Analysis of the use of LTE-A MCC among the military in operational scenarios

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Abstract – This paper aims to analyze the performance and the use of LTE-A MCC among the military of the army in operational environments that are integrated in Stabilization Operations and Civil Support Operations. The analysis focuses on how to transmit voice and data, in real time, in an infantry platoon in an ad hoc network with retransmission. With the use of LTE-A MCC system it is possible to cope with high data rates and allow the military to have several available services whose information is then forwarded to the upper echelon. For this purpose, propagation models were used in urban, suburban, rural and indoor environments. The key concepts of LTE-A system addressed were the device-to-device communications, the calculation of the coverage and the capacity of the services and the integration of the system into an ad hoc network with retransmission. The Central African Republic was used as a case study. The worst results occur for the video streaming service, in the outdoor environments for the 64 MHz and 890 MHz frequencies, due to lack of capacity. At 64 MHz, only 23 militaries could do video streaming up to a distance of 308 m. At 890 MHz, 27 militaries have the service available and they could do video streaming up to 364 m.


I. INTRODUCTION

Nowadays, in operational scenarios, the data transmission is very useful for the military forces and it represents a big evolution and an important technological leap. Portugal is integrated in NATO and participates in Peacekeeping Operations where the maximum priority is the protection of the civilian population. This type of operations is integrated in Stabilization Operations [MiDN11]. On the other hand, the Portuguese Army also participates in Civil Support Operations together with the Civil Protection, for example, in emergency scenarios and natural disaster recovery.

At the moment, there is a Quick Reaction Force (QRF) created by Comandos (Portuguese Army’s special unit) integrated in the United Nations Multidimensional Integrated Stabilization Mission in the Central African Republic (MINUSCA) with the mission to maintain peace, to prevent armed conflicts and to give humanitarian assistance. In the Theater of Operations (TO), the military use the Portuguese/Portable Radio Communications 525 (P/PRC-525) to transmit voice and data in an infantry platoon and then, to communicate with the high echelon. However, this radio has a very low bit rate (72 kbps) which greatly limits the transmission of the data [1].

One the other hand, in civil missions, the Integrated System of Emergency and Security Networks in Portugal (SIRESP) is the communications operator responsible for responding to the requirements of the operational missions of the set of users, among which is the Army [2]. SIRESP is based on Terrestrial Trunked Radio (TETRA) that is a technology which was designed to support voice and data services with a bit rate limited to 7.2 kbps [3]. The narrowband nature of this technology, similar to what happens with the system used by the P/PRC-525 radio, cannot provide support for intensive service data like streaming video in real time or file downloading [4]. These services offer a better understanding of the events on the field. As TETRA is a security and emergency system, it has characteristics that the Global System for Mobile Communications (GSM) or Long Term Evolution (LTE) commercial systems do not have. However, LTE-Advanced (LTE-A) system provides a robust set of quality of service (QoS) mechanisms that allow it to perform public security operations and solve problems related to network congestion and address the need for high data rates [5].

Mission Critical Communications (MCC) is defined as the ability to provide communications in situations where conventional fixed broadband networks cannot meet the required requests. For example, in the TO, there are many risk situations where military’s lives are in danger and, in certain circumstances, the Platoon Commander may need to transmit information to the entire platoon. That is why it is necessary to interrupt all communications that may be occurring at that moment, prevailing the priority of that call. Another example, is in the civil world, pertains to areas affected by natural disasters where telecommunication infrastructures collapse and local people are deprived of any means of communication.

Thus, LTE-A Mission Critical Communications (LTE-A MCC) is becoming the technology of broadband communication preferred for the public safety to replace TETRA technology.
The structure of this paper is as follows: Section I – Introduction; Section II – Basic concepts of LTE-A MCC and state of the art; Section III – Definition of the scenarios; Section IV – Development and implementation of the models; Section V – Analysis of the results; Section VI – Conclusions.

II. BASIC CONCEPTS OF THE LTE-A MCC AND STATE OF THE ART

A. Basic concepts of LTE-A MCC

The LTE system is based on Orthogonal Frequency Division Multiple Access (OFDMA), in downlink (DL), and Single Carrier-Frequency Division Multiple Access (SC-FDMA), in UL. With OFDMA, LTE seeks to divide a broadband into multiple subcarriers with narrow and orthogonal bandwidths spaced 15 kHz, where each one has a reduced throughput in order to reduce the intersymbol interference. With this multiple access technique, the smallest resource unit that can be assigned to a user is a resource block (RB), as shown in Fig 1.

