5G enabled Mobile Operating Hospital and Emergency Care Service

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***Abstract*—Critical care has frequently been fatal for trauma patients suffering from hemorrhage. The pre-hospital communication gap between the paramedics and the doctors contributes most towards this. This paper discusses a system model of a 5G-enabled communication architecture among the major trauma centres in the Greater Manchester. An Internet of sensors acquires and wirelessly communicates biosignals from the patient in real time, using 5G. These signals are then displayed as parameters to the closest trauma care management centres. This paper proposes a connectivity model that supports such a system by assessing and identifying the most optimal path for signal transmittance. A system-level 5G network modelling and simulation findings reveal that a signal-to-noise ratio of over 2dB is achieved for two base stations between the incident site and the nearest emergency medical centre. This value decreases by over 5 dB as the number of base station doubles. Hence, reconfigurable 5G base stations connectivity subsystems are required for critical vertical use cases of the radio standard.**

***Index Terms*—pre-hospital care, IoT, 5G network, communication, RF connectivity, modeling, simulation**

I. Introduction

There is a rising need to adopt new communication techniques in order to make progress in the healthcare industry. Many attempts have been made in terms of provision of connectivity between a remote patient and the healthcare practitioners. The end-to-end latency present in the previous communications systems made the implementation of an IoT based healthcare system non-feasible. Traditional cryptographic solutions can also be fully utilized with 5G thus contributing to the solution of potential security issues. 5G offers high reliability, high density, unmatched latency, high bandwidth and is energy efficient. A possible application is critical point-of-care management of a trauma patient.

Pre-hospital care has been an obstacle throughout history of trauma care management. This issue is constantly reinforced by the loss of lives due to delay in managing a haemorrhage. There have been improvements done like introduction of advanced equipment in the hospitals and the ambulatory care. However, it has become essential to utilize further resources to make significant contributions to this cause. This paper discusses the practical existence of a mobile hospital and emergency healthcare system. The first part of this paper illustrates the architecture and models incorporated into the internet of elements. The second part of this paper depicts the simulation of this system and discusses the projected outcomes and possible challenges in its deployment.

A communication link design is inevitable for ascertaining that the operational transmitted power is sufficient to successfully relay information at the desired data rate. Existing microwave links performances are qualified after a judicious and systematic analysis of components-, subsystem- and system-levels gains and losses. The result of this evaluation reveals the transmitted power required for a given symbol rate, range and losses. For a mobile hospital/emergency ambulance vehicle, power is at a premium. This is occasioned by the stringent requirement of radio frequency (RF) power generation and amplification amongst other factors.

There is therefore a need for achieving an adaptive microwave link performance that meets the fifth generation (5G) radio access technology (RAT) and network objectives through a judicious selection of RAT system parameters [1], [2]. A communication link design involves the development of a comprehensive budget based on the component, subsystem and system parameters that characterise a given radio communication network [3], [4]. A typical microwave communication link table states the data rate, maximum bit error rate, frequency, modulation and coding, symbol rate, transmitter, antenna gains, system gains and losses and receiver noise [1], [2] for achieving a given data communication application's required link margin [1].

The estimating relationship for a radio frequency communication link between a mobile vehicle and a basestation is given by:

$$P_{\mathrm{r}} = \frac{P_{\mathrm{t}} G_{\mathrm{t}} G_{\mathrm{r}} c^2}{(4\pi)^2 R^2 f^2} \quad (1)$$

where,
P_{r} = the power received by the receiving antenna;
P_{t} = the power applied to the transmitting antenna;
G_{t} = the gain of the transmitting antenna;
G_{r} = the gain of the receiving antenna;
c = the speed of light (i.e., approximately 300 × 106 m/s);
R = the range (path length) in meters; and
f = the frequency in Hertz.

The transmitted signal is affected by the free-space propagation path loss, L, and given by:

$$L_{\mathrm{p}} = 20log_{10}(\frac{4\pi df}{c}) \quad (2)$$

where, c = speed of light in air = 300000 km/s;
f = frequency (kHz);
d = the distance between the mobile hospital/emergency ambulance vehicle and the nearest base station neighbours (in km).

