lower compression efficiency.

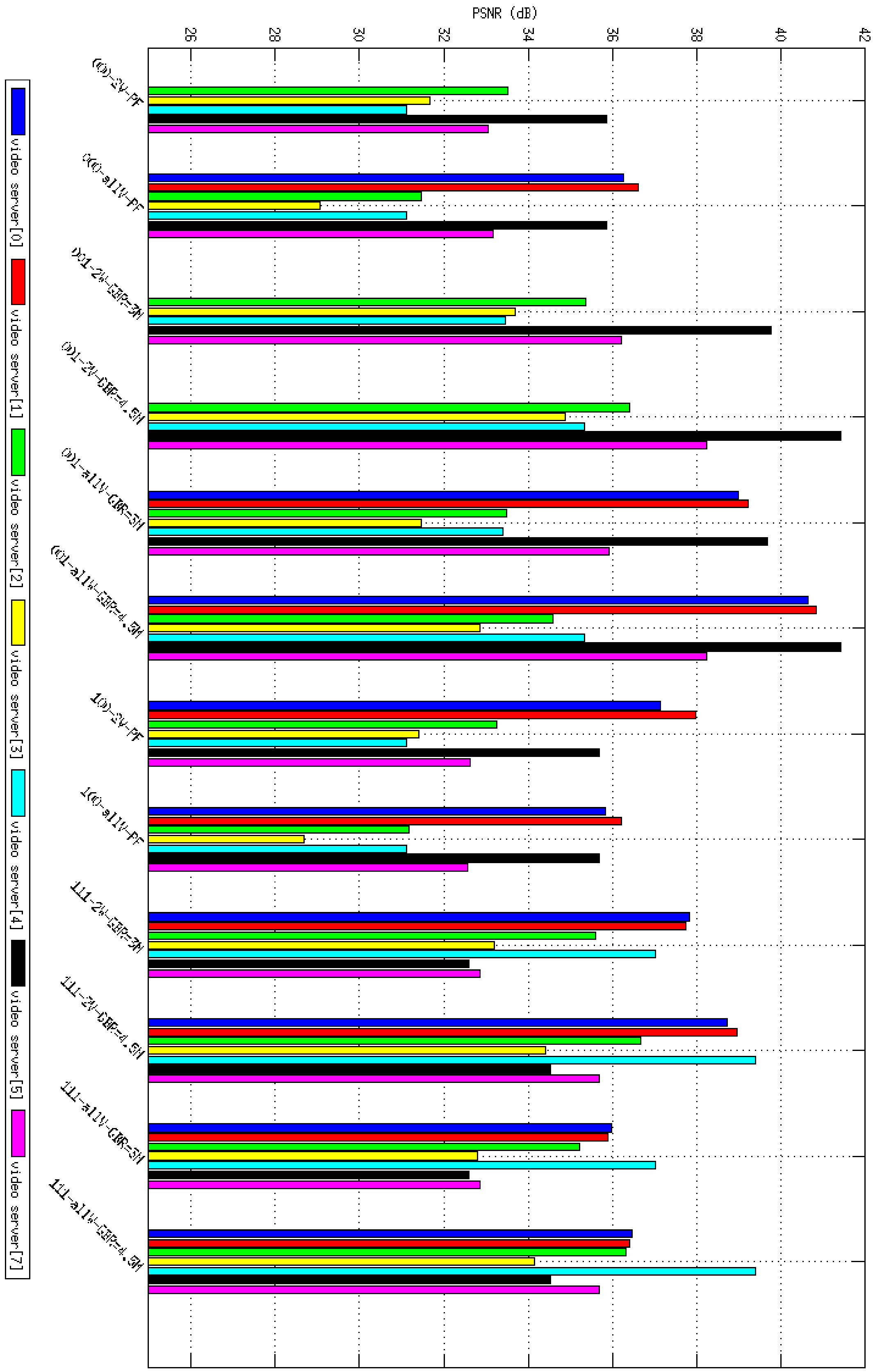


Figure 48 - Use Case 2: comparison of the average PSNR achieved for the received videos in the different cases.

