Enabling “Surgery 4.0”: 5G Data Transmission in Minimally-invasive Surgery

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Introduction

With the expansion of the digital functionalities in the OR in the sense of "Surgery 4.0” facilitating important applications such as real-time person or asset track- and tracing or tele-robotic surgery, the question of improved data transmission quality becomes more and more urgent (1).
As the currently available technologies for data transmission in the OR (Ethernet/LAN, W-LAN, Bluetooth) are limited in terms of transmission rate, latency and signal stability (2), the upcoming mobile data transmission technology 5G seem to offer a high potential.

5G includes the following characteristics as compared to the current mobile transmission standard 4G/LTE: a 100 times higher data transmission rate (up to 10 Gbps), an extremely low latency (1ms) and 1000 times higher capacity (3). The possibility of transmitting a high data volume almost without delay with high precision and stability makes the 5G technology interesting for different medical applications.

It is not yet known whether the promising 5G mobile telecommunication performance is sufficient for the demanding medical applications such as person or asset track- and tracing, video data transmission for telemedicine and telerobotic surgical operations, where fast, secure and ubiquitously available data transmission is essential.
The latter is the basic prerequisite for the emerging field of cognitive surgery (4), in which the surgical team is extensively supported in its work by the digitalized OR environment. It was the purpose of this research project to evaluate possible fields of applications for 5G to enable Surgery 4.0.

The manuscript comprehends of two different sections:

a) A Delphi study evaluating the expectations and acceptance of 5G in the medical (surgical) field in general
b) The evaluation of 5G technology for a surgical telepresence application (use-case tele-robotic surgery)

Materials and Methods

Delphi study

In order to first obtain an estimation of possible 5G applications in the medical field, necessary technical developments and comparison to currently available data transmission technologies (4G/LTE, WLAN), a Delphi study was carried out. The Delphi method is a structured communication method, which relies on a panel of experts. It is based on the principle that forecasts from a structured group of individuals are more accurate than those from unstructured groups (5).

In two rounds, a fixed panel of 12 experts (industry n= 9, small and medium size enterprises n= 2, academic institution n= 1) provided a written assessment of a list of 28 theses/questions related to the potential future developments of 5G, which was compiled as questionnaire by the authors. The theses/questions were grouped in five different sections: experience, trend, impact, promoting and detaining factors with/of 5G technology. For every thesis/question, probability was explored and in a second round, the results of the previous round were given as feedback. Subsequently, experts were asked to reassess the hypotheses and either confirm or revise their own opinion, where it diverges from the majority opinion.

Surgical Telepresence

Telepresence in general refers to a set of technologies allowing a person to feel as if they were present, to give the appearance of being present, or to have an effect (via telerobotics) at a place other than their true location (6).

The term teleconsultation in the medical field means an image- or video-based consultation of a remote expert giving verbal advice during an operation or procedure. Whereas surgical telepresence reveals a (real) physical action at the distant point of care by a consultant. In this case, a mechatronic support system (e.g. a surgical robot = slave) processes the haptic commands of a consultant entered into an interface (master) into precise manipulations at the remote surgical site (7). As compared to teleconsultation, the requirements of data transmission volume, rate and latency are significantly higher for telepresence, since any delay or interruption of the dataflow would be extremely hazardous.

To evaluate 5G performance for surgical telepresence, we set up an ex-vivo use-case using the robotic camera control arm SoloAssist® (AKTORmed, Barbing, Germany) as slave system maneuvering a laparoscope inside the abdominal cavity of the OR phantom ELITE (CLA Coburg, Germany). Data transmission characteristics were measured. Control commands for the slave system (move up-down-left-right, zoom-in and out) were manually entered into a graphical user interface (GUI, Fig. 1) and data transmission to the robotic camera control arm was conducted with 5G. Normally, data transmission from the input interface to the robot is tethered.
Communication with the SoloAssist® is bidirectional and was realized through a CAN-interface. It allows to send movement commands to and receive position information from the robotic camera control arm. The unidirectional (video) data exchange with the laparoscope unit (K. Storz, Tuttlingen, Germany) was realized through a frame grabber. It receives the analog signal from the laparoscope through a coaxial connection and converts it to digital format. Key capabilities of the 5G testbed (5G NR V2V oriented) are given in Table 1.

