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5G Network-enabled Smart Ambulance: Architecture, Application, and Evaluation

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ABSTRACT

As the fifth generation (5G) network comes to the fore, the realization of 5G-enabled service has attracted much attention from both healthcare academics and practitioners. In particular, the 5G enabled ambulance service seamlessly connects the patient and ambulance crew at the accident scene, or in transit, with the awaiting emergency department team at the destination hospital, thereby, improving the rescue rate of patients. However, the application of the 5G network in the ambulance service currently lacks a reliable solution and simulation test of performance in the existing literature. To achieve this end, the primary aim of this study is to propose a solution of 5G-enabled smart ambulance service and then test the Quality of Service (QoS) of the proposed solution in experimental settings. We consider the emergency scenarios to investigate the task completion and accuracy of 5G-enabled smart ambulances, and to verify the superiority of our proposed solution. Our study explores the value of 5G-enabled smart ambulances and offers practical insights for the 5G network construction, business development and network optimization of smart ambulance service.

INTRODUCTION

As the demand for ambulance services grows, many hospitals are struggling to meet response time targets. In the UK, approximately 500,000 ambulance hours were lost due to both hospital transfer and post-transfer preparation of ambulances in 2016, according to the NHS ambulance service's report [1]. Surprisingly, only 58% of hospital transfers meet the expectation of transferring a patient from an ambulance to an emergency department. In China, cities like Shanghai are suffering from the shortage of ambulance crews, indicating that the required ratio of ambulances per head of population far exceeds the national standard of one ambulance per 50,000 residents [2]. Such delays and shortages not only cause patients emotional distress, but also, put patients in life-threatening situations.

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In order to tackle turnaround delays in ambulance services, a great deal of research has prioritized the deployment of ambulance crews and the transportation of ambulances [3]. However, optimizing transfer time and the process of ambulance services through using a traditional operation approach is not sufficient. Prior works have applied wireless communication technology to the ambulance service [4] [5]. For instance, Rehman et al. [5] proposed a system model of ambulance scenario operation where a femtocellular base station and transceiver are deployed in the ambulance to transmit medical ultrasound video streaming to the hospital's emergency department. The most recent study, conducted by Mukhopadhyay et al. [6], develops a wireless communication system based on medical transit services in which real-time, patient vital data can be transferred to a doctor in the destination hospital though a smartphone application. These systems, developed by the above-mentioned, have been tested, or simulated, under various network conditions such as 2G (2nd Generation), 3G (3rd Generation), 4G (4th Generation), and Fiber to the Home (FTTH).

Nevertheless, the ambulance service, with traditional wireless communication technologies, needs to overcome several technological challenges. First, wireless communication capability may be limited due to the high mobility of the ambulance. Some advanced wireless communication systems, such as FTTH, are only being deployed in certain urban areas of the country, mostly for commercial purposes. 4G emergency service in the UK, for example, faces significant delays due to inefficiency in Terrestrial Trunked Radio network technology and the inability to integrate delivery partners and other contractors, according to the National Audit Office's (NAO) report [7].

Second, by using the current wireless communication technologies, it is difficult to provide reliable and high-quality communication capability for ambulance services. Clearly, real-time video streaming systems, deployed in ambulances, require high-speed data and high-resolution images/videos transmission. In some cases, limited and instable wireless communication may prevent awaiting emergency department professionals from remotely monitoring those patients with specific conditions such as skin pallor and patient demeanor. This limits the decision-making of paramedics and may cause potential patient risks.

Third, 4G networks currently encounter many challenges such as the high cost of energy consumption, high demand of ubiquitous coverage, and the varied quality of service and quality of experience requirements [8]. The ambulance service with 4G wireless communication technologies cannot deal with the rapid explosion of wearable medical devices. This requires additional, technical investment with potentially higher, networking flexibility and transmission performance to make it fit for purpose.

