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A New 5G eHealth Architecture based on Optical Camera Communication: An Overview, Prospects, and Applications

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Abstract—*Currently, various radio frequency (RF) technologies are used to transfer medical data in healthcare applications. The electromagnetic interference caused by RF can critically affect the performance of medical devices. The main goal of this paper, thus, is to provide reliable and low-latency fifth-generation (5G) electronic health (eHealth) solutions for monitoring patients at home, hospitals, ambulances, intensive care units, and outdoors. This monitoring is based on optical camera communication (OCC). In our proposal, the OCC system is used to receive the monitored data from wearable sensors/patches. OCC systems are connected to 5G access networks or wired networks to be linked with the core network. The proposed system is able to provide fast and secure connectivity for simultaneous monitoring of multiple patients. The monitored information is forwarded to hospitals, medical servers, doctors, cloud, and mobile systems for remote monitoring purposes. In this study, we provide a novel technical solution for monitoring patients remotely. A robot system with OCC is also proposed to monitor the health data of multiple patients in hospital. We provide several eHealth solution scenarios for better understanding of the proposed eHealth architecture.*

UPCOMING FIFTH-GENERATION (5G) communication systems are able to bring enormous evolution in the field of information and communication technology (ICT).[1] The 5G Public Private Partnership (5GPPP) aiming for new 5G-enabled markets in the fields of intelligent transport, smart cities, entertainment, media, electronic health (eHealth), and education. Commercialization of 5G is expected to have a huge impact on the implementation of eHealth systems. According to the World Health Organization (WHO),[2, 3] eHealth is the use of ICT for health. ICT-based devices, apparatus, and facilities are included in eHealth systems, and they enhance the performance of the medical sector by providing excellent monitoring, diagnosis, medication, prevention, and management systems. The use of ICT for healthcare can benefit the whole community by improving the system for access to care and quality of care. An eHealth system includes real-time remote monitoring of patients, exchanging medical records among patients, expert physicians, and health service providers through hub of medical information networks, recording patient health information and storing eHealth records on the cloud, providing remote monitoring and diagnosis facilities, provision of global access of medical data, monitoring patients remotely in and outside hospitals, and robotized patient monitoring and surgery.[4–6] Various services offered by eHealth systems can improve medical facilities and help in the decision-making process. eHealth solutions can be effectively used in every aspect of our lives.

5G communication is essential for the

deployment of the real phase of eHealth systems. The upcoming 5G communication can provide services with ultra-low latency, ultra-high system capacity, ultra-high security, massive device connectivity, ultra-low energy consumption, and extremely high quality of experience.[1] This paper aims to provide a novel framework for future 5G eHealth architecture based on optical camera communication (OCC). The 5G capabilities for eHealth solutions are considered. OCC,[7, 8] a subsystem of optical wireless communication (OWC),[9] uses light-emitting diodes (LEDs) or LED arrays as the transmitter and a camera or image sensor (IS) as the receiver. The proposed OCC-based 5G eHealth solutions can be applied to different places such as hospital, sports, homes, public places, workplaces, and pharmacies. Hospital solutions include real-time monitoring of patients in hospitals and ambulances as well as assisting in medical data transfer, storage, and sharing, among other tasks. Sports solutions include remote monitoring of players and remote caring for emergency cases, if any. Home-based eHealth solutions provide remote monitoring of healthy patients and old patients or those with disabilities. eHealth solutions for public and workplaces deal with providing emergency solutions to the public and employers, respectively, using smartphones or other smart devices. Interconnecting pharmacies with hospitals or medical specialists provide for a quick exchange of prescriptions and information about medicines as well as their storage in respective server. On the other hand, the application of OCC for human visual communication is also growing significantly.[10] Besides, OCC-based eHealth system can be effective in providing treatment during spreadable diseases such as COVID-19.