The received RF signal (in dBm), P_{r}, is obtained according to the following equation:

$$P_{\mathrm{r}} = P_{\mathrm{t}} + G_{\mathrm{t}} + G_{\mathrm{r}} - L_{\mathrm{p}} \quad (3)$$

The signal-to-noise ratio (*S*NR) (dB) of the receiver subsystem is the difference between the received and the noise floor or minimum detectable signal (dBm).

$$SNR = P_{\mathrm{r}} - Noise_{\mathrm{floor}} \quad (4)$$

II. Literature Review

Pre-hospital phase is the most critical phase for a trauma patient. In many cases, the patients arrive unannounced to the emergency rooms making it longer to accommodate their treatment [5]. Even if the hospital is aware, there is no data about the patient that is required for planning the treatment. Hence, a triage nurse is responsible to put a critical patient through a number of tests after the patient arrives. These tests determine the kind of treatment protocol the patient requires [6]. Triage is considered efficient in terms of time-saving as it paves the way for precision treatment [7]. However, it is undeniable that pre-hospital occurence of these tests could prove life-saving for the patient. Many attempts have been made to improve ambulatory care and these have led to a drop in deaths of about fifty percent from 1997 to 2011 [8].

Attempts have also been made to use wireless connectivity for transfer of patient data to hospitals. Most of these used older generations to support such communication. Issues such as latency, security, and low data rate rendered such systems non-feasible [9]. Many researches have proposed multiple improvements that will be brought about by the use of 5G in healthcare systems [10], [11], [12]. Even when emergency hospitals or ambulatory connectivity is concerned, many propositions have risen. These include the usage of 5G for high quality video calling between the doctors and the paramedics and the patients being treated in the ambulance [13]. Therefore, it is inevitable that a heterogenous wireless technology that provides high data rate like 5G, is the future of smart healthcare [14]. Strategic use of 5G is bound to save countless hospital hours, capital, and essentially, innumerable lives.

III. 5G MOHEC System Model Design and Architecture

A. Elements and functionality of the architecture

The central focus of connectivity will be the Manchester Royal Infirmary that has the highest level of trauma care in the whole of Greater Manchester. Additionally, relevant hospitals and medical centres across the Greater Manchester are relevant to this system. The database also contains the levels of emergency care these hospitals and centres provide. Hence, when an accident takes place, the paramedic is connected to all the nearest institutes that can manage trauma care. The patient data is then shared so the treatment can be planned and prepared without the need of excessive triage. These institutes are also connected to the surrounding trauma management centres so that the patient can be directed to a better equipped centre without wastage of time.

Biosensors are to be deployed in order to check for the vitals that define the criticality of the patient's health. The parameters needed are selected via thorough research on the most senstitive and quick indicators of patient condition. In order to not trigger any further damage to the patient, the data acquisition is decided to be minimally invasive and sensors are chosen accordingly. This data is to be collected a DAQ system and displayed to the paramedic executing the protocol. This data is also communicated to the Accident and Emergency Department of the nearest trauma care centre. A Graphical User Interface is designed for quicker interpretation of the information to reduce the time required to evaluate the patient and planning the care.

However, the model simulated in this paper solely incorporates the elements needed for the mechanism of data transmission. It will also take the specifications of the communication protocol into consideration and adapt them to the system. These elements include a number of hospitals and base stations within a certain radius of the Manchester Royal Infirmary. A combination of approximately 19 hospitals and medical centres from the Greater Manchester are taken into consideration. All the selected facilities have some level of trauma care incorporated.

B. System Modelling

A 5G-enabled mobile operating hospital and emergency care (MOHEC) network design is proposed that incorporates and provides an end-to-end resource-oriented architecture (E2E ROA). This patient-centric critical data connectivity provisioning enables a seamless and ubiquitous real-time response to remote/offsite emergency incidents by healthcare professionals (including paramedics and/or clinicians. In this paper, the 5G MOHEC model is designed to utilise the nearest advanced radio access technology and cloud-based medical resources from the nearest incidents' localities.