As the current wireless communication technologies are not sufficient to overcome these limitations and challenges, more advanced solutions should be embedded into the ambulance service. As the fifth generation (5G) network comes to the fore, the realization of a 5G-enabled service will have the potential to bring tremendous benefits to individuals, organizations and society as a whole [9]. In particular, the 5G network enables ambulances to connect a patient, who may be wearing emergency medical equipment and wearable devices, to the awaiting emergency department. Patient data starts to be collected at the incident scene and is continuously sent back to the destination emergency department while a patient is in transit. This allows the emergency department team to provide emergency treatment in a remote and immediate manner and offers ambulance paramedics more intelligent decision-making support in order to stabilize a patient. However, there is currently a lack of research focusing on developing a 5G network-enabled medical emergency service. Therefore, the primary aim of this study is to propose a 5G-enabled smart ambulance service and to test its performance in experimental settings.

In achieving this aim, the main contributions of this study are three-fold:

- A system architecture for the 5G-enabled smart ambulance service is proposed.
- As the application of 5G in ambulance services lacks a reliable simulation, we test the Quality of Service (QoS) of 5G-enabled smart ambulances in experimental settings.
- We consider the emergency scenarios (i.e. patients in transit at the speed of 30 km/hour and sending a 4.5 gigabytes of medical image data from an ambulance to a destination hospital) to examine the task completion and accuracy of the 5G-enabled smart ambulance, and to verify the superiority of our proposed solution.

The article is organized as follows. We introduce the 5G network technology and its applications to health care. The architecture of the 5G-enabled smart ambulance is then proposed. We verify the performance of the proposed 5G-enabled smart ambulance by stimulation tests. Lastly, conclusions are drawn in the final section.

THE 5G NETWORK AND ITS APPLICATION TO HEALTH CARE

The evolution of wireless networks can be traced back to the 1970s when voice communication was considered the main traffic of exchange. Since then, network communication has played a critical role in society and has experienced a dramatic evolution, as presented in Table 1. Compared to previous generations of network technology, 5G features increased capacity, reliability, coverage, connection density and energy efficiency whilst reducing latency [10]. Low latency communication, ubiquitous connectivity, and high-speed gigabit connection represent the most important features for supporting real-time, content delivery and user interaction [11] [12] [13]. These features enable smart devices to share data without human assistance and seamlessly interact with each other.

TABLE1. Evolution of Network Communication.

Generations	Year	Key features	Data rate	Core network
1G	1980s	Analog signals for voice	1.9 Kbps	PSTN
2G	1990s	Digital signals for voice and text	14.4 Kbps	PSTN
3G	1998-99	• Voice and text • Wireless mobile • Internet access	2 Mbps	Packet network
4G	2008-2009	• IP based network • Speed up to hundreds of megabits per second	200 Mbps	Internet
5G and beyond	2019-2020	• Low latency communication • Ubiquitous connectivity • High-speed gigabit connection	Up to 10-20 Gbps	Improved network as an anchor point for multi-access technologies

With the rapid adoption of 5G network in the health sector, some major deficiencies in healthcare systems can be revamped and addressed. First, communication and access to healthcare resources in the current system are problematic due to the limited bandwidth of 4G [14]. As an example, patients have to physically visit the hospital for medical consultations, and healthcare facilities, or services, are not equally accessible. This causes inconvenience. The latest wireless technology (i.e. 5G core network) supports the applications of telemedicine such as tele-surgery, tele-diagnosis, and tele-rehabilitation, which enable patients to remotely access medical resources. Such wireless connectivity can advance telemedicine and the provision of expert-based care.

Second, most medical data generated from equipment and stored in medical information systems and video communication systems is highly heterogeneous. 5G enables the storage of data in the distributed database system through the adoption of edge computing, cloud computing, distributed storage and other technologies, and then filters, cleans, converses and integrates the data in order to build a pre-hospital, emergency data center. Specifically, to solve the problem of unstructured data in pre-hospital, emergency systems, databases and systems being adopted include NOSQL database for data storage, Apache Hadoop platform for heterogeneous data management, MapReduce for operating tasks of data analysis, and secured access for the centralized stored data, visual display and emergency decision support [15]. These technologies contribute to standardized rules of data acquisition mode, transmission protocol and storage so that the data can be converted and packaged for sharing among the heterogeneous systems.