For different eHealth applications, a high-quality wireless technology is required to advance the service flexibility and mobility. Wireless connectivity is used to collect the measured data of wearable sensors/patches, which are subsequently forwarded to core network (CN). Wireless connectivity using radio frequency (RF) in a healthcare environment possesses major challenges. Several medical devices are very sensitive to electromagnetic interference and are affected by RF transmissions. This interference can result in malfunctioning of the medical devices (e.g., errors in reading, automatic restart/shutdown, and waveform distortion).[11] Consequently, it can potentially be harmful to patients. Therefore, the designing of wireless communication systems for eHealth services should be done very carefully, especially for hospitals or other healthcare centers. Therefore, we propose OCC-based eHealth solutions. OCC-based systems can provide highly reliable communication for access network-to-sensor/patch connectivity. The application of an OCC system to a healthcare system is a novel idea. The patients have wearable sensors/patches with LEDs or LED arrays. Sensors/patches measure the health data, e.g., electrocardiography (ECG), electroencephalogram (EEG), photoplethysmogram (PPG), electromyography (EMG), pulse rate, and blood pressure, whereas LEDs or LED arrays transmit the information. The OCC systems receive the medical information and forward it to the desired destination, e.g., hospitals, doctors, servers, and smartphones. The contribution of this paper can be summarized as follows:

- An overview regarding eHealth is presented.
- The features of OCC-based eHealth system are discussed.
- A novel technical solution based on OCC for monitoring patients remotely is proposed.
- A robot system with OCC to monitor the health data of multiple patients in hospital is proposed.
- OCC-based several eHealth solution scenarios for better understanding of the proposed eHealth architecture are presented.
- The challenges for OCC-based eHealth system are discussed.

OVERVIEW OF EHEALTH

In this section, we briefly introduce background information that is related to eHealth.

Current Progress of eHealth[3]

Nowadays the importance of eHealth is realized by various nations and around 58% of 194 WHO countries are constructing infrastructure for eHealth. A survey done in 2016 elucidates that approximately 75% countries offer professional training for providing eHealth services. Currently, 90% of countries get proper funding for developing eHealth systems. Some efforts are already underway for improving eHealth systems, e.g.,

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mobile health (mHealth) programs, telemedicine, and electronic health records (EHR). Around 87% countries have shown interest in implementing the mHealth program in order to make eHealth successful. Additionally, 57% of WHO members are implementing policies for use of telemedicine. Besides, interest in EHR is higher in developed countries (more than 50%) than in developing and underdeveloped countries (35% and 15%, respectively).

Why Interconnected eHealth with 5G?

During an emergency condition, a physician can provide a diagnosis from a remote location using high-speed network infrastructure. Most of the cases in healthcare systems are decisive, e.g., remote diagnosis of patients, monitoring of cardiac patients, and monitoring patients in an intensive care unit. On the basis of the quality of service (QoS) for data communication, complete eHealth applications are classified into four groups[12]: (i) remote-control applications, (ii) real-time critical applications, (iii) real-time non-critical applications, and (iv) office or support applications. Special features of 5G networks especially ultra-low latency, ultra-high system capacity, and massive device connectivity, all of which offer to satisfy the QoS for all eHealth applications in indoor as well as outdoor environments. More importantly, 5G macrocellular network is able to provide very high quality connectivity for outdoor scenarios. Figure 1 shows the basic architecture of the proposed OCC-based 5G eHealth systems. All the medical systems and patients are under reliable connectivity. 5G networks provide connectivity through macrocellular base station (MBS) outdoor and small cell BS (sBS) indoor.

Existing Technologies for Wearable Sensor-to-Access Network Connectivity[6]

Currently, Bluetooth, ZigBee, near-field communication (NFC), wireless universal serial bus (WUSB), IPv6 over low-power wireless personal area networks (6LoWPAN), among others, are used to receive the measured medical data of the wearable sensors. All of these technologies are RF-based ones. These technologies can seriously impact on medical devices as well as patients. Bluetooth has features such as low-consumption idle operation mode and low latency. ZigBee operates on the IEEE 802.15.4 standard and focuses on applications that require low data rate and data encryption. NFC is a group of technologies featuring with low coverage. WUSB is the wireless USB standard extension, which is based on the ultra-wideband technology.