![Fig. 1 – Structure of a RB (Extracted from [6]).](image)

According to [7] the main features introduced in Release 10 for LTE-A are presented below:

- carrier aggregation (CA) up to a total band of 40 MHz, with the possibility of reaching 100 MHz, to obtain higher data rates;
- the evolution to MIMO 8x8 for DL and 4x4 for UL, with the introduction of more antennas, for higher spectral efficiency;
- the introduction of relay nodes to increase the network’s coverage;
- coexistence of macro, pico and fento-cells in order to increase the spectral efficiency per coverage area.

LTE-A MCC has the same network architecture as LTE-A system. This system has features that are extremely important for military communications and in emergency scenarios and public safety, such as priority and fast call establishment, group calls, emergency calls and data services [8]. In a military structure there is a hierarchical environment where the Platoon Commander needs to transmit the orders from the upper echelon to the subordinates and to send back the situation of the mission.

The device-to-device (D2D) communications do not require an architecture, because this technique allows the mobile terminals (MTs) to communicate with each other directly, over LTE-A networks. D2D communications offers great advantages when used with LTE-A, as it improves the spectral efficiency [8].

With the increase in the amount of real time information that needs to be transmitted, in the TO, traditional network architectures cannot handle this problem. Mobile technology is required to ensure flexibility and reliability and to face the needs of the military on the field. The military are constantly on the move and need a communications network that ensures the availability of voice and data services, making it possible to circulate information between the different echelons.

An ad hoc network is a network created directly between two connected devices, without the need for an access point or router. These networks have an interest in circumstances characterized by a lack of infrastructure, for example, in situations that require the rapid implementation of a Local Area Network (LAN) or in the case of a failure in an infrastructure, as a consequence of a military activity, a natural disaster or a conference [9].

A Mobile Ad hoc Network (MANET) consists of a set of mobile nodes that form autonomous and dynamic networks independent of any infrastructure. Thus, the node mobility results in a possible and rapid change in the network topology. The nodes communicate with each other without the intervention of a base station (BS). As the coverage in the wireless network is limited, it is necessary to perform several hops to exchange information between the various nodes of the network. In this type of multi-hop networks each node is a router or a host [10].

B. State of the art

The LTE system is evolving towards becoming the dominant technology in MCC, given the higher disadvantage of TETRA technology is the reduced bitrate [11]. LTE-A system provides higher uplink (UL) bitrates (up to 500 Mbps) and new procedures for better coverage through retransmission nodes. LTE-A MCC provides procedures for the priority handling of emergency calls, multimedia services with priority and transmission of alert messages. The Alcatel-Lucent 9907 Rapidly Deployable Network (RDN) is a compact, autonomous and fourth generation (4G) network that enables highly mobile units to rapidly establish a secure network for voice, video, data and sensor services in real time [12]. The introduction of retransmission in LTE-A MCC system provides greater coverage and greater capacity to the system. The importance of retransmission can be demonstrated through the development of an ad hoc wireless network. It consists of a set of nodes directly or indirectly connected by a wireless channel that communicate with each other without any centralized network infrastructure [13].
III. DEFINITION OF THE SCENARIOS

This section consists of the presentation and description of several possible scenarios where the military can act. These scenarios can occur in three types of environments: urban environment, suburban and rural. It was also analysed the propagation inside buildings, however this scenario can exist in any type of environment.

The urban environment is characterized by a high concentration of population and high density of infrastructure and buildings, for example, cities. The suburban environment is characterized by areas that are located on the outskirts of cities. The rural environment is characterized by places with low population density, dispersed houses and the existence of many free spaces, for example, villages.

Thus, several scenarios can be defined within the three types of environment.

- Urban environment
  o High-density urban: it has a large number of multi-store buildings and narrow streets, there is a high population density, a high density of infrastructure, communication and transport routes and few green spaces. Example: New York (USA).
  o Low-density urban: it has buildings with less floors and narrower streets than in the previous area, lower population density and more green areas. Example: Lisbon (Portugal).
  o Indoor: there is an additional attenuation in the propagation of the electromagnetic waves due to the penetration in the walls and obstacles indoors. It can also be analysed in the suburban and rural areas.

- Suburban environment
  o Suburban: it consists of the outskirts of the city and has low buildings (maximum 3 floors) and wide streets, predominantly houses. Examples: Neighborhood of Arco do Cego (Lisbon, Portugal).

- Rural environment
  o Highly wooded: area occupied by large tracts of dense vegetation, trees with size between 30 and 50 meters, and there are no houses. Example: Amazon rainforest (Brazil).
  o Wooded: existence of trees and vegetation, few houses and infrastructures. Example: Bom Sucesso (Coimbra, Portugal).
  o Hilly: existence of mountains and small houses. Example: Afghanistan.
  o Low-wooded: there are constructions dispersed with only one or two floors, there is a few population and a few vegetation. Example: Alentejo (Portugal).
  o Not wooded: absence of vegetation and, in an extreme situation, it is considered the case of the desert. Examples: Iraq (Asia).