Latency	< 2ms
Data rate	Uplink 6 Mbps (HD), Downlink < 10kbps
Wireless range between terminal / sensor and 5G access point	Indoor < 20 m
Interface	1 Gigabit Ethernet (cat6)
Transfer mode	Ultra-reliable low latency communication (URLLC)
Terminal speed	0 kmph
Duplex Mode (LTE)	Time Division Duplex (TDD)
Frequency	2.6 GHz / 20MHz

Table 1. Characteristics of the Huawei 5G testbed (USRP X310). Versatile data interface configurable to support different 5G applications using low-latency (<1ms) machine-type communication.

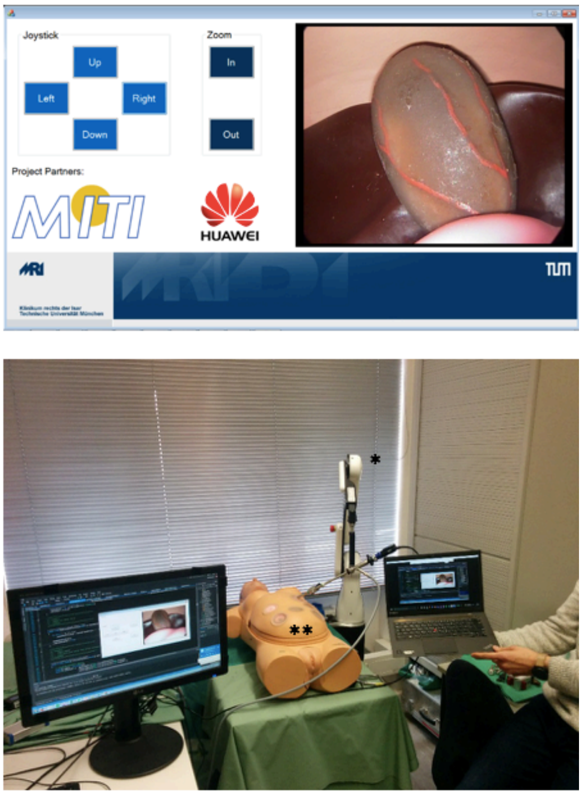

Figure 1. Upper figure: Graphical user interface (GUI) on a tablet computer. Touchscreen to enter the direction of movement for the robotic camera arm SoloAssist® (move up-down-left-right, zoom-in and out), display of the video image (gallbladder). Lower figure: The robotic camera arm (*), maneuvering the laparoscope inside the abdominal cavity of the operating phantom ELITE (**, CLA Coburg), is controlled via GUI by means of 5G data transmission.

Results

Delphi study

At time of abstract submission n= 10 experts (83 %) had completed two survey rounds. Principal points are: 5G technology is regarded as trend-setting for the future transfer of information in the healthcare domain (85.7% agree / 14.3% agree fully). The current mobile standard 4G/LTE is assessed not to be sufficiently suitable for the expected future data transmission requirements (57.1% agree fully). According to expert opinion, the financing of 5G-based services should be actively supported by healthcare politics (42.9% agree fully / 57.1% agree more likely) and potential industry partners should be involved as early as possible in the process of 5G integration in healthcare applications (71.3% agree fully / 28.7% agree more likely).

Preliminary study results confirm our use-case hypotheses that telepresence with 5G data transmission improves medical care in remote regions by actively including specialist knowledge and skill into patient diagnostic or treatment (85.7% agree with operation of 5G technology).

Uncertain yet is the question, whether the experience gained so far with mobile data technology (4G/LTE) allows a good assessment of which problems, requirements and opportunities arise with the implementation of the new 5G data technology or not (57.1% neutral / 28.6% hardly agree / 14.3% tend to agree).

Telepresence

The active involvement of an expert over a distance in the course of an operation was realized in the telepresence use-case. By implementation of the 5G data transmission module, the robotic camera-control arm SoloAssist® was successfully maneuvered wireless without any data transmission interruptions or data transmission delay. A prototype installation of the system was presented at the Mobile Broad Band Forum (MBBF) in London in December 2017.

5G technology allows different settings of the transmission parameters of the physical layer. Especially for the URLLC mode that is used in our setup, a careful parameter selection (e.g. subcarrier spacing and time transmission internal (TTI) length) is important to achieve a minimum of latency combined with a high robustness against transmission errors (Fig. 2).