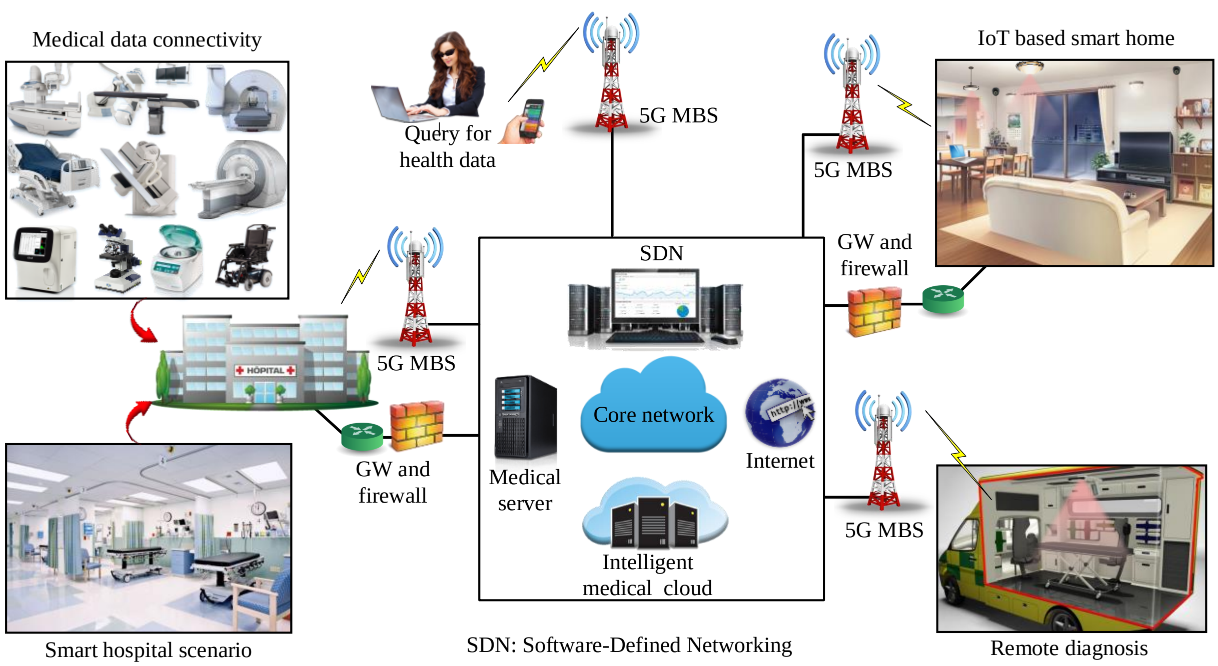

Figure 1. Basic architecture of OCC-based 5G eHealth systems.

OCC FOR EHEALTH SOLUTIONS

In this section, an overview of OCC-based eHealth system architecture is presented.

Overview of OCC

Currently, many wireless applications based on RF technologies are replaced by optical wireless technologies. OCC is one such new promising technology, which is part of the OWC family. OWC technologies use unlicensed spectrum as communication media. Visible light communication (VLC)[9] is already a well-established technology. However, OCC technology is still under development and standardization. The main differences between VLC and OCC are (i) VLC uses visible light as the communication medium, while OCC uses both infrared (IR) and visible light; (ii) VLC uses both LEDs and laser diodes (LDs) as physical transmitters, whereas OCC uses only LEDs; and (iii) a photodetector (PD) or camera (or IS) is used as the receiver in VLC, while a camera (or IS) is used in OCC. As previously reported,[8] on using an OCC system, a data rate of 45 Mbps without bit error and 55 Mbps with a bit error rate (BER) of 10^{-5} were experimentally demonstrated. Light incoming from different angles can be projected onto various positions on a sensor plane. This feature enables it to separate light from different sources and directions, which is ideal for spatial-division multiplexing and imaging multiple-input and multiple-output (MIMO) systems.[7] The data transmitted from different LED transmitters, i.e., LED arrays, are captured easily and distinguished concurrently using IS. In the same manner, the background noise sources are discarded by separating pixels associated with such noise sources. Thus, OCC can provide secure, interference-free, and reliable communication to collect data from multiple LED sources. Other important advantages of OCC technology include high signal-to-noise ratio (SNR) and stable communication against changing distances.