Furthermore, the current healthcare system is not patient-centric nor customized to personal requirements. Tailoring treatments on the basis of individual medical profiles and history is difficult and costly [14]. The 5G network allows wearable devices to be attached to the core network and transit data through sensors in a real-time manner which sustains crucial medical information and has the potential to achieve personalized treatments. In particular, a 5G medical, customized network utilizes technologies, such as MEC and network slicing, and thus, is compatible with VPN, Internet, cellular network and satellite. In its deployment, exclusive access could be designed for hospital and inter-hospital business, as the fixed location of medical services, long-term, frequent existence, large business flow, high security and stability requirements require a dedicated bandwidth-guaranteed line that is not occupied by other business.

Additionally, 5G enables better data analysis which can be used to assist decision-making for smart ambulances. With real-time interaction and the sharing of heterogeneous information, such as geographical location, a patient's medical records, medical examinations and medical images in pre-hospital emergency service, 5G assists specialists at the hospital in obtaining information regarding pre-hospital, first aid location, real-time video and medical condition and transmission, which therefore enables better decision-making before the patient enters hospital.

PROPOSED ARCHITECTURE

The architectural components of 5G-enabled smart ambulances proposed in this paper include: (1) 5G communication network, (2) remote video communication and (3) telemedicine medical data exchange. ***5G communication network*** supports the access of vehicle-mounted, positioning terminals, video communication equipment and multi-monitor acquisition equipment in ambulances, while ***the remote video communication*** allows the real-time picture transmission of audio and video information at the accident scene, ambulance, command center and hospital. ***Telemedicine medical data exchange*** is interconnected with hospital information systems (HIS), laboratory information systems (LIS), geographic information systems (GIS), picture archiving and communications systems (PACS), and document management systems (DMS), which enable doctors in hospital emergency centers to browse patients' historical and medical records, register first aid information and issue examination sheets. This would simplify the medical treatment process and improve the efficiency of patient treatment. The components of 5G-enabled smart ambulances is demonstrated in Fig. 1.

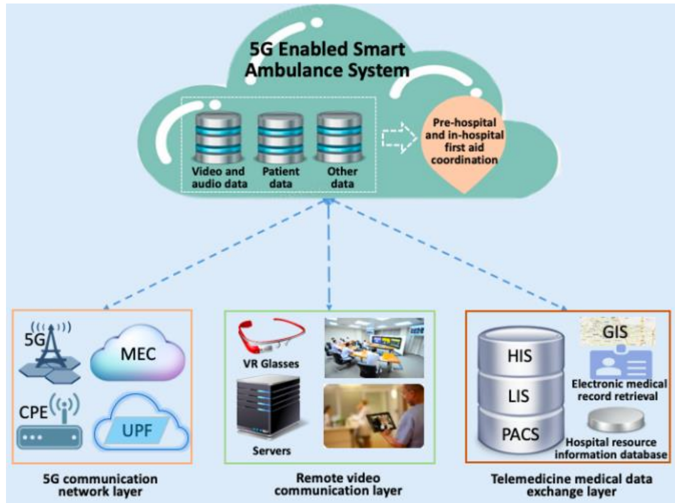


FIGURE1. The proposed architecture of a 5G-enabled Smart Ambulance

5G COMMUNICATION NETWORK LAYER

Ambulance planning encompasses decisions to be made on strategic, tactical, and operational levels [3]. In the current ambulance service, significant challenges remain at each level. At the strategic level, selecting the locations of ambulance-based stations is generally determined for a considerable time. At the tactical level, the deployment of ambulances and crews at base stations is not efficient. At the operational level, real-time dispatching of ambulances to incidents lacks reliable and high-quality wireless communication.

Our proposed 5G communication network attempts to fuel the next leap in shortening response and transfer times. Based on the wide range of scenarios that may occur at the accident scene, mobile first aid, command center and medicinal emergency treatment, hardware equipment [such as mobile edge computing (MEC), base band units (BBU), customer-provided equipment (CPE) and user plane function (UPF) gateway] are deployed by using 5G fusion network characteristics, and the compatible fusion test, medical private network of wired, wireless and cellular networks that is built on the standalone (SA) architecture. Bearing in mind the diversified business needs of vehicle positioning, audio and video interaction, medical data information sharing, medical resource scheduling and remote treatment guidance in the process of the ambulance service, this provides a reliable network, supporting the deep integration of data, resources and services and the development of multi-party, collaborative work.