The architecture integrates artificial intelligence (including machine learning and deep learning) techniques to support an emergency (as-it-happens) decision making process. Moreover, the 5G MOHEC coordination is flexibly managed between the field paramedics and the clinicians. A reliable and secure access to the healthcare facilities is provided to enable the responsible healthcare professionals ensure a near risk-free excellent care. Consequently, humans, manned (including mobile hospital and emergency ambulance service) and unmanned aerial (such as drones) vehicles can have secure access to the patients and provide real-time critical point-of-care treatment.

The power received at an emergency medical centre (EMC) such as the Manchester Royal Infirmary (MRI), UK traverses through several base stations. Furthermore, the occurrence of incidents is a random process that follows the Poisson distribution as a continuous process involving stochastic variables. Each incident site, i, is expected to have at least a connected nearest 5G macro or femto base station (BS). From an incident site to the nearest EMC where a life-saving treatment can be offered, the data communication link and network parameters are dynamic and unpredictable except where adaptive subsystems [1, 3, 4] are deployed.

Hence, there is a need for the development and deployment of reconfigurable RAT components for an integrated terrestrial-space communication applications [6, 7]. Moreover, this architecture is promising for 5G vertical use cases applications that rely heavily on adaptive beamforming [5].

Consider a 5G cellular network deployment (Fig. 1) to support mobile operating hospital and emergency care. For n base stations, and from Eqns. (1) to (3), the received power, PrEMC, is given by:

$$P_{\mathrm{rEMC}} = P_{\mathrm{ti}} + G_{\mathrm{ti}} + \sum_{k=1}^{n} G_{\mathrm{tk}} + \sum_{k=1}^{n} G_{\mathrm{rk}} + \sum_{k=1}^{n} G_{\mathrm{BSk}} + G_{\mathrm{rEMC}} - L_{\mathrm{p}} \tag{5}$$

where,

$$L_{\mathrm{p}} = \Big(\sum_{i=1, j=i+1}^{i=n, j=(n+1)} L_{\mathrm{pij}} + L_{\mathrm{p1EMC}} \Big) \tag{6}$$

and,

P_{ti} = transmit power from the incident site to the nearest BS, dBm;

G_{ti} = gain of the ith incident site transmit antenna (onboard a vehicle), dBi;

G_{tk} = gain of the kth BS transmit antenna, dBi;

G_{rk} = gain of the kth BS receive antenna, dBi;

G_{BSk} = forward transmission gain of the kth BS dB;

G_{rEMC} = gain of the emergency medical centre receive antenna, dBi;

L_{pij} = line-of-sight path loss between the ith and the jth BS, dB;

L_{1EMC} = line-of-sight path loss between the nearest (first) 5G BS and the EMC, dB.

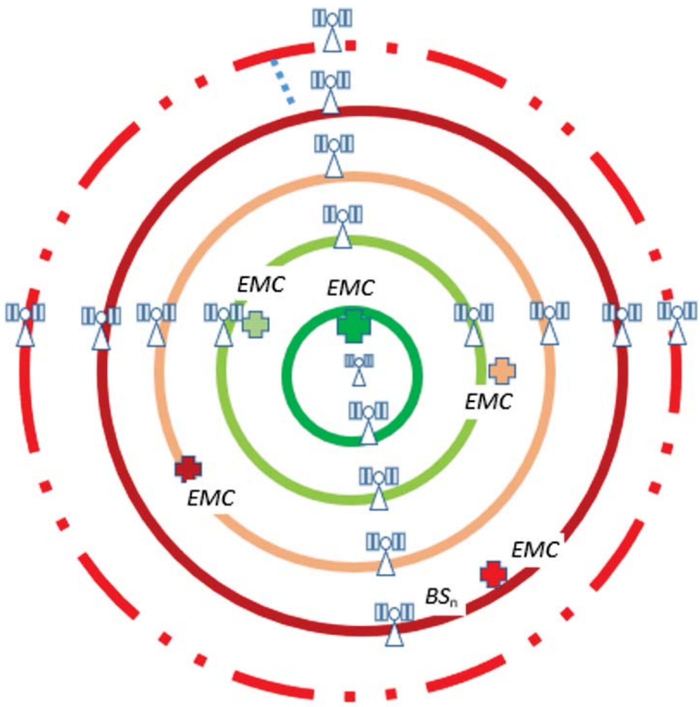

Fig. 1. 5G MOHEC System Model Design and Architecture for Emergency Healthcare Applications.