Tables I and II show the parameters describing the reference scenarios for the three environment types, which will be used in the COST 231 Walfish-Ikegami, Irregular Terrain Model (ITM) and Weissberger models to calculate the coverage. As the voice and data transmission will be in a D2D communication among the military, the transmitter and receiver antenna heights of the MTs will be the same \( h_m = 1.8 \text{ m} \), approximate value for the height of the military. The maximum distance considered between the two farthest military was 400 m.

### TABLE I. PARAMETERS FOR THE REFERENCE SCENARIOS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_m )</td>
<td>[m]</td>
<td>1.8</td>
</tr>
<tr>
<td>( P_t )</td>
<td>[dBm]</td>
<td>1 to 23</td>
</tr>
<tr>
<td>( G_i = G_r )</td>
<td>[dBd]</td>
<td>3 or -6</td>
</tr>
<tr>
<td>( L_u )</td>
<td>[dB]</td>
<td>10</td>
</tr>
<tr>
<td>( M_t )</td>
<td>[dB]</td>
<td>1</td>
</tr>
<tr>
<td>( F )</td>
<td>[dB]</td>
<td>10</td>
</tr>
<tr>
<td>( \Delta f )</td>
<td>[kHz]</td>
<td>180</td>
</tr>
</tbody>
</table>

### TABLE II. PARAMETERS FOR THE COVERAGE CALCULATION.

<table>
<thead>
<tr>
<th>Environment</th>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>( w_u )</td>
<td>[m]</td>
<td>20</td>
</tr>
<tr>
<td>Suburban</td>
<td>( w_u )</td>
<td>[m]</td>
<td>35</td>
</tr>
<tr>
<td>Rural</td>
<td>( L_u )</td>
<td>[dB]</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>( H_u )</td>
<td>[m]</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>( \phi_u )</td>
<td>[°]</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>( w_r )</td>
<td>[m]</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>( L_{ish} )</td>
<td>[dB]</td>
<td>0</td>
</tr>
</tbody>
</table>

\( f = 64, 890, 1682 \text{ MHz} \)

The parameters required for scenario analysis and capacity calculation are presented in Table III.

### TABLE III. PARAMETERS FOR THE CAPACITY CALCULATION.

<table>
<thead>
<tr>
<th>Frequency Bands</th>
<th>61 – 68 MHz</th>
<th>873 – 876 MHz</th>
<th>918 – 921 MHz</th>
<th>1675 – 1690 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f ) [MHz]</td>
<td>64</td>
<td>890</td>
<td>1682</td>
<td></td>
</tr>
<tr>
<td>Bandwidth (BW) [MHz]</td>
<td>7</td>
<td>6</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td># RBs</td>
<td>35</td>
<td>30</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td># Subcarriers occupied</td>
<td>466</td>
<td>400</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td># OFDM symbol</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time-slot duration [ms]</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcarrier BW [kHz]</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

In the TO there are tactical communications vehicles (shelters) that are intended to provide the voice and data services...
directly to the military. The minimum services available within a platoon are voice, e-mail, machine-to-machine (M2M) services, file sharing and video streaming.

IV. DEVELOPMENT AND IMPLEMENTATION OF THE MODELS

There are several propagation models, but there is not only one that is capable of covering all the scenarios described.

A. Outdoor environments

To obtain a correct evaluation of the performance of LTE-A MCC system, propagation models were used, according to the different scenarios where the military operate. These models depend on certain parameters such as frequency, distance between sender and receiver, number of military personnel communicating and type of environment. The last parameter is the first one to take into account, since it is from the selection of the environment where the operations occur that differentiate the remaining parameters.

The model used for urban, suburban and rural environments at the 64 MHz frequency was the ITM [15], also known as the Longley-Rice Model, because it has the characteristics that are closer to those desired. This model is valid for distances greater than 1 km, however it has been extended to a range of distances from 20 to 400 m, which is outside the validity range, therefore the application errors of the model will be larger.

The model used in urban and suburban environments for the 890 MHz and 1682 MHz frequencies was the COST 231 Walfish-Ikegami [16] model. This model has the limitation of a minimum height for the antenna of emission of 4 m, however it will be used the value of $h_m = 1.8$ m, however it is known that the error obtained will be greater. As an alternative to this model, tools based on Ray Tracing Model [17] could have been used, for distances of less than 500 m, but it is a more complex model that is outside the framework of this paper.

For the rural environment, it was used the Weissberger model [16], which respects all conditions, for the 890 MHz and 1682 MHz frequencies.