Why OCC for eHealth Solution?

For any potential eHealth solution to be viable, wearable sensors/patches-to-access network connectivity is necessary. Currently, this communication is performed using wireless technologies where unlicensed RF is used as communication media. Wireless connectivity based on unlicensed RF, especially for healthcare solutions, causes serious electromagnetic interference. Many medical devices are extremely sensitive to such electromagnetic interference as it can lead to the device malfunctioning. We can provide an example of the effect of using Bluetooth technology in healthcare. Currently, Bluetooth technologies are widely used in healthcare systems. The main limitations of Bluetooth technology include the following:

- Battery life is seriously degraded.
- A critical problem is security because Bluetooth operates on RF and can penetrate through walls.
- It creates considerable interference when RF technology operates unlicensed frequencies.
- Bluetooth offers limited data rates.
- It provides very short range communication.
- Its lifetime is short.
- It can be hacked.
- It can connect limited devices simultaneously.
- It can lose connection in certain conditions.
- It is harmful to the human body.

OCC is a new wireless technology concept. It can overcome the limitations of Bluetooth and other existing RF-based technologies. The power consumption using OCC is considerably low. Because of being a strictly line-of-sight (LOS) communication technology, OCC is less susceptible to interference and hence, provides very high security. The camera can provide a connection with many sensors/patches simultaneously. The lifetime of OCC is very high and its data cannot be hacked. OCC can provide stable connectivity at a long distance without affecting the performance of other medical devices. Finally, OCC is not harmful to the human body. Moreover, if privacy is not a concern, cameras used in OCC systems can record ultra-high-definition (UHD) video as needed, which can help for real-time monitoring of patients, augmented reality (AR), and virtual reality (VR). Therefore, this technology is very promising for use in future 5G eHealth systems.

OCC is currently being a promising LED-based communication system for low data rate internet-of-things (IoT) applications e.g., eHealth. OCC has recently been adopted in the ongoing OWC standardization at IEEE 802.15.7m Task Group (TG). Among the other OWC technologies e.g., VLC, Light Fidelity (LiFi), using OCC in eHealth can be considered as the incredibly germane approach for the following reasons:

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- Due to the spatial separation of the interfering element from the IS, OCC can provide a superior SINR, which particularly leads to an excellent BER performance. VLC or LiFi can be affected by interference generated from the neighboring light sources to a considerable extent. The reception of the healthcare signals must be as precise as possible. A higher BER can generate serious problems in real-time health monitoring. Therefore, using OCC is a great approach in terms of precise healthcare data reception.
- OCC supports multiple links with less complex system configuration than LiFi or VLC. It is very difficult to implement MIMO in LiFi or VLC because of the complex signal-separation technique. Consequently, multiple PDs are required to support multiple links. However, in OCC, the LED images are projected in different pixels of the IS, which actually makes it easy to separate the signals from each other.
- The communication range using OCC is higher than VLC or LiFi, which actually works at a maximum distance of around 8-10 m. Also, the LEDs integrated into the patches are generally small in size. As the signal level will be low, it is not sophisticated to consider LiFi or VLC in this application other than OCC.
- It is not common or cost-effective to use PDs for receiving the signals from LED patches. On the other hand, OCC can utilize the existing closed circuit television (CCTV) cameras to receive the data from LEDs.
- OCC mainly uses visible light for communication. However, it can also use IR rays for communication.[13] The cases where a patient has issues with LED flickering, IR rays can be used.

It is important to note that LiFi or VLC can achieve a very high data rate than OCC. However, in eHealth, healthcare data is generally not very large in nature. For example, an ECG signal contains several bytes of data. Therefore, the data rate must not be a significant concern here. Rather the BER should be taken into consideration, and OCC is a suitable technology in this regard.