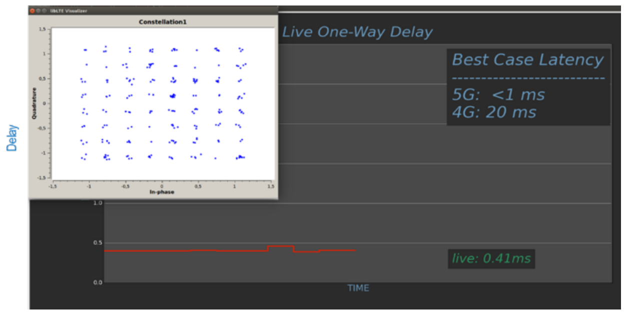

Figure 2. Latency of 5G data transmission can be reduced to < 1ms by carefully selecting the transmission parameters. The measured signal delay of the deployed 5G module including encoding and decoding was 0.41ms.

The evaluation of the transmission properties in terms of reliability is shown in Figure 3. Classic OFDM (Orthogonal Frequency-Division Multiplexing, used in 4G) was compared with a filtered variant (p/f- OFDM, used in 5G). Two different radio channels were used. Measurements showed that a minimum signal-to-noise ratio of 15dB is required to achieve a 99.999% reliability.

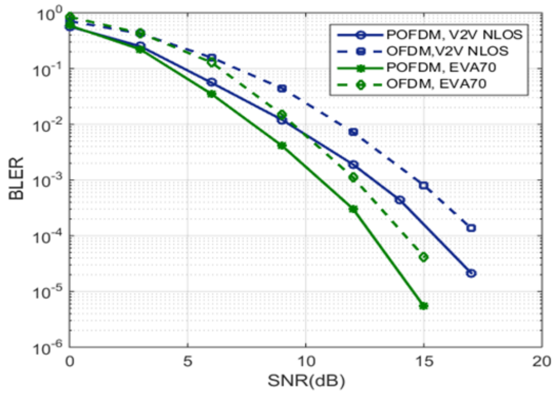

Figure 3. Reliability of radio transmission. OFDM (Orthogonal Frequency Division Multiplexing, used io 4G). p/f- OFDM are filtered variants used in 5G. Radio channels: V2V (Vehicle to vehicle), NLOS (Non line of sight pass) and EVA70 (Extended vehicular A). BLER = block error rate, SNR = signal to noise ratio.

Conclusion

Advanced mobile telecommunication technologies have the potential to enable future applications of "Surgery 4.0". Preliminary results of the Delphi study reveal a positive perspective of 5G implementation in a clinical environment. 5G data transmission creates a future-oriented possibility of telepresence, which is not yet available in this form. For upcoming research, special focus should be put on medical real-time interaction applications, especially remote robotic surgery, as the future 5G standard will not only provide high data rates for the transmission of multimedia content up to virtual reality, but also an extremely reduced latency and simultaneously high reliability of data transmission.

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References

1. Feußner H, Park A. Surgery 4.0: the natural culmination of the industrial revolution? Innovative Surgical Sciences.
2. Li QC, Niu H, Papathanassiou AT, Wu G. 5G network capacity: Key elements and technologies. IEEE Vehicular Technology Magazine. 2014;9(1):71-8.

3. What is 5G? Characteristics and usages 2018. Available from: https://www.gemalto.com/mobile/inspired/5G.
4. Kranzfelder M, Schneider A, Fiolka A, Koller S, Reiser S, Vogel T, et al. Reliability of sensor-based real-time workflow recognition in laparoscopic cholecystectomy. International journal of computer assisted radiology and surgery. 2014;9(6):941-8.
5. Okoli C, Pawlowski SD. The Delphi method as a research tool: an example, design considerations and applications. Information & management. 2004;42(1):15-29.
6. Draper JV, Kaber DB, Usher JM. Telepresence. Human factors. 1998;40(3):354-75.
7. Kranzfelder M, Schneider A, Fiolka A, Koller S, Wilhelm D, Reiser S, et al. What Do We Really Need? Visions of an Ideal Human–Machine Interface for NOTES Mechatronic Support Systems From the View of Surgeons, Gastroenterologists, and Medical Engineers. Surgical innovation. 2015;22(4):432-40.