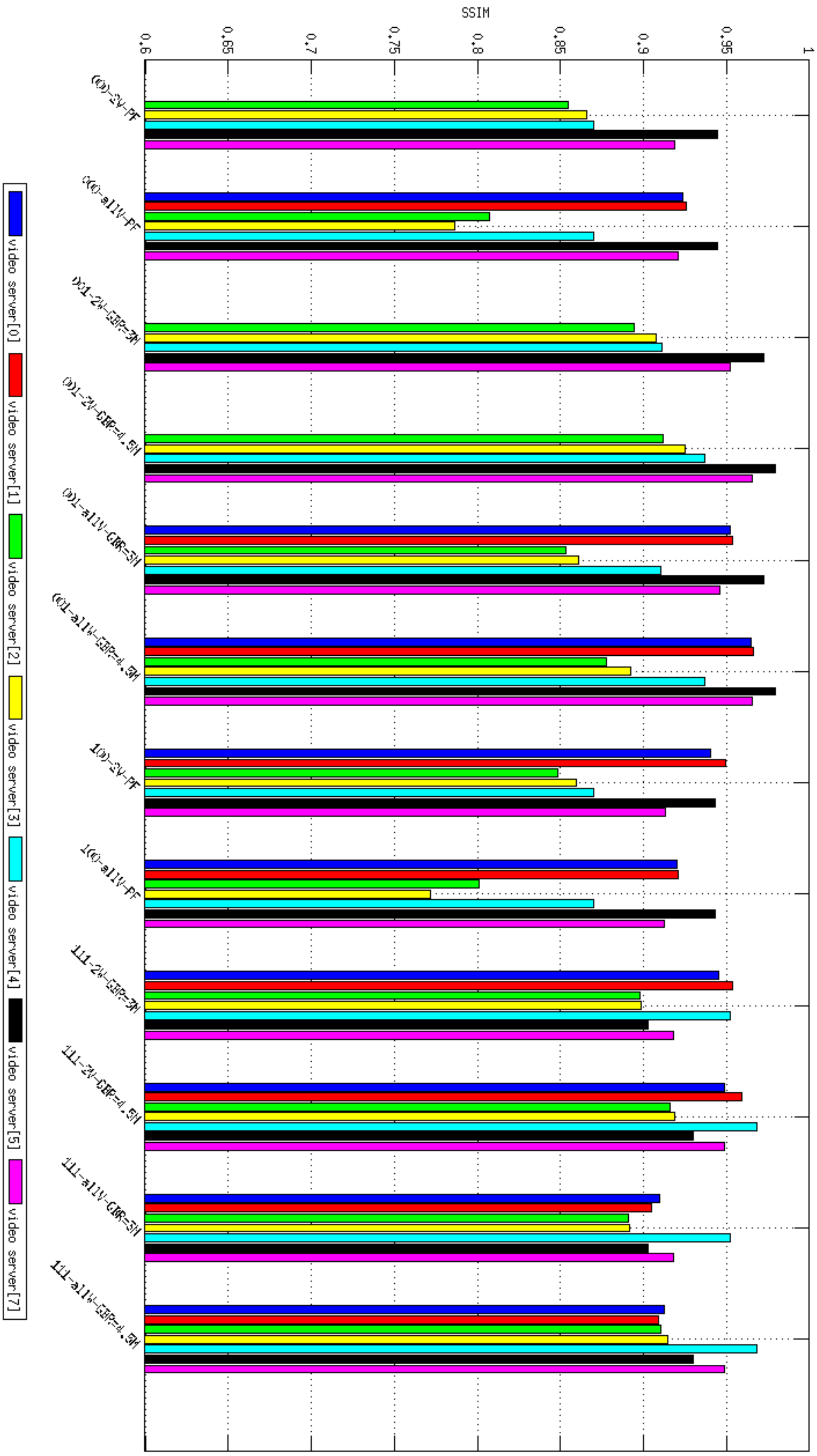


Figure 49 - Use Case 2: comparison of the average SSIM achieved for the received videos in the different cases.