System Architecture

There are three steps for the connectivity for 5G eHealth systems: (i) body sensor/patch-to-camera/smartphone connectivity, (ii) camera/smartphone-to-gateway connectivity, (iii) gateway-to-CN connectivity. Although indoor and outdoor connectivity differs due to the environmental specifics, LOS communication is a compulsory prerequisite. For the proposed 5G eHealth system, LOS connectivity between patch-to-camera needs to be guaranteed for reliable communication. Both the 5G MBS and OCC-based networks are considered for outdoor connectivity. For indoor connectivity, we mainly consider VLC, 5G small cell, and OCC networks as well as their hybrid systems.[14] Figure 2 shows the basic OCC-based CN-to-sensor/patch connectivity for the remote health monitoring system. Wearable sensors/patches measure all possible parameters regarding health conditions, e.g., blood pressure, EMG, ECG, PPG, EMG, and pulse rate. Each patch/sensor has LEDs or LED arrays, transmit measured data simultaneously to camera. The cameras present in a system, e.g., webcams, CCTVs, smartphones, smartwatches, and robots simultaneously receive multiple data that are transmitted through LEDs or LED arrays. OCC systems are connected to access networks or directed to backhaul networks. For indoor scenarios,

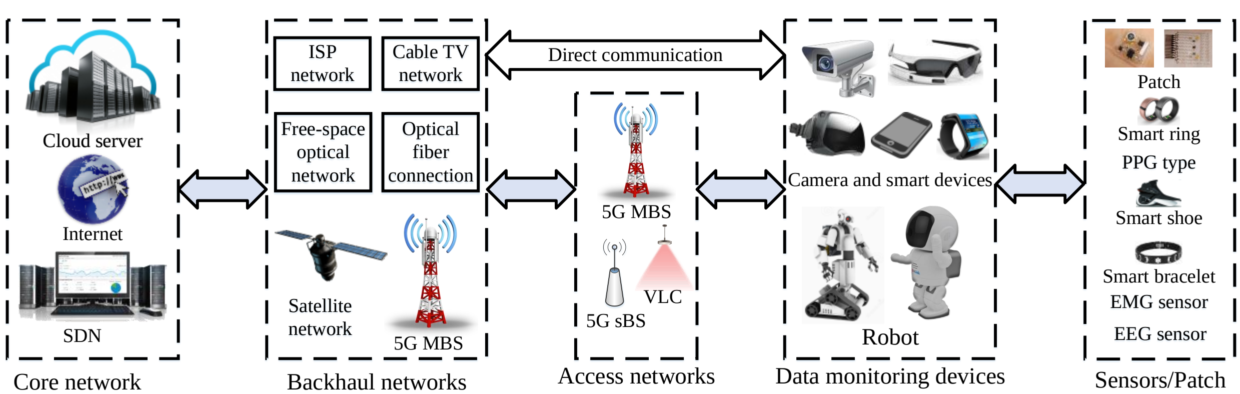

Figure 2. OCC-based CN-to-sensor/patch connectivity.

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backhaul networks. The indoor OCC system can also be connected to a 5G small cell network or a VLC network. These networks are then connected to an available backhaul network. For outdoor environments, OCC systems are connected to satellite networks or 5G cellular networks.

Figure 3 shows the basic architecture of the proposed OCC-based eHealth monitoring system. The skin-type patch sensor senses the body condition and observes various medical parameters. The transducer converts these medical parameters to electrical signals. The analog electrical signal is converted to the digital form using an analog-to-digital converter (ADC). The encoder provides the encoded form of the digital data, which is modulated by a modulator. Finally, LEDs or LED arrays transmit the digital signal through the optical frequency band. The camera has multiple functionalities, including UHD video capture, emotion detection, and OCC. The video system is optional because of the privacy issue. If no privacy issue is concerned, the optional video system can be turned on. The camera uses multiple interfaces, e.g., 5G and VLC, to make wireless connectivity with a backhaul network. The OCC system can also be connected via wired networks. An implementation approach of OCC system using smartphone is presented in our previous work.[15]