The 5G network meets the demands of bandwidth, delay and other network performance for the application of pre-hospital emergency systems. The main advantages are reflected in many aspects. First, accurate and timely access to geographical location and real-time positioning of vehicles can automatically provide accurate, real-time, spatial location, according to the scheduling information of the command center, to avoid traffic congestion. This would greatly shorten the scheduling time. Second, virtual reality (VR) glasses are used at the scene of the accident. The doctors in the destination hospital are allowed to grasp the real-time status of patients and the accident scene through a panoramic perspective. Third, real-time, vital signs data, such as patient blood pressure, blood sugar, blood gas and other patient medical records and data information, are collected through on-board, medical equipment and then delivered to the doctor at the destination hospital. This provides real-time guidance and treatment for the patient.

The REMOTE VIDEO COMMUNICATION LAYER

Through the application of multimedia processing technology and audio and video interactive technology, hospital doctors can use VR glasses, or video terminals, in real-time, to grasp the condition of patients in transit. Emergency and critical patients can immediately receive expert rescue guidance, improving the quality and efficiency of ambulance doctors and minimizing the rescue time. This truly achieves a seamless connection before arriving, and in the hospital, so that emergency patients receive better treatment, further improving the success rate for emergency and critical patients and building a more convenient platform. The main advantages of using remote video communication are: (1) through the VR glasses, or the video terminal in the ambulance, real-time tracking of patients and their treatment can take place; (2) the remote video communication can initiate remote consultation while a patient is in transit. It is helpful for hospitals to make timely rescue preparations and guide the treatment.

TELEMEDICINE MEDICAL AND DATA EXCHANGE LAYER

Telemedicine medical data exchange utilizes the identity index and keyword identification approaches to solve inefficient systems and integration issues. This layer allows the user to capture, store, and process the patient data in HIS, LIS, PACS, hospital resource information database, and geographical resource information database. This would also support the online input of past diagnosis and treatment information, patients' vital signs data, rescue on-site video information and rescue information and achieve real-time data exchange and sharing among different healthcare systems.

In addition, the telemedicine medical data exchange supports the functions of real-time acquisition of patients' vital signs data, online transmission of medical images and video on-site pictures, online storage of patients' medical records information. It provides medical data support for the multi-linkage of doctors, hospitals and command centers in the emergency scene (including ambulances).

The telemedicine medical data exchange brings many benefits to the 5G-enabled smart ambulance. First, doctors at the destination hospital use the expert knowledge base and other intelligent systems to make a preliminary diagnosis and carry out pre-hospital monitoring and treatment of patients. Second, the real-time understanding of the patient's condition and their arrival time could solve the problem of the hospital emergency department being unable to assess the treatment and patient's condition in real-time. Third, through the image and video function cloud, first aid can be automatically recorded online to generate electronic files. Patients' personal information and medical record information can be automatically shared among institutions in real-time. Fourth, this system allows access to the hospital database and patient medical history. This enables the development of pre-hospital treatment programs. Finally, this system could obtain information from the first aid database and first aid decision model. This allows the command center to dispatch the appropriate medical staff and vehicles, optimize the rescue route, and co-ordinate pre-hospital, first aid tasks.

TEST AND SIMULATION

Research on the 5G network mainly focuses on developing 5G enabled collaborative models and exploring their service functions and applications. The 5G network quality and data transmission quality for 5G service have not yet been tested and compared to the performance of the 4G network. As the proposed 5G enabled smart ambulance solution needs to meet the requirements of medical data collection, medical images transmission and medical information sharing in real-time, we aim to test the actual performance of the 5G network from the QoS perspective. Specifically, we tested the network carrying capacity of medical data, cross-area network jitter, and network bandwidth in a real-time transmission setting by comparing the conditions of 4G with 5G in two scenarios. The first scenario was set up to test the network carrying capacity and network jitter when the remote video consultation, along with medical data, was uploaded and downloaded under the conditions of the ambulance travelling at the speed of 30 km/hour. In the second scenario, the uploading process of large volume, medical data was tested by 4.5 gigabytes of medical image being sent from the ambulance to the awaiting emergency department team at the destination hospital.