LTE Uplink Performance:

A comparison of the average throughput achieved in the different schemes of use case 2 is given in in Figure 2. In particular, the performance of the ambulance (the CONCERTO UE) and the aggregate throughput of the non-Concerto UEs (FTP) is reported. In Figure 51, the 3rd quartile of the packet delay at the LTE link, i.e. the packet delay that is exceeded with probability 25%, is plotted.

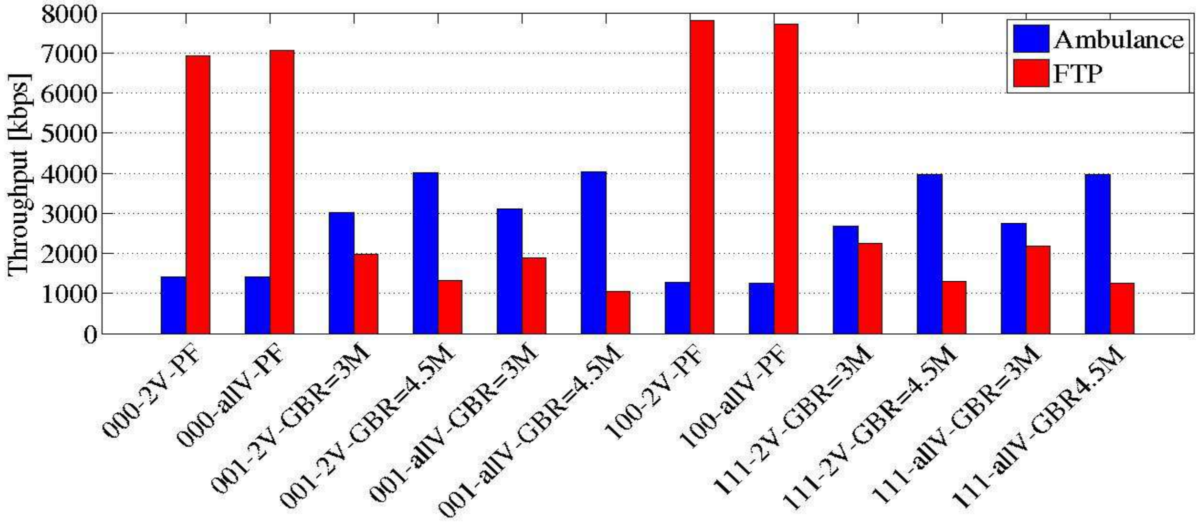


Figure 50 - Use Case 2: average throughput of the ambulance and FTP users (aggregate) for each simulated scheme

