Publishable Summary

Overview: The objective of the DRIVEN project is to develop a unifying framework for reliable communication of medical video over emerging wireless networks that is suitable for critically-needed (remote) clinical diagnosis. The goal is to approach the quality of in-hospital examinations and aid toward the adoption of mHealth medical video communication systems in standard clinical practice. Such systems can facilitate remote diagnosis and care for patients residing in (distant) areas without access to specialized care, emergency response for in-ambulance patients as well as for major disaster victims, mass population screening for cardiovascular diseases (especially in developing countries), while they can accommodate 2nd opinion provision and medical education. The project's objectives are aligned with the 'eHealth Action Plan 2012-2020'[1] and the Digital Agenda for Europe[2], where the wider adoption of mHealth and eHealth systems and services is identified as a top priority, and World Health Organization (WHO)[3] recommendations regarding mHealth adoption in developing countries.

The DRIVEN project framework was validated for cardiovascular remote diagnosis applications, and more specifically for the transmission of symptomatic atherosclerotic plaque ultrasound video (associated with critical stroke events) and abdominal aortic aneurysm (AAA) that can cause life-threatening internal bleeding. In both cases, timely surgical intervention may be needed. In addition, the developed system investigated the communication of emergency scenery video for assisting decision making in disaster incidents, as well as trauma video transmission of different emergency incidents for emergency response. The developed methods established how specific diagnostic decisions can be safely made based on the transmitted medical video.

Diagnostically robust and resilient wireless medical video communication systems that provide for reliable and dependable diagnosis necessitate a multidisciplinary research approach including medical video processing, wireless transmission, and video quality assessment. Moreover, the whole process has to be guided by the relevant medical expert according to the underlying medical video modality. The DRIVEN project has made significant contributions in all associated disciplines and aspires to become the key framework for future deployments of mHealth medical video communications systems. An abstract system diagram of the developed system appears in Fig. 1.

Research Outcomes: To increase diagnostic robustness and bandwidth efficiency during transmission over error-prone wireless channels, a novel video coding algorithm exploiting diagnostic region(s)-of-interest (d-ROI) was developed. The approach uses image analysis or user feedback to identify the d-ROI and then applies a *spatially adaptive compression algorithm* that provides uncompromising quality over the d-ROI and higher compression ratios over less diagnostically important regions. The latter approach leads to *significant bandwidth demands savings for equivalent perceptual quality*. Diagnostically robust communication is achieved by applying *stronger error-resilient mechanisms* over the clinically important regions. Likewise, the developed system provides the framework for clinically sensitive video regions to be assigned higher priorities than non-diagnostically important regions during wireless communications, protected more strongly, and even employ selective retransmission schemes for safe guarding video's diagnostic quality.

To compensate for the additional bandwidth requirements imposed by ultrasound acquisition process introducing noise (speckle) in the captured ultrasound video, the proposed system examined the use of despeckle filtering algorithms prior to video encoding. Results demonstrated that *dramatic bandwidth reductions* can be achieved by *applying mild despeckle filtering* prior to encoding without compromising diagnostic quality. The basic idea is to eliminate high-frequency speckle ultrasound components that do not impact diagnostic quality. Nevertheless, the DRIVEN project was the first project to investigate the efficiency of the recently introduced High Efficiency Video Coding (HEVC) standard for medical video communications. The proposed approaches were validated using a variety

[1]eHealth Action Plan 2012-2020 - Innovative healthcare for the 21st century
[2]A Digital Agenda for Europe 2010 – COM(2010) 245
[3]WHO, mHealth: New Horizons for Health Through Mobile Technologies, vol. 3 of Global Observatory for eHealth Series, 2011.

of despeckle filters and several video compression standards (MPEG-2, H.263, MPEG-4, H.264/AVC, and HEVC) as depicted in Fig. 1. For comparable clinical video quality, HEVC reduces bitrate requirements by as much as 33.2% compared to H.264/AVC, while the best performing despeckle filter achieves additional bitrate savings of 43.6% compared to standard, unfiltered HEVC encoding.