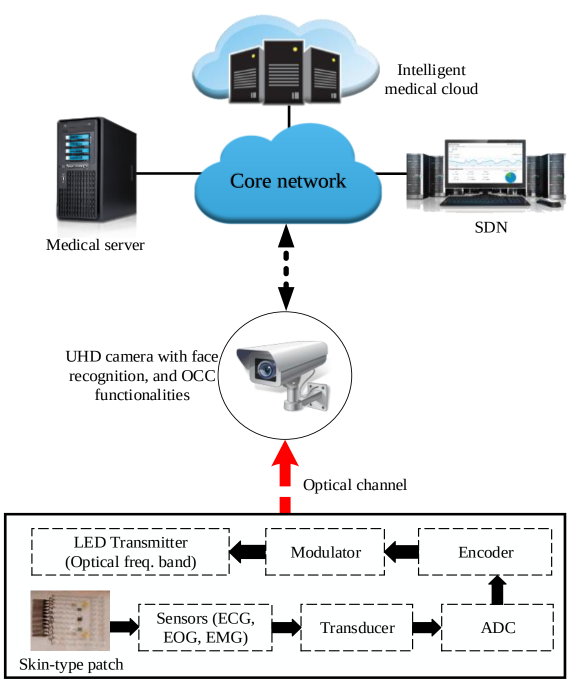

Figure 3. Basic architecture for OCC-based eHealth monitoring system.

APPLICATION SCENARIOS

Our proposed use cases mainly focus on 5G eHealth applications for patient health monitoring in and outside hospitals. Monitoring outside the hospitals includes remote monitoring of healthy patients or patients with disabilities at home, in ambulances, and with wheelchairs. Monitoring the health of a patient requires continuous observation of their health conditions and measurement of several medical parameters. Mostly, these medical data are observed by doctors or nurses manually using various medical devices. A few examples of these medical devices are thermometer and sphygmomanometer to check the patients' body temperatures and blood pressures, respectively. In addition, a doctor or nurse usually counts the pulse to determine the respiratory rate of a patient. The doctor or nurse needs to check these medical parameters individually from one patient to another. This is a time-consuming process. This system can also cause inaccuracy in a data record, which may not be practicable if a large number of patients need to be monitored. Therefore, the automatic health monitoring of multiple patients and multiple medical parameters is an important issue for healthcare systems. Moreover, the proposed OCC-based system can be very useful in providing assistance during the outbreak of contagious diseases. COVID-19, a recent respiratory illness, can be considered as a significant example. Our proposed eHealth system can support remote monitoring of the affected patients.

Nowadays, in health monitoring processes, the wearable sensor act as a physical assistant to monitor the patient's physical conditions during the absence of a physician or a nurse.[16] Currently, these sensors use RF technologies to transmit monitored data. The simultaneous monitoring of multiple patients' multiple medical parameters is impossible using the existing technologies. Therefore, we propose OCC-based patient-monitoring solutions to overcome the existing limitations. In remote monitoring, a patient outside the hospital is monitored from the hospital or other far locations. Wearable sensors/patches measure medical parameters before the OCC system collects those data. Finally, these data are forwarded in real-time to the desired destination e.g., hospital, doctor, or a server. In some cases, the patient's relatives can also observe them through smartphones. Following

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analysis of the monitored medical data, a quick response can be sent back by the doctors to the patient in case of any emergency situation or just for some general advice. Remote monitoring systems should satisfy the requirements of wearability, reliability, and security. Our proposed solutions based on wearable sensors/patches and OCC can satisfy all these requirements. The OCC-based eHealth system can be applied to various scenarios. A few scenarios of OCC-based 5G eHealth systems are shown here.

Robot-assisted OCC System

A robot system can be designed to monitor the health conditions of people at home or in a hospital. The robot can be integrated with the OCC system to receive data from LEDs or LED arrays of wearable sensors/patches. A doctor needs to check a patient's ECG, EOG, EMG, among other vital signs. As a result of 5G eHealth deployment, doctors can remotely monitor a patient from his/her chamber. Wirelessly powered systems in wearable sensors/patches are able to transmit data through NIR (near IR) light. The OCC system receives these data and conveys it to doctors. Therefore, doctors can remotely monitor patients. At a hospital, the robot can check-up on patients on a regular basis. Using the integrated OCC system, the robot receives the measured data by wearable patches/sensors. The robot has 5G and LiFi or VLC interfaces. It communicates to a doctor regarding the patient's monitored data, and the medical data are stored. The camera of a mobile robot has multiple simultaneous connections with patch sensors of patients. Figure 4 shows a robot-based fast access scheme. The robot can move around a hospital. The camera also has the functionalities, such as video capture, emotion detection, and OCC. It can transfer the captured video, monitored data, and emotion-detected information to local or global hospitals. In case of COVID-19 situation, the mobile robot will be used for monitoring the health conditions of multiple patients remotely such as measuring of temperature. The monitored data are transmitted to a robot through an OCC system. Then, 5G or VLC system connects the robot to the gateway. The monitored data can be observed by a remote doctor and authentic mobile users. These data can be accessed locally or globally.