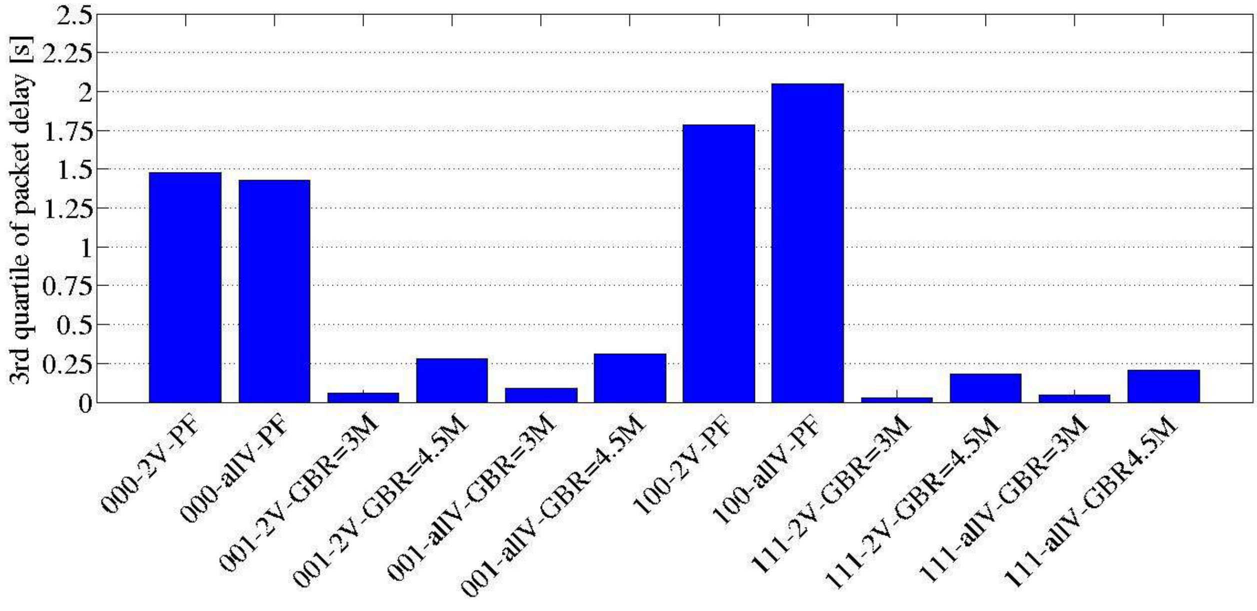


Figure 51 - Use Case 2: 3rd quartile of the packet delay, i.e., 75th percentile, of the packet delay CDF for each simulated scheme

We can easily observe that the PF strategy (Sim.000 and Sim.100) distributes the resources according to the channel condition of the users, thus providing an average bit-rate to the ambulance of approximately 1.6 Mbps and an aggregate throughput to FTP users around 7 Mbps. This results in a low video quality, in both the cases with 2 and 4 videos transmitted during Phase 1, as shown in Figure 48 and Figure 49, with an high packet delays around 1.5s.

The optimized GBR-ALRE strategy allows to improve the QoS of the ambulance by significantly reducing the FTP best-effort throughput. This is mainly due to the fact that, with respect to the downlink, the per-user budget limits the achievable rate per unit-bandwidth when several resource blocks are allocated to a user to satisfy his rate requirement. Nevertheless, no FTP user is starving in all considered cases. When the GBR is set to 3 Mbps, the LTE eNodeB is able to strictly satisfy the rate requirements, whereas when the GBR is set to 4.5 Mbps the user throughput is about 10 % below the GBR setup due to deep fading holes occurring in Phase 2. Nevertheless, the packet delay is still limited, with respect to the PF approach, as shown in Figure 51, and under the reasonable values of 200 ms, suitable for real-time and near-real time video transmissions.

5. Conclusion

This document is aimed at validating the CONCERTO solution through the project simulator developed on the OMNeT++ framework. The simulator structure has been presented, showing the relationship with the CONCERTO architecture and detailing the implementation of the most significant modules. Input and output information, as well as a technical reference to the documents describing the implemented algorithms have been included.

Several use cases have been addressed showing the benefits of the proposed system in managing different emergency and healthcare situations. Different levels of optimization have been considered, in order to evaluate the potential system performance in case of different extent of CONCERTO in the next future. In particular, we have assumed the presence of a centralized coordination unit (i.e. the CC), capable to prioritize the available ambient and medical streams. Camera ranking is applied at the CC to guarantee the transmission of significant and high quality contents throughout the emergency event. Multi-stream adaptation is performed within the ambulance and source coding optimization is realized by dedicated application controllers. In addition, we have evaluated the benefits deriving from the adoption of advanced multiuser scheduling and resource allocation techniques within the LTE eNodeB, capable to guarantee a fixed bitrate to the CONCERTO user. Different combinations of the abovementioned solutions have been simulated and compared to a proper benchmark, representing traditional communication systems. Finally, end-to-end RTP communications have been compared with MPEG-DASH transcoding system and the benefits of PL-FEC protection schemes have been shown with respect to traditional unprotected transmissions.

The considered use cases have been evaluated addressing different service metrics, e.g. throughput and delay, and video quality indicators, i.e. PSNR and SSIM. Based on these numerical results, the overall benefits of the CONCERTO solutions have been presented in different situations.