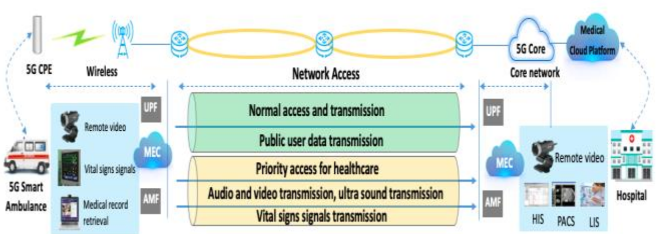
As part of this study, we built a test platform for a 5G-enabled smart ambulance in the National Engineering Laboratory of Internet Medical System and Application of the First Affiliated Hospital of Zhengzhou University. We then performed the simulation test of QoS for the 5G enabled smart ambulance. The test platform consisted of an intelligent mobile terminal module, a 5G network transmission module, an edge cloud computing node and a cloud computing node, as shown in Fig.2a.

The intelligent mobile terminal module is composed of a medical data acquisition device, a doctor workstation and a video communication terminal, wherein the vital signs information from patients can be collected in real-time. The medical staff can react to rapid rescue response at any time and in any place, participate in the whole process of pre-hospital first aid and in-hospital special treatment, and support real-time, medical data acquisition and remote consultation video communication.

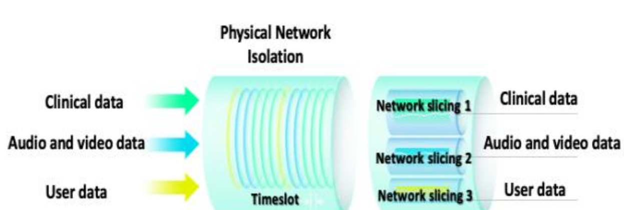
The 5G network transmission module includes a 5G CPE signal transceiver and a 5G UPF gateway service flow forwarding device, which realizes the separation of the user plane and the control plane. The identification of the corresponding ambulance service and first aid assistant decision model are deployed on the edge computer point and the cloud computing node, which improves the service quality and medical treatment level of remote first aid. The video communication equipment synchronizes the panoramic information in the ambulance and delivers it to the hospital in real-time. The collected information automatically distributes the mobile, medical, private network according to the service type 5G UPF gateway, and uploads to the appropriate computing platform (i.e. local cloud or remote cloud) in real-time.

The proposed 5G-enabled smart ambulance is deployed on the edge cloud computing node and the cloud computing node. This allows for the collection of the transmission link state from the intelligent terminal to the edge computing node and from the edge computing node to the cloud computing node. At the same time, the system can also collect vehicle location, patient medical record information, video call information, and share medical information and available computing resources between the ambulance and the destination hospital. After the intelligent terminal collects the vital signs signals and patient video information, the intelligent terminal is divided by the 5G network transmission module and transmitted to different computing nodes, and the processing results are fed back to the ambulance and the destination hospital. This supports the data collection, transmission, processing and display of the emergency medical service.

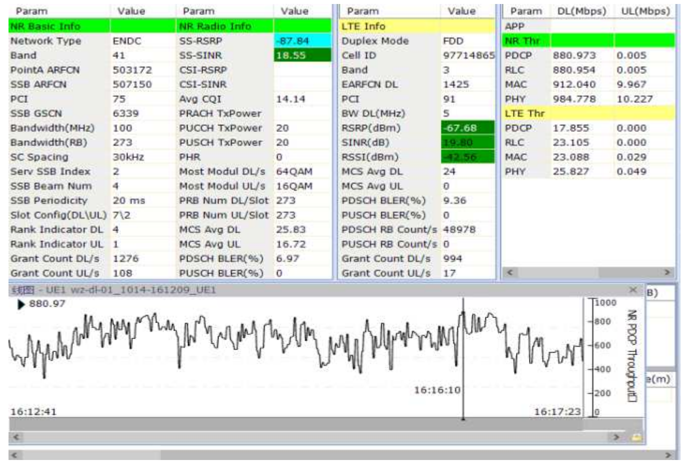
Fig. 2b demonstrates the 5G standalone medical network. The network test equipment is connected to the vehicle-mounted 5G CPE through the CTA6 gigabit network cable to collect the network performance data when the smart ambulance service operates. The network bandwidth, delay, jitter and other specific conditions of the service network can be intuitively seen through the network test software. The dashboard of traffic surveillance, using 5G network monitoring software, is shown in Fig. 2c.