The graphs relating to the evolution of propagation attenuation along the distance, for some scenarios described above, for the 64 MHz, 890 MHz and 1682 MHz central frequencies are presented below. In Fig. 3 and Fig. 4, the rural environment is characterized by a highly wooded rural environment, for example, the scenario described by the Amazon rainforest.

Regarding the attenuation of the propagation of the radio waves as a function of the frequency, taking into account the frequencies of the used carriers, the range of values between [60,1700] MHz was chosen. It was chosen the fixed distance of 100 m. Up to 800 MHz, the ITM model was used for urban and suburban environments. It was used the COST 231 Walfish-Ikegami model from 800 to 1700 MHz. For a rural environment it was used the ITM model, from 60 to 1700 MHz, and the Weissberger model for a highly wooded rural environment. Although the Weissberger model is not applicable for frequencies below 230 MHz, it has been extended in the frequency from 60 to 230 MHz that is outside its validity range, so the application errors of the model will be greater. As shown in Fig. 5, over the entire range of frequencies analysed, the greatest attenuation of radio wave propagation is found in urban environments. For an environment with a high density of vegetation, it is observed that the attenuation is even higher than in a suburban environment. And, lastly, the lowest mitigation is for a rural environment.
B. Indoor Environments

Indoor propagation differs from outdoor propagation. In the case of the interior, the coverage is well defined by the geometry of the building and its boundaries affect the propagation, causing an additional attenuation. The parameters that influence this attenuation are reflection and diffraction around the objects inside the rooms (including walls and floors), loss of transmission through these same obstacles, and additional attenuation through the building materials. The propagation inside the buildings has associated an additional loss due to the internal walls, the several floors, the furniture and other infrastructures. On the other hand, the penetration in the buildings also contributes to the increase of the losses, since the diverse characteristics of the building materials of the same ones’ influence and have different attenuation factors [18].

In order to determine the attenuation within buildings and their calculation of the coverage, it was used the model defined by recommendation ITU-R P.1238-8 [18], which is valid in a frequency range from 300 MHz to 100 GHz. There may be a limit to the insulation caused by the various floors, as the radio signal may find other ways to complete the connection with less attenuation than crossing the various floors [18].

C. Antennas

In this section the antennas used by the military are presented. The gain of an antenna indicates the apparent increase in transmission power due to its ability to concentrate energy, that is, the gain is a form of how the antenna concentrates the available power for a limited number of directions (for example, two directions in the case of the dipole). The gain of the antennas is provided by directivity, that is, by driving the power of the antenna in a limited direction, it appears that the antenna radiates a higher power [19].

According to [19], in vertical polarization, the vertical electric field force lines are perpendicular to the ground and the radio wave can travel a considerable distance along the earth's surface with a minimum amount of losses. For very high frequency (VHF) and ultra-high frequency (UHF), it can be used antennas with VP or horizontal polarization. Since the radio wave is transmitted directly from the transmitting antenna to the receiving antenna, the original polarization produced in the transmitter is not changed until it reaches the receiver. Since the antenna heights to be used are less than 3.05 m, the VP offers the advantage of providing a stronger received signal at frequencies up to about 60 MHz. Above 100 MHz, the interference between the two polarizations is small, however, when antennas are located near dense forests, horizontally polarized waves suffer less losses than vertically polarized waves. When the VP is used, the interference produced or captured from strong VHF or UHF transmissions is smaller, as they use horizontal polarization. This is important when antennas are used in urban areas due to the existence of televisions and FM broadcasting stations.

For the communication between two MTs, the transmitting and receiving antennas must be polarized in the same direction, so that the antenna of the receiver may receive the maximum signal. Simple vertical antennas provide omnidirectional communication, which is an advantage when communications occur from a moving tank. Therefore, the type of polarization chosen was the VP so that the TM antennas of the military can communicate with each other and later with the antenna inside the tank, which will also be vertically polarized.

The usual whip antenna has a gain greater than the gain of an antenna that can be integrated into a wearable antenna [20], but the former has drawbacks: the military carrying it is a target easily detectable on the TO, because the whip antenna protrudes from the silhouette of the soldier; the antenna is easily broken by branches of trees and shrubs and limits the movements of the military [21]. These limitations can be eliminated by replacing the whip antenna with a portable and flexible antenna integrated into the vest [22]. Thus, the antennas chosen for the MTs were the VHF-LB Vest Antenna for VHF (Fig. 6) and the LTE Wearable Antenna BW-700-3000, for UHF (Fig. 7). The LTE tactical vehicle antenna UHF710VM/HG is an antenna for military environments.
The Harris Fusion Tactical Cellular (Fig. 9) is a robust, reliable and standalone LTE system with wireless technology and high bandwidth. This equipment can be assembled on shelters or temporary masts on the communication modules [24].

