

22ND ICCRTS

**Experimenting with 4G LTE for Area Coverage and the
Envisioned C2 Deployments over 5G**

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Topics
Battlefields of the future
Methodology, Experimentation, Analysis, Assessment and Metrics
Highly connected, Automated, and Autonomous forces

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Abstract—The evolution of the Next Generation Network Technologies such as the Fourth Generation (4G) and Fifth Generation (5G), have made them an adoption option in Command and Control (C2) tactical deployments for wireless communication network access. Features promised by 5G (low latency, high mobility, ubiquitous coverage area) will be enablers of services and capabilities such as Machine to Machine (M2M) communication, Internet of Things (IoT), sensory networks, self-healing networks, flexible spectrum management, massive machine communications, mission critical operations. These services and capabilities present opportunities for C2 such as granular monitoring of nodes (e.g. monitoring troop heart rate), convoy vehicle communication, realistic training through simulations, sensor driven environment. This paper presents results of experimenting with a LTE system in providing broadband area coverage for C2 deployment environments (bushveld, inner city and maritime) for the South African National Defence Force (SANDF). Multimedia services (voice, video, and data) and distance were used as performance measure metrics. Using a 400 MHz portable LTE system, a 10 km and 11 km radii coverage area was achieved in Line of Sight (LOS) for bushveld and maritime, respectively. While an 8 km radius was achieved in inner city urban environment with Non-LOS. The opportunities and the challenges of adopting these network technologies (4G and beyond) are also discussed, including the envisioned C2 deployments over 5G.

Index Terms—4G, LTE, 5G, Command and Control (C2), tactical environment

I. INTRODUCTION

Over the past decades, the advancement in cellular technologies have surpassed the proprietary military wireless communications network development [1]. Figure 1 shows the peak data rate of the commercial cellular and the military technologies over the past two decades. The commercial cellular is expected to have peak data rate of over 10 Gbit/s (with 4G advanced and beyond), while the military Joint Tactical Radio System - Waveform Network Manager (JTRS-WNW)

to have 10 Mbit/s by the year 2020. This evolution of cellular technologies have made them a viable option for adoption in Command and Control (C2) for tactical environment deployments [2].

A number of militaries around the world have experimented with these cellular technologies, in particular the Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE). The French military selected a local communication organisation to investigate how LTE can be used by the military forces in collaboration with security services [3]. One of the United States Department of Defense base in Maryland, tested a compact LTE deployment in providing secure military communication over a network isolated from the public cell networks or satellite data relays [4].

The Defence, Peace, Safety and Security (DPSS) research group of the Council for Scientific and Industrial Research (CSIR)¹ in South Africa has also experimented with these cellular technologies, WiMAX and LTE, in addressing C2 area coverage communication requirements for mobile deployments for the South African National Defence Force (SANDF). In both experiments, multimedia services (voice, data and video) and distance were used as performance measure metric. This paper presents the result of the LTE experiment in providing broadband area coverage for different deployment environments (bushveld, inner city and maritime). The opportunities and the challenges of

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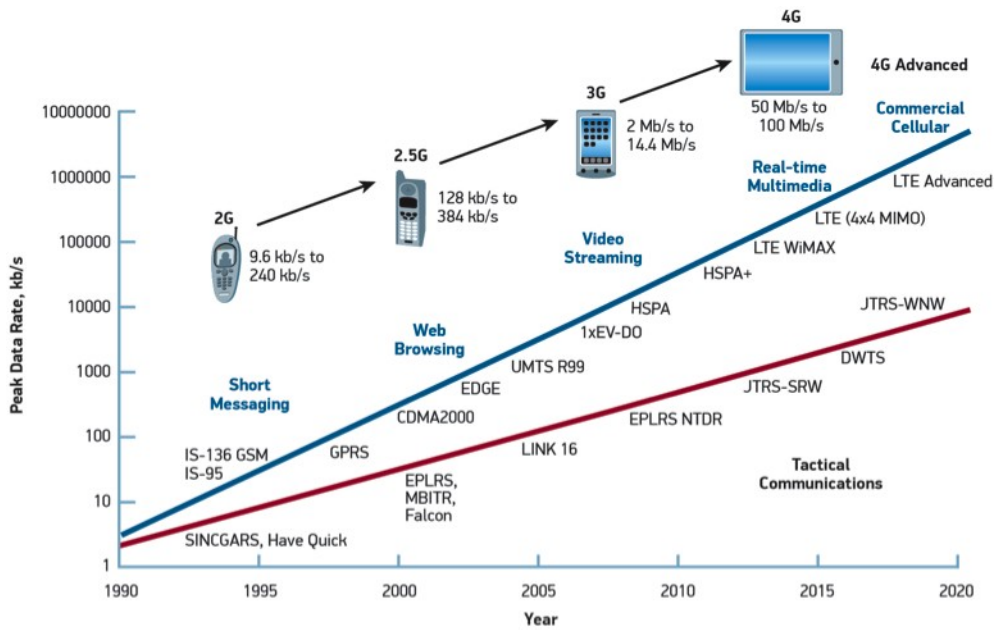