We conclude this document by observing that the software tool here described complements the system demonstrator described in D6.4. In particular, the software simulator has permitted to validate the system architecture and the algorithms developed during the project in situations not easily reproducible through the CONCERTO demonstrator, such as evaluating the effects of an ambulance on the move or comparing the performance with different resource management strategies implemented at the LTE eNodeB.

Appendix: message table

In this Appendix we report a table listing the main messages currently exchanged among the modules in the simulator. The goal of this table is, first of all, to help the developers debug the code.

LABEL EXPLANATION

Class name: in this column each message is discriminated based on its class.

Source module (Identification field in the message): source module generating the message; in brackets the identification field within the message is reported, specifying an ID for the source module that created the message (typical identification fields are the IP addresses, the MAC addresses, etc.).

Destination module (Identification field in the message): destination module receiving the message; in brackets the identification field within the message is reported, specifying an ID for the destination module (typical identification fields are the IP addresses, the MAC addresses, etc.).

Macro-module source → macro-module destination: in this column the macro-modules generating and receiving the message are reported. Typical examples for CONCERTO are: hospital 1 → emergency area, ext_video_user → hospital 2, etc…

Intermediate modules: in this column we list all the modules that do not generate the message but exploit some information carried by the message or modify the message itself in some way. Typically, the modules reported in this column can:

- Read some fields and then forward the message,
- Modify some fields and then forward the message.

Ancestor: this field indicates if the generated message is obtained as the "transformation" of another message (e.g. encapsulation). For example, the IEEE80211DataFrame will be generated starting from an IPMessage.

Table 1 – Message table.

Class name	Source module (Identification field in the message)	Destination module (Identification field in the message)	Macro-module source → macro-module destination	Intermediate modules	Ancestor	NOTES
phyMsg	Base Station Controller (--)	Generic MAC (--) Frame DeAssembler (destUser)	Base Station (internal)	Generic MAC – Channel Codec – Mimo Modem	IEEE80211DataFrame	The destination is the Generic MAC of the Base Station if the user is NRT
phyFrame Msg	Frame DeAssembler (--)	Frame DeAssembler (destUser)	Base Station → Mobile User	Radio Channel - Base Station Controller	phyMsg	The destUser ID belongs to the incorporated phyMsgs
ddeMSG	DDE module (Source IP address and DDE Event Producer ID)	DDE module (Destination IP address and DDE Event Consumer ID)	Any	IP Network – MAC – Radio Channel	cMessage	Cross-layer messaging. Can be called (theoretically) from anywhere
PHYInfoMsg	PHY	MAC	Base Station / Wireless Client (internal)	None	cMessage	The PHY layer informs the MAC about the 802.11n link state and parameters.
Ieee80211FrameMsg	MAC module (Source MAC address)	MAC module (Destination MAC address)	Base Station ⇔ Wireless Client	PHY – WiFi Radio Channel	IpMessage	All information transmitted over the IEEE 802.11n link is formatted as IEEE 802.11 MAC frames.
csiMsg	RadioChannel module (Source MAC address)	MIMO modem, BS Controller	All modules including wireless links	None	None, generated based on the channel coherence time	The source MAC address refers to the interested terminal
Application Msg	Encoder/Application controller	RTP module	Server and clients		IpMessage	It contains user data (e.g., video frames)
RtpMsg	RTP module	UDP lite module	Server and clients	SRTP, Pecc	IpMessage	It contains user data
IpMessage	--	--	--	--	cPacket	General structure for data messages
TCPsegment Msg	TCP	TransportCtrlManager	Server and clients		IpMessage	It contains user data
IpPhyMsg	BS Controller (IP Address)	LTE MAC module (Ip Address)	Base Station ⇔ Base Station	LTE MAC and PHY submodules at receiver and transmitter side	IpMessage	It contains user data: the BS controller generates it, the Tx LTE MAC fulfil it and the it is sent back
IpInfoMsg	Bs Controller (IP Address)	BS Controller (Ip Address)	Base Station ⇔ Base Station	LTE MAC at the transmitter side	IpMessage	The BS controller generates it in order to know the queue status of LTE each user