Monitoring Multiple Patients at Hospitals

Continuous monitoring of patients in hospitals is a regular task. The monitored data are sent to a medical doctor for analysis. Sometimes, busy doctors need to visit a patient to know the patient's health conditions. The OCC-based eHealth system can provide a good solution for this issue. It is possible to simultaneously receive multiple information from multiple patients using the OCC system, which is a big advantage of our proposed eHealth system. In Figure 4, a robot is simultaneously monitoring the medical data of

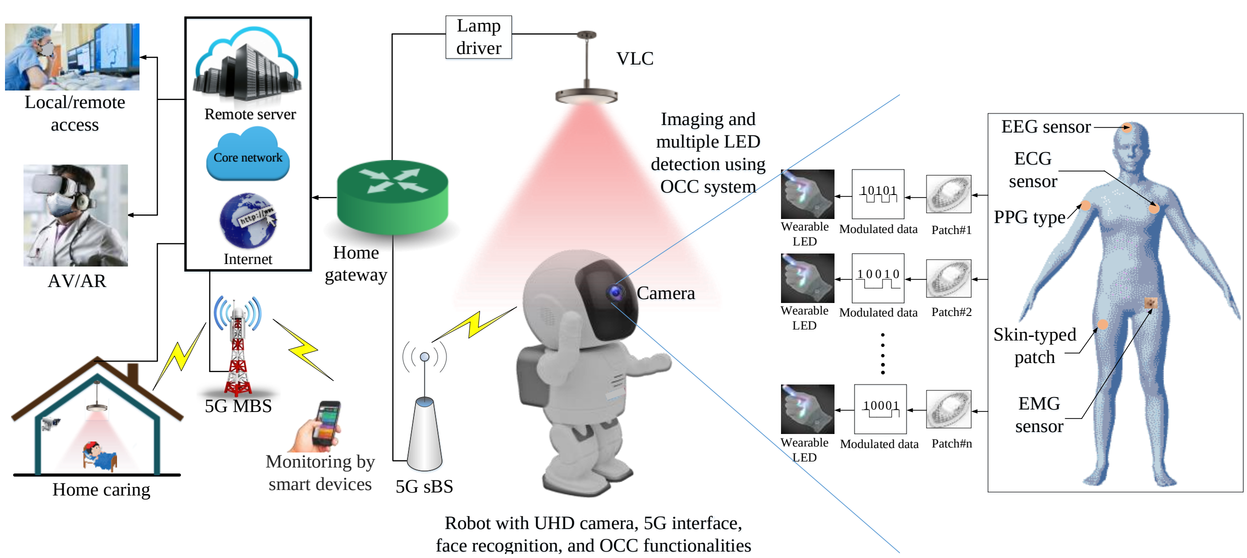

Figure 4. Robot-assisted multiple patient monitoring and remote home caring.

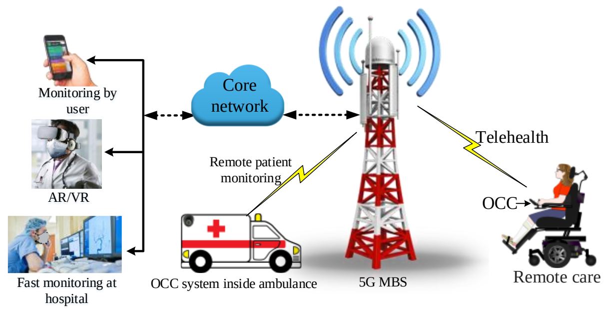

Figure 5. OCC-based remote caring for patient in ambulance and disable person in outside home.

multiple patches from multiple patients. The robot is intelligent enough to analyze the data. The data received by the OCC system are forwarded to servers, doctors, or other systems.