D. Coverage calculation

It is proposed to determine the maximum distance between the military that guarantees coverage of the network that allows them to communicate, whether voice or data. In order to evaluate the propagation losses between the MTs, all losses and gains of the antennas must be taken into account, as well as the emission and reception powers of the antennas [16], according to:

\[ L_p [\text{dB}] = P_t [\text{dBm}] + G_t [\text{dBi}] + G_r [\text{dBi}] - P_r [\text{dBm}] \]  \hspace{1cm} (1)

where:
- \( P_t \): power fed to the transmitting antenna
- \( G_t \): gain of the transmitting antenna
- \( P_r \): power available at the receiving antenna
- \( G_r \): gain of the receiving antenna

The maximum coverage radius of the MT is obtained by combining the expression of the power balance with the expression of the path losses, according to:

\[ R_{\text{max}} [\text{km}] = 10^{\frac{P_t [\text{dBm}]+G_t [\text{dBi}]+P_r [\text{dBm}]+G_r [\text{dBi}]-L_p [\text{dB}]}{10 \alpha}} \]  \hspace{1cm} (2)

where:
- \( \alpha \): average power decay

E. Capacity calculation

Capacity can be evaluated in terms of the number of users that can be served by the network, which depends on the modulation and binary throughput required for each user. This is represented by an estimate of the total number of users for a given rate [25]. Thus, it can be calculated from:

\[ N_u = \frac{N_{\text{sub, RB}} \cdot N_{\text{sym, sub}} \cdot N_{\text{RB, a}} \cdot N_{\text{bits, sym}} \cdot N_{\text{MIMO}}}{R_b [\text{Mb/s}] \cdot t [\mu \text{s}]} \]  \hspace{1cm} (3)

where:
- \( N_{\text{sub, RB}} \): number of subcarriers per RB
- \( N_{\text{sym, sub}} \): number of symbols per subcarrier
- \( N_{\text{RB, a}} \): number of RBs per user
- \( N_{\text{bits, sym}} \): number of bits per symbol
- \( N_{\text{MIMO}} \): MIMO order
- \( R_b \): throughput per RB
- \( t \): duration of a RB

F. Ad hoc network with retransmission

There are two ways of approaching ad hoc networks, from the standpoint of architecture and radio interface, regarding the existence or not of signal regeneration. The network retransmission nodes act as repeaters that carry out the amplification of signals. They are responsible for retransmitting the signal and, thus, increasing the network size. The repeater acts on the physical layer of the OSI Model where it receives the packets and retransmits them without performing any other type of data processing on them other than the amplification of the signal. In this way, there is no regeneration of the signal, that is, the network configuration is passive as well as its repeaters. Nodes only amplify and route the received signal with reduced power consumption. On the other hand, repeaters may also perform other functions than amplification such as decoding, collision detection in one segment and signalling the occurrence to the other segments. These actions are part of an ad hoc network with active configuration, where there is greater power consumption [26].

In order to guarantee the communication between the military it is necessary that the received power in the next node is sufficient to allow the continuity of the transmission of voice or data, that is, the power received must be greater than or equal to the sensitivity of the receiver.

Fig. 10 shows a communication scheme within the platoon and its connection to a tank, but it is only a representation because it does not imply that the military must be aligned as in the figure.

The general received power in the different nodes of the ad hoc network is given by:

\[ P_{rn} [\text{dBm}] = P_{tn} [\text{dBm}] + G_{rn} [\text{dBi}] + G_{rn} [\text{dBi}] - L_p [\text{dB}] \]  \hspace{1cm} (4)
Furthermore, the following conditions must be met:

\[ P_{rn} [\text{dBm}] \geq P_{RX \ min} [\text{dBm}] \]  \hspace{1cm} (5)
\[ R_{b}^{err} [\text{kb/s}] \leq R_{b}^{BB} [\text{kb/s}] \]  \hspace{1cm} (6)
\[ P_{rn} [\text{dBm}] \leq P_{RX \ max} [\text{dBm}] \]  \hspace{1cm} (7)

\[
\left\{ \begin{array}{l}
P_{rn} [\text{dBm}] = P_{t \ initial} [\text{dBm}] + 10 \cdot \log_{10}(\#\text{RBs}), \\
P_{rn} [\text{dBm}] = P_{t \ n-1}[\text{dBm}] + 0 \ \text{dBm},
\end{array} \right\} 
\]  \hspace{1cm} (8)
\[ R_{b}^{err} [\text{kb/s}] = R_{b}^{err} [\text{kb/s}] + R_{b1}^{err} [\text{kb/s}] \]  \hspace{1cm} (9)

where:
- \( R_{b}^{err} \): throughput of the service voice or data

\section*{V. ANALYSIS OF THE RESULTS}

This section presents, as case study, the TO in CAR in 2017. The ad hoc retransmission network approach and the respective coverage and capacity calculations are applied in a real scenario in the three types of environment: urban, suburban and rural. The two critical services were analysed with respect to the throughput, that is, the voice service with the 8 kbps and the video streaming service with 500 kbps, both of which were minimal bitrates.