The model, shown in Figure 1, depicts N number of radii as dicrete distances from the MRI. Each radius has j number of base stations where j can vary between 6 and J. These base stations are labelled according to the radius they are present in, as well as j.

$$R_1 : BS_{11}, BS_{12}, BS_{13}...BS_{1\mathrm{j}}...BS_{1\mathrm{J}} \tag{7}$$

$$R_2 : BS_{21}, BS_{22}, BS_{23}...BS_{2\mathrm{j}}...BS_{2\mathrm{J}} \tag{8}$$

$$R_3 : BS_{31}, BS_{32}, BS_{33}...BS_{3\mathrm{j}}...BS_{3\mathrm{J}} \tag{9}$$

$$R_{\mathrm{n}} : BS_{\mathrm{n}1}, BS_{\mathrm{n}2}, BS_{\mathrm{n}3}...BS_{\mathrm{nj}}...BS_{\mathrm{nJ}} \tag{10}$$

$$R_{\mathrm{N}} : BS_{\mathrm{N}1}, BS_{\mathrm{N}2}, BS_{\mathrm{N}3}...BS_{\mathrm{Nj}}...BS_{\mathrm{NJ}} \tag{11}$$

Equation (5) assumes that the nth BS is the closest to the ith incident site. For n = 1, Eqn. (5) becomes thus:

$$P_{\text{rEMC}} = P_{\text{ti}} + G_{\text{ti}} + G_{\text{t1}} + G_{\text{r1}} + G_{\text{rEMC}} + G_{\text{BS1}} - (L_{\text{p12}} + L_{\text{p1EMC}}) \quad (12)$$

From Eqns. (4) and (5), the SNR of a 5G RAT transceiver for a MOHEC application involving sectored multiple input multiple output (MIMO) data communication is given by:

$$SNR_{\text{EMCRx}} = P_{\text{rEMC}} - Noise_{\text{floor}} \quad (13)$$

IV. 5G MOHEC Simulation and Discussion

A system-level simulation has been carried out to test the proposed 5G-enabled mobile operating hospital and emergency care (MOHEC) network design. The key performance metrics that are reported are the signal-to-noise ratio and the sensitivity of the receiver subsystems. The sub-6 GHz frequency range is considered. The noise floor is assumed to be -95 dBm at the receiver subsystem located at the emergency medical centre.

The gains of the BS transmit and receive antennas =10 dBi; the gain of the incident site antenna = 5 dBi; forward transmission gains of the BS repeaters = 80 dB. The prelim modelling and simulation results show that the SNR values for two and four BS hops are 104 dB and 96 dB respectively. Hence, the more the BS hop counts for the 5G-enabled real-time MOHEC data to traverse, the higher the required signal quality enhancement (Fig. 2).

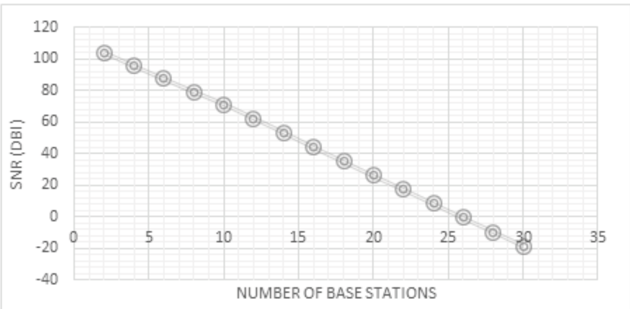

Fig. 2. Signal-to-Noise Ratio variation with distance.

The SNR incorported free space path loss only. However, in practical settings, a signal experiences many types of losses. When environmental conditions of the Greater Manchester are considered, the affects of rain and gases in the air, over the signal, can not be ignored. Figure 3 shows the effect of rain rate on the attenuation in sub-6 GHz frequencies. In the Greater Manchester, the average rain rate is between 5 and 12 mm/hr. However, 30 mm/hr has also been recorded at certain points of time. It can be seen that rain rate starts affecting more with increasing frequencies of signal as opposed to lower frequencies. This also paves way for adaptation of the network via frequency hopping in times of rainfall.