Fig. 1. Comparison of the peak data rate of the cellular technologies and the military wireless network development [1].

adopting such technologies (4G and beyond) are also discussed, including the envisioned C2 deployments over 5G.

II. LTE OVERVIEW

LTE is a wireless cellular communication standard defined by the 3rd Generation Partnership Project (3GPP) that aims to meet the requirements set forth by the International Telecommunication Union Radio sector (ITU-R)² of the International Mobile Telecommunications (IMT) advance specification for 4G technologies [5]. Some of the requirements for the 4G technologies are: *low latency*, *flexible spectrum* and *bandwidth configurations*, *high throughput* and *high peak data rate*.

LTE is an all Internet Protocol (IP) technology, with a flat and simplified core network architecture, compared to its predecessor Third Generation (3G). LTE enables real-time multimedia services such as voice, video streaming and data transfer to be realised with low latencies.

Figure 2 shows a basic LTE network architecture consisting of the following network components:

- **Evolved Packet Core (EPC):** The EPC forms part of the core network functions of the system. This

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core consists of three nodes: Mobility Management Entity (MME), Serving Gateway (S-GW), and the Packet Data Network Gateway (PDN-GW). The MME is a signalling node between the EPC and the user equipment, the S-GW provides interface between the EPC and the LTE wireless link (also called the Evolved Universal Terrestrial Radio Access (E-UTRA)), and the PDN-GW provides interface between the EPC and external IP networks.

- **eNodeB:** performs the functions of a base station and the antennae. It is responsible for the transmission and reception of the LTE wireless link in one or more cells.
- **User Devices:** Two types of user devices, User Equipment (UE) and Customer Premise Equipment (CPE), that enable access to the LTE network via the E-UTRA. A UE is usually an LTE compliant device which connects directly to the LTE network via the eNodeB - Example: smart phone, while a CPE connects other IP devices to the LTE network through the eNodeB - Example: laptop.

Other network nodes that interface with the EPC such as are: Home Subscriber Server (HSS) - central database for subscribers, Policy and Charging Rules Function (PCRF) - enables more control over the triggers for the establishment of new connections.

The radio interface of LTE, E-UTRA, is based on Orthogonal Frequency Division Multiplexing (OFDM) digital modulation scheme [6]. In a nutshell, this digital modulation scheme uses sub-carriers and divides the available spectrum into sub-carriers to modulate the information signal, and to efficiently utilise the spectrum.