1) **Urban Environment**

This environment is characterized by the city of Bangui (Fig. 11).

![Fig. 11 – Bangui (Extracted from [27]).](image)

\textit{a) Voice}

The voice service was analysed for 64 MHz. It was used the ITM model. First, the direct communication was analysed between the military farther away from the tank and itself, for a distance of 400 m. It was possible to establish the connection, since the power received was higher than the sensitivity.

Then, communication with relay was used to ensure that the service is available to all military. Assuming that the military moved at a distance of 14 m between each one, the path loss of was calculated for each hop until they reach the tank.

In the 1st hop, it was used a transmission power of 1 dBm, 1 RB and the modulation of QPSK. Based on (4), the received power at the 2nd node was calculated. Then, the sensitivity was calculated to verify that the received power is above it and the communication can continue. In the 2nd hop, the rate of transmission of the voice service increased to 16 kbps, since the voice signal to be transmitted from the 2nd node is added, also, the voice signal to be transmitted from the 1st node. Thus, the signal to noise ratio (SNR) value increases and consequently increases the sensitivity value to -117.64 dBm. As the distance between the military is equal and the gain remains until the 29th hop, the received power is always the same over 29 hops and equal to the first. In the 30th hop, from the last military to the tank, the bit rate of the service is 240 kbps, the sensitivity is -106.39 dBm and the received power is -56.08 dBm. The communication was successful.

For the frequencies of 890 MHz and 1682 MHz, the COST 231 Walfish-Ikegami model was used for the same scenario described above, with the addition of the possibility of LoS or NLoS.

First, D2D communication was made between the farthest military, in a NLoS scenario, for a distance of 400 m. It was not possible to establish the connection, because the received power was lower than the sensitivity. Therefore, communication with relay was used where the distance of 14 m between military personnel was established, in a LoS scenario.

The path losses were calculated for a distance of 14 m and, subsequently, the received power and the sensitivity. For all cases there was success with only a transmission power of 1 dBm. The value of the sensitivity increases along the number of hops. For the voice communication there were no problems, since all the military can use the service and reach the minimum of 420 m.

\textit{b) Video streaming}

The same scenario was applied to the video streaming service in order to make video transmission/reception available to all military personnel. The minimum speed of this service is 500 kbps, so for QPSK modulation, it is necessary to use two RBs on the first hop. According to Table III, at 64 MHz, 890 MHz and 1682 MHz there are 35, 30 and 75 RBs available, respectively. Thus, we proceeded in the same way as described in the previous section to calculate the successive received power.

When using the QPSK modulation, at 64 MHz, the 35 RBs were all used and the capacity was limited to the 26th hop, that is, only 27 military could communicate which makes a maximum distance of 364 m. At 890 MHz, the 30 RBs were used up to the 22nd hop, that is, only 23 military personnel, which makes a distance of 308 m. Thus, the communication was compromised due to lack of capacity. At 682 MHz, 420 m could be achieved with the use of 40 RBs, as there is sufficient capacity.

Since the bit rate of video streaming service is high, 16-QAM modulation was also used in the same scenario. This modulation has a maximum bit rate of 1128 kbps per RB. When using 16-QAM modulation, at all frequencies it is possible to reach the 420 m. For the three frequencies it was possible to establish the connection and transmit video, with a 16-QAM modulation, using a maximum of 14 RBs.

2) **Suburban Environment**

This environment is characterized by the city of Bambari (Fig. 12).
To analyse the voice service, for 64 MHz, it was used the ITM model. Since this model does not present a specific expression for the computation of radio wave path loss in suburban environments, and as a consequence, it is not possible to determine exactly the coverage. It was made an average between the path loss values obtained for the urban environment and the path loss obtained for the rural environment, both for the voice service.

For the frequencies of 890 MHz and 1682 MHz, it was used the COST 231 Walfish-Ikegami model. First, it was calculated the path loss in D2D communication between the farthest military for a distance of 400 m using the QPSK modulation and a transmission power of 1 dBm. However, for the 1682 MHz frequency, the connection could not be established because the received power was less than the sensitivity. Therefore, it was calculated the communication with relay where the distance of 14 m was established between the military.