(a) Experimental environment



(b) 5G SA medical network



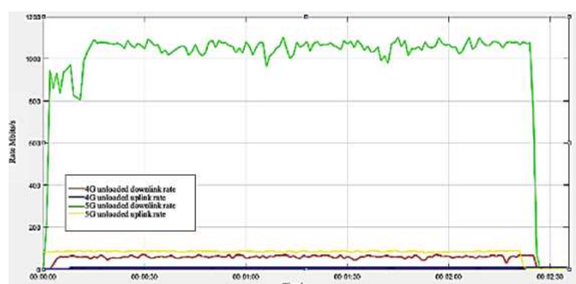
(c) 5G network monitoring software and traffic waveform

FIGURE2. Test and verification platform

RESULT ANALYSIS

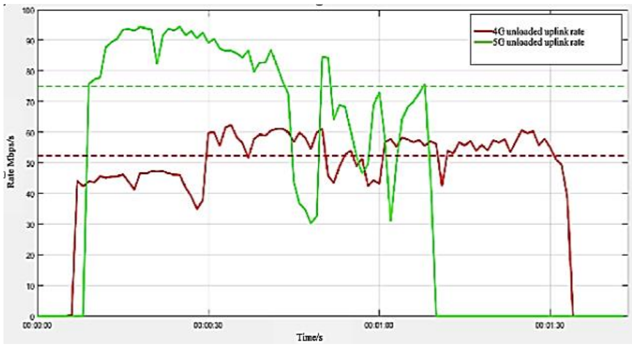
The results of comparison analysis are presented in Fig. 3. The measured peak value of 5G unloaded downlink rate is 18 times that of the 4G network, while the measured peak value of 5G unloaded uplink rate is 9 times that of the 4G network (see Fig. 3a). In the first scenario, the average downlink speed of 1080 p/30Hz high-definition video in the 5G network environment is 4.6 Mbps. Comparatively, the average downlink speed in the 4G network is 3.5 Mbps with unstable network and packet loss which occurred during video calls (see Fig. 3b).

In the second scenario, the 5G network upload rate is significantly higher than 4G. The upload time is shortened by 33%, compared to 4G (see Fig. 3c). The average delay of 5G is 12.88 Mbps, while the average delay of 4G is 76.85 Mbps, which is 6 times that of 5G (see Fig. 3d). Overall, with sufficient 5G support, our smart ambulance solution provides more efficient and stable medical data delivery.

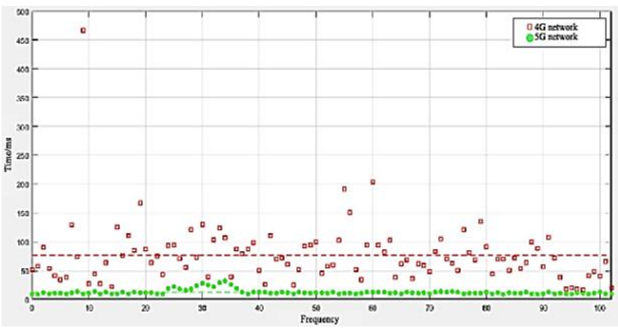


(a) Comparison of network no-load rate

(b) Comparison of downlink rate of remote video service



(c) Comparison of uplink rate of medical image



(d) Comparison of uplink delay of medical image

FIGURE3. Performance comparison of 4G and 5G remote emergency network

Conclusion

This article proposes an architecture for a smart ambulance solution, enabled by the 5G network, with the aim of achieving response time targets of medical emergency services. The 5G enabled smart ambulance consists of three key components: 5G communication network, remote video and telemedicine medical data exchange. Given the higher capacity of 5G network, these three layers are interconnected to optimize transfer time and process of ambulance services. Patient data can be processed effectively to make timely rescue preparations and guide the treatment while patients are at the accident scene or in transit. We tested the proposed solution in the experimental settings to ensure the performance and quality of the ambulance service. This is one of the first studies to examine the performance of the 5G-enabled smart ambulance. To be specific, our solution fully considers the emergency scenarios to investigate the network carrying capacity, cross-area network jitter, and network bandwidth of the ambulance service. Future work should focus on improving the quality of service of the proposed architecture and solution.