Remotely Monitoring Patients at Home

Future eHealth systems are expected to remotely monitor patients at home. The OCC system is possibly the best solution in this regard. The remote monitoring of a patient at home is also shown in Figure 4. The doctor at a hospital can remotely monitor the patient's condition and give advice. Wearable patches/sensors collect the patient's monitored data; then, LEDs or LED arrays with the patches/sensors transmit the collected data to the OCC system installed inside the home. The OCC system can be connected to any wired backhaul network, e.g., ISPs and cable TVs. If wired backhaul connectivity is unavailable, it can be connected through a wireless backhaul network, e.g., 5G networks.

Monitoring Patients in an Ambulance:

During transportation, it is extremely important to care for the patient. OCC-based eHealth system installed inside an ambulance can also help to remotely monitor the patient. The doctor can observe the patient continuously from a hospital. Figure 5 shows fast patient monitoring at an ambulance through OCC and 5G systems. While transporting a patient by an ambulance, our system can provide remote caring and monitoring of the patient. The OCC system in the ambulance receives the monitored data and then forwards it to the hospital or doctor through 5G networks. If a 5G network is unavailable, satellite network is a possible alternative for backhauling the data.

Patient Monitoring at Outside Home:

It is extremely important to monitor a person with disabilities when they are out of home. For any emergency condition, OCC-based eHealth system installed in the wheelchair can help to monitor the disabled person. In Figure 5, an example of providing fast monitoring to a person with disability who moves outside using a wheelchair is shown. The patient's conditions can be observed by their family members as well as a doctor. An OCC system is installed in the wheelchair, and the person bears wearable patches/sensors. Subsequently, the OCC system collects the patient's medical information. This OCC system with 5G interface facilitates to send the monitored data to doctors and to others. Moreover, it is possible to localize the person with disability using the OCC system.

CHALLENGES

The OCC system is not standardized yet. It is still under research and development. Following challenges should be overcome to implement OCC-based eHealth system:

- The same camera can be used for recording video or capturing the image of a patient and getting signals from wearable sensors/patches simultaneously. Here, the combination of computer vision and OCC functionality is a challenging issue. Therefore, a system that combines these two technologies on the same platform needs to be implemented.
- The data rate of OCC system should be increased to improve upon its current performance and to overcome the upcoming demands of high data rate.
- Instead of using (or comparing with) conventional cameras, implementing a commercial 360° camera on monitoring devices can provide a larger field of view.
- Platform for OCC-5G connectivity is not ready yet. Meanwhile, a standardization named IEEE 802.15.7m for OCC is progressing. Therefore, the full presence of OCC technology for eHealth is delayed.
- For OCC, the time for algorithm execution should be improved and faster than the current time (e.g., longer time exposure delay row by row[17] can cause higher execution time especially for that of the MIMO topology).

We have released IEEE 802.15.7-2018 in 2019.

IEEE 802.15 may start the new TG called 802.15.7a, High Rate OCC TG very soon.

CONCLUSIONS

The aforementioned promising features of 5G networks open the door for many new exciting services. 5G eHealth is one of such services. 5G networks can support the establishment of novel eHealth solutions, delivering eHealth services for everyone globally, especially for remote caring, mobile health services, and smart pharmaceuticals. For the complete eHealth system, network infrastructures for both the sensor-to-access network and access network-to-CN are extremely important issues. Currently, the used RF technologies for sensor-to-access network connectivity result in serious interference issues. We provide an OCC-based solution, which minimizes the limitations of RF technologies. This paper aims to provide reliable 5G eHealth solutions for monitoring patients and patients with disabilities in hospitals as well as remotely monitoring them at home, in ambulances, intensive care units, and outdoors. In addition, the proposed system can be effective in providing assistance during spreadable diseases such as COVID-19. The proposed OCC system can be used for the purposes of communication, imaging, emotion checking, and positioning. More cases are applicable to the proposed system. We provide several use cases of our proposed eHealth system. The successful implementation of our proposed OCC-based 5G eHealth system can be the real evolution of healthcare system.

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