The results were the same as in the urban environment, because the model used was the same and the scenario is also in LoS, where the environmental characteristics do not interfere. Thus, there was success in communication between the platoon and the tank.

a) Video streaming

In the video streaming service, as mentioned above, for the 64 MHz, the ITM model does not have a specific expression for the path loss calculation, the average between the urban and rural environments was calculated.

It was used the QPSK modulation, in a NLoS scenario, for the frequencies of 890 MHz and 1682 MHz. In this case, to calculate the received power and the sensitivity were required two RBs due to the bit rate of the service in the first hop.

The received power was calculated and the value was below the sensitivity, so the farthest military cannot communicate directly with a tank. In order that the entire platoon may have access to the service, the received power was calculated by relay communication, in a LoS scenario.

The results, as well as the conclusions, are the same as in the urban environment.

3) Rural Environment

This environment is characterized by the region of Gongo (Fig. 13).

a) Voice

The ITM model was used for the frequency of 64 MHz. The Mobaye region, which belongs to the Gongo, was analysed. It is bordered by the Democratic Republic of Congo and it is a highly wooded region, so the vegetation attenuation factor chosen was 6 dB. The path loss was calculated for a NLoS situation at a distance of 400 m where the connection was successful. Then, communication with relay was used to ensure that the service is available to all the platoon, where it was established a distance of 14 m between each one, in a scenario with LoS. The received power was above the sensitivity, so the desired distance was achieved.

For the frequencies of 890 MHz and 1682 MHz we used the Weissberger Model for the same scenario. First, the NLoS scenario was analysed for a distance of 400 m and where only the farthest military transmits. It was not possible to communicate at the highest frequencies. Then, the communication was made with relay so that all military could communicate, where the distance between military was 14 m and therefore there is LoS. The QPSK modulation was used.

b) Video streaming

In the video streaming service, the results of the capacity were limited by the number of RBs when using the QPSK modulation. There was only success at 1682 MHz where the 400 m were reached and at frequencies of 64 MHz and 890 MHz, the communication was limited due to lack of capacity, respectively, to 27 and 23 military, under the conditions described.

Since QPSK modulation was not completely successful, 16QAM modulation was used. This modulation has a maximum bit rate of 1.128 kbps per RB. Likewise, as in previous environments, with the use of 16-QAM modulation, for all frequencies it was possible to reach the 420 m, using a maximum of 14 RBs.

4) Indoor Environment

In this section the results presented are referred to a typical house in the suburban and rural environments in RCA, only with the ground floor. There are 3 military inside the house where the voice communication and the video streaming services were analysed.

a) Voice and video streaming

To analyse the voice service the model defined by the recommendation ITU-R P.1238-8 was used. It was calculated
the path loss for the three frequencies for a distance of 20 m between two military inside the house. For the three frequencies it was obtained success in the communication.

In order to analyse the video streaming service, in the same scenario, the same model was used. This service requires a minimum throughput of 500 kbps, so it was necessary to use 2 RBs and a transmission power of 4 dBm. The path loss is the same as that of the voice. Thus, the two soldiers could communicate with each other inside the house.

As described previously, there are three military inside the dwelling. The communication with relay was performed for the two available services. It was considered a distance of 10 m between each military, making a total distance of 20 m. There was no problem with voice communication.

For the video service, two RBs were required to perform the 1st hop, with a transmission power of 4 dBm and three RBs in the 2nd hop with a transmission power of 8.77 dBm, because to transmit in the 2nd hop 1 Mbps is needed. Thus, the received power will be different, as well as the sensitivity. Anyway, the three military could transmit between them.

Finally, Table IV presents a summary of the results obtained for the three types of environment and for the two services where QPSK modulation was used. The critical cases, both in terms of coverage and capacity, are only for the video streaming service for the 64 MHz and 890 MHz frequencies, because there is a lack of RBs and, therefore, problems capacity (values in red in the Table IV).

<table>
<thead>
<tr>
<th>Service</th>
<th>Type of environment</th>
<th>Frequency [MHz]</th>
<th>Coverage [m]</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>Urban/Suburban</td>
<td>64</td>
<td>420</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>890</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1682</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>64</td>
<td>420</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>890</td>
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<td></td>
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<td>1682</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>64</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>890</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1682</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video streaming</td>
<td>Urban/Suburban</td>
<td>64</td>
<td>364</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>890</td>
<td>308</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1682</td>
<td>420</td>
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<td>1682</td>
<td>420</td>
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<tr>
<td></td>
<td>Indoor</td>
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<td>1682</td>
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</tbody>
</table>

VI. CONCLUSIONS

The main objective of this paper was to analyse the performance and use of LTE-A MCC among the military in operational environments, allowing the transmission of voice and data, in real time, and ensuring a solution to the high data rates of the different services. It was calculated the coverage and capacity of an ad hoc network with retransmission in different scenarios where the military operate, characterized in three types of environments: urban, suburban and rural. It was also analysed a scenario of interior of buildings, being this one integrated in any one of the mentioned environments. In order to reach the objective, it was chosen the Central African Republic (CAR) as a case study to analyse specific scenarios of the country, in the three types of environment, where the Commandos are integrated in the IFND/MINUSCA. Propagation models were developed and implemented in different scenarios, in order to calculate the coverage and capacity of the ad hoc network used by the infantry platoon.