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References

[1] National Audit Office. NHS Ambulance Services. https://www.nao.org.uk/wp-content/uploads/2017/01/NHS-Ambulance-Services.pdf, 2017.

[2] A. Yan, Ambulance Crew Shortage Costing Lives, Shanghai Experience Shows. https://www.scmp.com/news/china/article/1586875/ambulance-crew-shortage-costing-lives-shanghai-experience-shows, 2014.

[3] T. C. Van Barneveld, S. Bhulai, and R. D. van der Mei, "The effect of ambulance relocations on the performance of ambulance service providers," *European Journal of Operational Research*, vol. 252, no. 1, 2016, pp. 257-269.

[4] M. C. Batistatos, G. V. Tsoulos, and G. E. Athanasiadou, "Mobile Telemedicine for Moving Vehicle Scenarios: Wireless Technology Options and Challenges," *Journal of Network and Computer Applications*, vol. 35, no. 3, 2012, pp. 1140-1150.

[5] I. U. Rehman, N. Y. Philip, and R. S. Istepanian, "Performance analysis of medical video streaming over 4G and beyond small cells for indoor and moving vehicle (ambulance) scenarios," In 2014 4th International Conference on Wireless Mobile Communication and Healthcare-Transforming Healthcare Through Innovations in Mobile and Wireless Technologies, 2014, pp. 211-216.

[6] A. Mukhopadhyay, S. Sreekumar, B. Xavier, and M. Suraj, "A Cloud-Based Smartphone Solution for Transmitting Bio-Signals from an Emergency Response Vehicle," *International Journal of E-Health and Medical Communications*, vol. 10, no. 3, 2019, pp. 22-38.

[7] National Audit Office, Progress Delivering the Emergency Services Network. https://www.nao.org.uk/wp-content/uploads/2019/05/Progress-delivering-the-Emergency-Services-Network.pdf, 2019.

[8] C. X. Wang, F. Haider, X. Gao, X. H. You, Y. Yang, D. Yuan, H. M. Aggoune, H. Haas, S. Fletcher, and E. Hepsaydir, "Cellular Architecture and Key Technologies for 5G Wireless Communication Networks," *IEEE Communications Magazine*, vol. 52, no. 2, 2014, pp. 122-130.

[9] H. Lu, Q, Liu, D. Tian, Y. Li, H. Kim, and S. Serikawa, "The Cognitive Internet of Vehicles for Autonomous Driving," *IEEE Network*, vol. 33, no. 3, 2019, pp. 65-73.

[10] L. Bai, L. Zhu, X. Zhang, W. Zhang, and Q. Yu, "Multi-satellite Relay Transmission in 5G: Concepts, Techniques, and Challenges," *IEEE Network*, vol. 32, no. 5, 2018, pp. 38-44.

[11] N. C. Luong, P. Wang, D. Niyato, Y. C. Liang, Z. Han, and F. Hou, "Applications of Economic and Pricing Models for Resource Management in 5G Wireless Networks: A Survey. *IEEE Communications Surveys & Tutorials*, vol. 21, no. 4, 2019, pp. 3298-3339.

[12] M. Chen, Y. Qian, Y. Hao, Y. Li, and J. Song, "Data-driven Computing and Caching in 5G Networks: Architecture and Delay Analysis," *IEEE Wireless Communications*, vol. 25, no. 1, 2018, pp. 70-75.

[13] I. Parvez, A. Rahmati, I. Guvenc, A. I. Sarwat, and H. Dai, "A Survey on Low Latency towards 5G: RAN, Core Network and Caching solutions," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 4, 2018, pp. 3098-3130.

[14] S. Latif, J. Qadir, S. Farooq, and M. Imran, "How 5G Wireless (and Concomitant Technologies) Will Revolutionize Healthcare?" *Future Internet*, vol. 9, no. 4, 2017, pp. 93.

[15] Y. Wang, L. Kung, and T. A. Byrd, "Big data analytics: Understanding its capabilities and potential benefits for healthcare organizations," *Technological Forecasting and Social Change*, vol. 126, 2018, pp. 3-13.

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