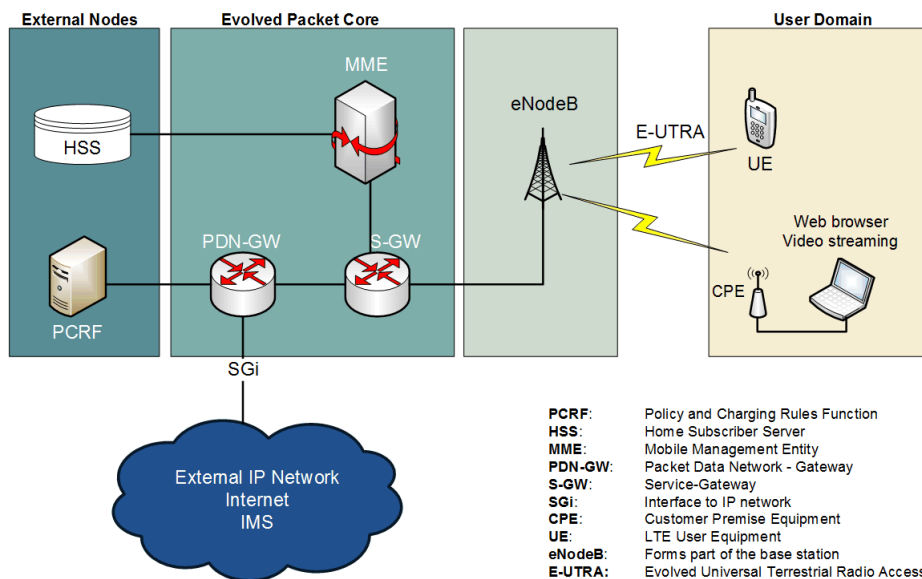


Fig. 2. Basic LTE network architecture [5]

Using OFDM in conjunction with other multi-access techniques such as Multiple Input Multiple Output (MIMO) antennae configuration, enables LTE to achieve a throughput uplink (UL) of 50 Mbit/s and a downlink (DL) of 100 Mbit/s. To ensure backward compatibility with its predecessors, LTE is able to operate across a flexible range of channel bandwidths from 1.4 MHz through to 20 MHz per channel. It can operate in a number of Time Division Duplex (TDD) and Frequency Division Duplex (FDD) frequency bands. This flexible frequency band configuration ensures that LTE can accommodate as many different regulatory environments as possible, making it ideal for rapid mobile deployment.

III. EXPERIMENT

The objective of the LTE experiment was to assess the area coverage of a typical compact and portable LTE system in various rapid deployment environments: bushveld, inner city, and maritime by using multimedia services (voice, video, and data). The experimentation with cellular technologies is a multi-phase project with various milestones and performance requirements. For this phase, the requirement was to achieve a 10 km radius coverage area with Line of Sight as determined based on certain operations and mission requirements.

A. Network

Three C2 nodes were used for the experiment - See Fig.3 for the network architecture. For the purpose of classification during the experiment, the nodes were labelled: *remote*, *hub*, and *tactical*. These nodes were connected to one another over an IP based network. The remote and the hub nodes were spatially fixed, while the

tactical node was deployed on a experiment-dependant mobile platform - road vehicle for bushveld and inner city, and sea-vessel for maritime.

The remote node was connected to the hub node through a satellite simulated IP link. The satellite simulator was used to reduce the risk and cost of using a real satellite link, while factoring in the effects - propagation delays, latency - of a satellite communication link in the experiment. An analogue telephone was commissioned in this node, and connected to the satellite IP link through an Analogue to IP (A2I) gateway. The function of this gateway was to translate the analogue voice signal into IP packets to be transmitted over the IP link, and vice versa. Also, this device had the capability of enabling interoperability between the connected analogue devices, i.e. establishing a call between analogue telephones.

The hub node was configured to perform as a rendezvous communication point, i.e. all the communications between the deployed nodes went through this node. This node consisted of a host with the multimedia applications installed, an analogue telephone, an analogue emergency service radio, and the LTE EPC. The multimedia applications were for: file or data transfer, video streaming, and to establish digital phone calls using the Session Initiation Protocol (SIP) [7]. The A2I gateway was also commissioned in this node, to connect the analogue telephone and the service radio system to the IP backbone. The A2I gateway connected to the LTE EPC through the S-Gi interface - i.e. to the PDN-GW interface. Table I shows a snapshot of the LTE system parameter configurations. A 400 MHz band LTE-TDD was selected due to its potential to be used in the tactical environment, and the access to this band by the DOD.