Another environmental factor include air gases. Average temperature, atmospheric pressure and vapor density are used to estimate the effects of air gases. The results are shown in

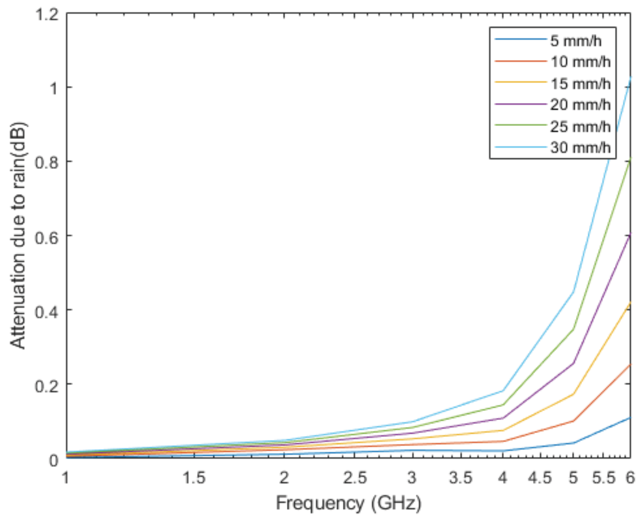

Fig. 3. Attenuation in signal due to rain rate in sub-6 GHz frequencies.

Figure 4. The two curves show change in just one variable i.e. vapor density from average to zero.

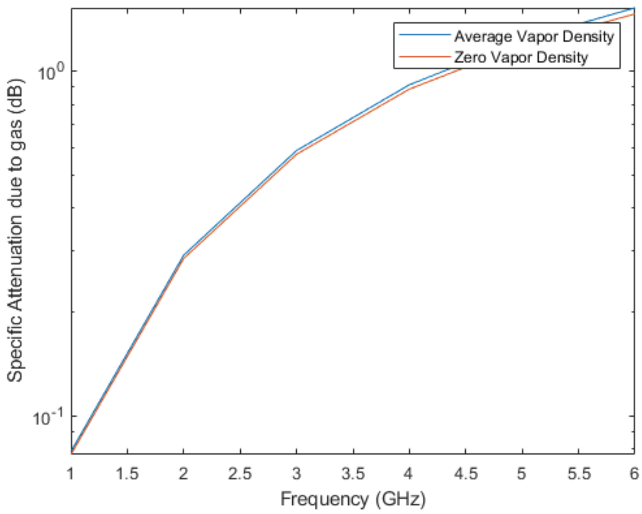

Fig. 4. Attenuation in signal due to air gases in sub-6 GHz frequencies.

The hospitals of Greater Manchester, that are capable of trauma management to some extent, are taken into consideration. The GPS coordinates of these hospitals are used to establish receiving and transmitting sites for the signal. The system parameters were initiated with the values mentioned above. The SiteViewer results from MATLAB for this simulation are shown in Figure 5.

This also gives an idea of the distances between trauma care facilities. Manchester Royal Infirmary (MRI) still serves to be the central position within these facilities.If two equally equipped facilities are equidistant from an incident site, the decision would be to choose the destination closest to MRI.

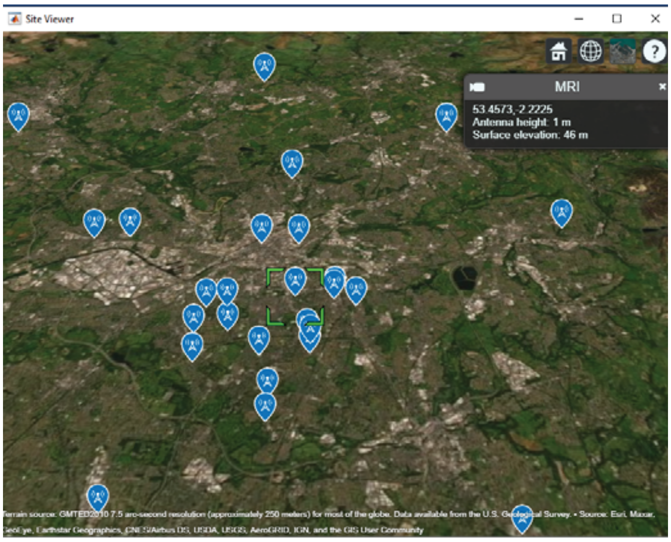

Fig. 5. 5G MOHEC locations of incorporated Emergency Medical Centres in Greater Manchester.