6. References and glossary

6.1 References

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[13] IETF Network Working Group, RFC 3828: "The Lightweight User Datagram Protocol (UDP-Lite)", July 2004, http://www.ietf.org/rfc/rfc3828.txt

[14] CONCERTO Consortium, "D4.3 – Final evaluation of context-awareness solutions," version 1.0, May. 2014

6.2 Glossary

4G	*Fourth generation*	
AF	*Assured forwarding*	
AMC	*Adaptive modulation and coding*	
AP	*Access point*	
AVC	*Advanced video coding*	
AWGN	*Additive white Gaussian noise*	
BCJR	*Bahl, Cocke, Jelinek and Raviv*	*Decoding algorithm*
BER	*Bit error rate*	
BLER	*Block error rate*	
BPSK	*Binary phase shift keying*	
CC	*Coordination Center*	
CP	*Cyclic prefix*	

CQI	*Channel quality indicator*	
CSI	*Channel state information*	
CSMA/CA	*Carrier sensing multiple access / collision avoidance*	
DASH	*Dynamic Adaptive Streaming over HTTP*	
DCF	*Distributed coordination function*	
DDE	*Distributed decision engine*	
DIM	*Distance info module*	
DLL	*Data link layer*	
DSCP	*Differentiated services code point*	
EDCA	*Enhanced distributed channel access*	
FEC	*Forward error correction*	
FER	*Frame error rate*	
HCCA	*HCF controlled channel access*	
HCF	*Hybrid coordination function*	
HTTP	*Hypertext transfer protocol*	
HW	*Hardware*	
IDE	*Integrated development environment*	
IRA	*Irregular repeat-accumulate*	
ISO/OSI	*International standard organization / Open system interconnection*	
JSCC	*Joint source and channel coding*	
LDPC	*Low-density parity check*	
LDPCC	*LDPC code*	
LLR	*Log-likelihood ratio*	
LTE	*Long term evolution*	
LTE-A	*Long term evolution – advanced*	
MAC	*Medium access control*	
MAP	*Maximum a-posteriori*	
MIH	*Media independent handover*	
MIIS	*MIH information service*	
MIMO	*Multiple-input multiple-output*	
ML	*Maximum likelihood*	
MPDU	*MAC protocol data unit*	
MPEG	*Moving picture experts group*	
MRC	*Maximum ratio combining*	
MSM	*Multi-source management*	
MSS	*Maximum segment size*	
MVC	*Multi-view video coding*	
NALU	*Network abstraction layer unit*	
NGN	*Next-generation network*	
OFDM	*Orthogonal frequency division multiplexing*	
OFDMA	*Orthogonal frequency division multiple access*	
PAN	*Personal area network*	
RCPC	*Rate Compatible Punctured Convolutional code*	
PCF	*Point coordination function*	
PDM	*Proportional delay differentiation model*	
PHB	*Per-hop behaviour*	
PHY	*Physical layer*	
PL-FEC	*Packet-level forward error correction*	
PLR	*Packet loss rate*	
PSK	*Phase shift keying*	
PSNR	*Peak signal to noise power ratio*	
QAM	*Quadrature amplitude modulation*	
QCI	*QoS class identifier*	
QoE	*Quality of experience*	
QoS	*Quality of service*	
RCPC	*Rate compatible punctured convolutional code*	
RRM	*Radio resource management*	

RS	*Reed-Solomon*	
RTO	*Retransmission timeout*	
RTP	*Real-time protocol*	
RTT	*Round trip time*	
RX	*Receiver*	
SC-FDMA	*Single-carrier frequency division multiple access*	
SNR	*Signal to noise power ratio*	
SSIM	*Structure similarity index metric*	
SVC	*Scalable video coding*	
SW	*Software*	
TCP	*Transmission control protocol*	
TDMA	*Time division multiple access*	
TX	*Transmitter*	
UDP	*User datagram protocol*	
WLAN	*Wireless local area network*	*WiFi is a commercial name for a WLAN realization.*