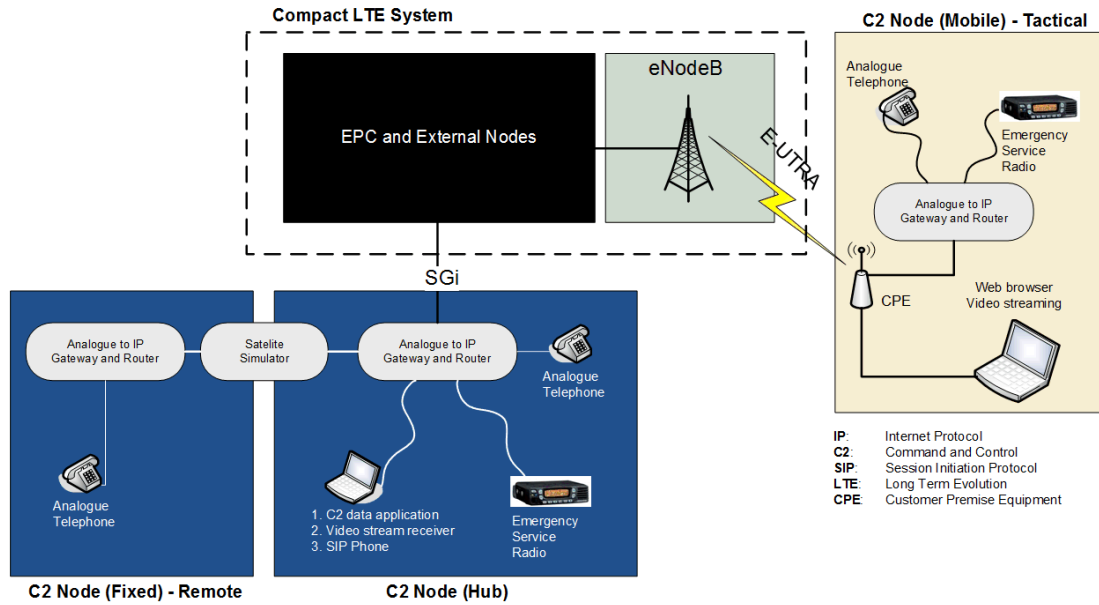


Fig. 3. Network architecture and configuration

TABLE I
LTE SYSTEM PARAMETER CONFIGURATION

Parameter	Value
Frequency	380 - 450 MHz (band 60)
Antenna configuration (Base Station)	2x2 MIMO (Omni) 1.5 m separation 8 m mast 2 dBi gain
Duplex Mode	TDD
Cell Throughput	100 Mbit/s (DL) 50 Mbit/s (UL)
Bandwidth	20 MHz (UL and DL))
Modulation	64QAM enabled
RF maximum transmitter power (0.1 dBi)	413

The tactical node was commissioned with similar multimedia applications and devices (digital and analogue) as in the hub node. However, a CPE was used to connect the A2I gateway to the IP backbone through the LTE wireless link.

B. Configuration

The analogue telephones were configured, through the A2I gateway, to establish calls to one another, to the service radios, to the SIP phones, and vice versa. The service radios were also configured to talk to each other, similarly to the SIP phones. The video application in the tactical node was configured to stream a saved video file to the video application in the hub node. The data or file transfer application in the tactical node was configured to upload and download a file from the host

in the hub node through the file transfer application in the hub node.

C. Execution

The tactical node was moved away from the hub node and stopped, if possible, at pre-determined intervals. There was no requirements on recording data on the move. In each interval, the services were executed as configured and the quality assessed - voice calls established, video streamed and file uploaded and downloaded.

The 400 MHz band was also utilised by other emergency services, as the result frequency scanning was performed prior to commencement with the experiment to determine a frequency range that can be used and to reduce signal interference.

D. Results and Discussions

Table II shows the experiment results for the three deployment environments. The base station antenna affects the achieved coverage area. In bushveld deployment, a 10 km radius was achieved with LOS and with the base station antenna height of 20 m, while with the same base station antenna height, an 8 km radius could be achieved in the inner city environment. In maritime, an 11 km radius was achieved with LOS and with the base station height of 200 m (deployed on a hill approximately 200 m above sea level), while with the same base station height, a 15 km radius was achieved in the inner city environment without LOS (Non LOS). The quality of the multimedia services degraded as the distance between the mobile node and hub increases, with video and data being the worst, followed by the

voice. The antenna height of the CPE was kept constant throughout the experiments.