For the first scenario, in an urban environment, characterized by the city of Bangui, voice service and video streaming were analysed in the three frequencies under study. Firstly, for the voice service, the path loss was calculated in a no line of sight (NLoS) situation, with the lowest modulation, where the distance of 400 m between the first and the last military limits them to communicate directly, in the frequencies of 890 MHz and 1682 MHz, where received power is lower than the sensitivity. It was only possible to communicate in the frequency of 64 MHz. The communication with relay was used, where it was obtained success for the three frequencies, that is, the distance of 420 m was reached and the 30 militaries had the service available. Receiving power ranged from -60.92 dBm to -55.39 dBm and the sensitivity of -106.39 dBm. For the video streaming service, on the other hand, when QPSK modulation was used there were capacity problems on two frequencies, and therefore only a maximum distance of 364 m was reached for the lowest frequency and 308 m for 890 MHz. For the first situation 27 militaries had the service available, while in the second situation, only 23 militaries did. Thus, to solve the problem, 16-QAM modulation was used. As the minimum flow rate is 500 kbps, a maximum of 14 RBs were used. At the end, the communication was guaranteed, with a received power between -66.08 dBm and -43.93 dBm and sensitivity of -103.23 dBm.

For the second scenario, the suburban environment characterized by the city of Bambari had an analysis similar to the urban environment. For the frequency of 64 MHz, for the NLoS situation, since the ITM model does not present a specific expression for a suburban environment, it was done the average of the urban and rural environment values. For the remaining frequencies, path loss, received power and sensitivity were calculated in an NLoS situation, using the typical characteristics of Bambari. It was not possible to successfully communicate at 1682 MHz, with a received power of -126.38 dBm lower than -119.84 dBm. Therefore, in the relay communication, the results obtained were the same as those of the urban environment, since the propagation model used was the same and the parameters of each type of environment did not vary in a line of sight (LoS) situation.

For the third scenario, the rural environment is characterized by the region of Gongo. As it is a region with a high density of vegetation, it was not possible to communicate directly in the higher frequencies, with a received power of -129.07 dBm and -143.24 dBm for 890 MHz and 1682 MHz respectively, in contrast to the sensitivity of -119.84 dBm. Relay communication
was used and received power was higher than sensitivity, with values ranging from -70.15 dBm to -48.49 dBm, for a maximum sensitivity of -106, 39 dBm. Regarding streaming video, once again in the communication with relay, it was not possible to have the service available to the entire platoon, due to lack of capacity, except for the frequency of 1682 MHz, since the BW is the highest of the three frequencies. When the 16-QAM modulation was used, the distance of 420 m was reached, where the entire platoon was able to transmit video, with received power values varying from -70.14 dBm to -57.03 dBm, for a maximum sensitivity of -103.23 dBm.

For the fourth scenario, in the indoor of a typical CAR house, the D2D communication was made between two military for a distance of 20 m and it was possible to have both services available, as expected, with received power values in the voice service, ranging from -74.66 dBm to -51.46 dBm, for a maximum sensitivity of -119.84 dBm and, in the video streaming service, ranging from -71.66 dBm to -48.46 dBm, for a maximum sensitivity of -88.59 dBm. Subsequently, communication was used with relay, for the voice service, received power values ranging from -64.12 dBm to -42.12 dBm were obtained for a maximum sensitivity of -117.64 dBm and, in the video streaming service, varying from -61.12 dBm at 34.35 dBm, for a sensitivity of -85.59 dBm.

Finally, it was possible to achieve one of the main objectives of this paper: to realize that, along an ad hoc network with relay, that is, an unstructured network, it is not only power issues that limit the communication, but also the capacity of the network itself. Considering the analysis carried out, the main limitation of the communications is, therefore, the capacity, and more specifically, the number of RBs available in each BW, when the communication with relay is performed. Thus, there are services that are limited by the capacity of the network due to the high throughput. With voice communication there is no capacity or power problems, even using the lowest modulation, the Q-PSK. However, for the video streaming service there were scenarios in which it was not possible for the 30 militaries to transmit video.

REFERENCES