To maintain reliable medical communications over time-varying wireless channels, the DRIVEN project facilitated adaptive mechanisms, based on different scenarios involving different wireless networks (e.g., beyond 3.5G and mobile WiMAX), associated network parameters and topologies. The approach was to create an adaptation table, which was then used by the adaptation model to trigger an encoding mode switch to match the current network conditions, while conforming to a predefined clinical quality threshold. Experimental evaluation showed that *low-delay high-resolution (and high frame-rate) ultrasound video communications can be achieved using commercially available (beyond) 3.5G infrastructure*, provided efficient fine tuning of both source encoding and wireless network parameters.

Medical video quality assessment (VQA) was primarily based on *clinically established protocols* developed within the context of the present project. As a result, individual components of the developed system were essentially validated using the mean opinion scores (MOS) of at least two relevant medical experts. The latter allowed deducting *threshold values* (of popular objective VQA algorithms), *above which clinical quality is preserved in the communicated video*. At the same time, experimentation showed that the limited correlation of computerized VQA means and clinicians MOS results in inefficient utilization of the available resources.

The above-described generated knowhow was capitalized towards the development of an open-source telemedicine platform to be used for real-time wireless transmission of medical video of reliable clinical quality. The key concept is to facilitate open-source and hence inexpensive means of assessing the capacity of both wired and wireless networks to accommodate medical video communications. The developed software is particularly useful for triggering researchers as well as other stakeholders in the broader area of mobile Health (mHealth), to engage and challenge research in mHealth video systems and services. The immediate benefits attributed to open-source software implementation, minimum setup time, and relatively low learning curve, are expected to generate initiatives that will both advance the provided platform, as well as expedite the adoption of wireless medical video communication systems in standard clinical practice (especially in developing countries).

Future Directions: The wider adoption of wireless medical video communication systems relies on the development of effective methods that can match the quality of in-hospital examinations. Thus, ongoing and future work aims at integrating emerging compression technologies (e.g. HEVC) and wireless networks infrastructure (beyond 4G, towards 5G) in a diagnostically driven fashion that will allow beyond high-definition -and stereo- video transmission with the low-delay and quality requirements for emergency telemedicine. This is especially true for point-of-care highly portable ultrasound devices (e.g., transducers connected to smartphones) and tele-operated robotic assisted examinations. The challenge is then developing the appropriate mechanisms that will be used to *predict clinical quality using automated techniques*.

Societal Impact: MHealth medical video communications systems in standard clinical practice are expected to remove socioeconomic barriers in access to specialized care, especially in developing countries, by developing cost-effective portable systems for mass population ultrasound screening. Moreover, to enhance responsiveness in emergency and disaster incidents and accommodate enhanced triage provision. Linked with emerging mHealth systems and services, improvement in patient's quality-of-life is envisioned, by reducing hospitalization times and hence associated healthcare expenditures.

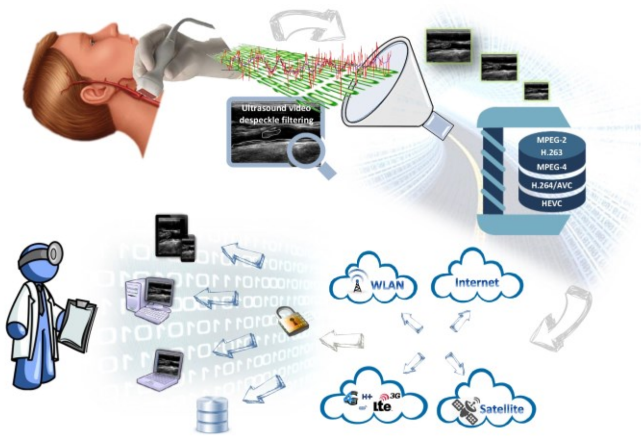

Fig. 1. MHealth medical video communication system diagram. Following pre-processing, diagnostically driven video encoding adapts to each medical video modality. Wireless transmission then takes place over the current best available wireless network. At the receiver's side, clinical quality assessment is performed by the relevant medical expert providing remote diagnosis. Here, for ultrasound videos of the common carotid artery.