This would prove useful in case the patient is needed to be retransfered.

Incident sites are randomly generated within the bounds of the Greater Manchester. The nearest trauma management centre is identified. A signal path is generated for incident location, and associated signal parameters calculated. The new location, and thus, the distance between the incident location and nearest trauma management centre serves as a variable for each simulation. The path loss experienced by the signal, changes, and hence, the Signal-to-Noise Ratio varies. This means the signal received at the Emergency Medical Centre is of different strength. The path formation from generated incident site is shown in Figure 6.

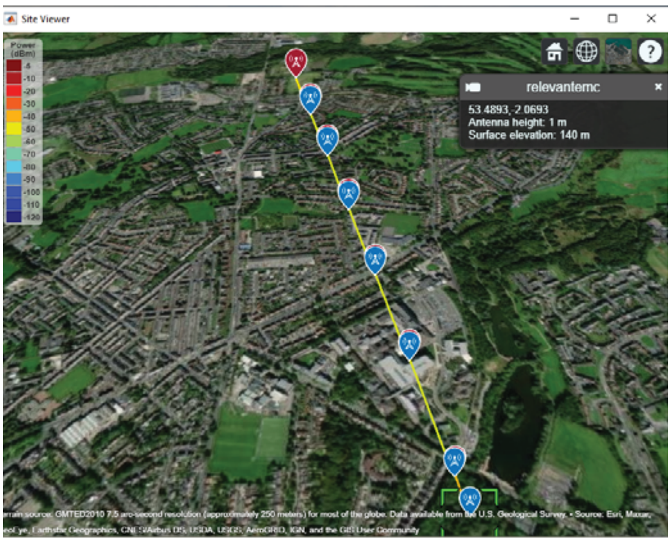

Fig. 6. Path propagation for the Mobile Operating Hospital to the relevant Emergency Medical Centre.

With an integrated artificial intelligence technique to search the best route and implement an adaptive subsystem reconfiguration, the network resources (including network slicing and forward gain adjustments) can be optimised for a reliable and sustainable high quality data transmission.

V. Conclusion

A 5G-enabled real-time connectivity network for mobile operating hospital and emergency care services has been developed, modelled and simulated. The findings are promising as they provide an insight into the relevant vertical use cases deployment scenarios and network resources enhancements required for critical applications. The signal-to-noise ratio of the transmitted data increases by eight times when the algorithm selects a connectivity route of 2 rather than 10 base stations. After multiple simulations, maximum distance and average distance calculated of any recurring incident locations, were identified.

The signal quality against these distances, was calculated and it was concluded that a video transmission is possible at average distance between a randomly generated incident site and the nearest EMC. Moreover, a minimum of 15 dB SNR would be received at the maximum distance generated. This means interpretable required patient data could be sent. The application of 5G is one to bring a range of benefits to the stakeholders in healthcare. Efficient path selection is critical to the effective functioning of this project. This is because no signal loss or latency can be afforded in medical emergencies. Frequency hopping and reconfigurable antenna gain could be used as vital tools to revamp the signal after further environmental losses are taken into consideration.

The signal has to choose a path that leads to the least amount of path loss, and hence, signal deterioration. Many other companies have started to deploy 5G for real-time video streaming of the patient. Furthermore, AI and virtual reality are being used to carry out treatments in the ambulances. This leads to saving a lot of time and money. However, there are ethical considerations that need to be brought into this loop. Treatment aspects in the mobile healthcare devices would entail treatment without a doctor. Even though the doctors are involved, there is a big question mark on presence of authorised personnel during the treatment. Hence, this project only concerns the transmission of the data and providing a low-loss data connectivity throughout the Greater Manchester. The system will help manage the treatment in a more efficient way without meddling with patient satisfaction or authorisation issues.

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