LOS requires the transmitter and the receiver to be in clear vision of each other i.e. it excludes hills, mountains, buildings, and any other significant obstacles between the transmitter and the receiver. This was only possible in the bushveld and the maritime environments. However, the multipath propagation property of LTE enabled communication without LOS in the inner city environment.

TABLE II
EXPERIMENT RESULTS

Environment	Base station antenna height (m)	CPE antenna height (m)	Radius (km)
Bushveld	20	2.5	10.2 (LOS)
Inner-City	20	2.5	8.17 (Non LOS)
	200	2.5	15.04 (Non LOS)
Maritime	200	2.5	11.96 (LOS)

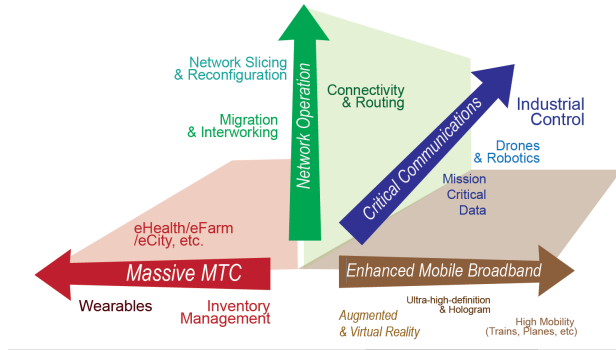


Fig. 4. The Smarter 5G [8]

IV. ENVISIONED C2

In 2012, the ITU-R embarked on a programme to develop IMT for 2020 and beyond, setting the stage for 5G research activities around the world [9]. The focus on 5G is to enable a seamlessly connected society in the 2020 timeframe that brings together people, devices, data, applications, transport systems, and cities in a smart networked communications environment.

5G is based on technologies such as: *millimetre wavelength*, *beam forming*, *massive MIMO*, and aims to achieve low latency, high peak data rate, high mobility and ubiquitous coverage, amongst other features that enable services and capabilities such as: Machine to Machine (M2M), Vehicle to Vehicle (V2V), Device to Device (D2D) communications, Software Defined Networks (SDN), Gigabits throughput, IoT, sensory networks, self-healing and self-configuration networks (also known as Complex Adaptive Systems (CAS)), flexible spectrum management, and mission critical operations. Figure 4 shows the services that 5G technologies plans to provide as defined by 3GPP. These services

and capabilities will present opportunities for C2 such as, granular monitoring of nodes (e.g. monitoring troops heart rate), convoy vehicle communication, realistic training through simulations, recognisances, and sensor driven environment over secure communication links.

Previous experiments, by the DPSS, with the cellular technologies focused mainly on the coverage area by using user-operated multimedia service devices and applications. The advancement of the technologies introduces other means of communications and information transfer options, and this necessitates the need to continue experimenting with these technologies and their new means of information sharing.

A. Objective of the Future Experiments

The objective, by the DPSS, is to continue experimenting with these cellular technologies, and extend deployment scenario capabilities, including the impact of the security of information. Figure 5 shows three tactical network deployments, a training centre interoperability, the operation centre and the integration to the city smart grid. Future work includes experimenting with the X2X communication (V2V, M2M, and D2D), integration to the smart city (weather information, air traffic, etc.), simulation in the loop (threat injections), and backhauling to the operation centre via a gateway (developed in-house), whose function is to translate different protocols to the C2 application protocol in the operations centre.

B. Challenges

The high throughput, as promised by the 5G technologies, is expected to be achieved under millimetre wavelength technologies. Previous experimentation by the DPSS with the GHz frequencies (using 2.4 GHz WiMAX), provided a short coverage area, approximately 2 km with similar multimedia configuration - with single cell. Using a lower frequency band (400 MHz in LTE), a larger coverage area was achieved. Therefore, a trade-off will have to be considered between the high throughput and the larger coverage area while factoring in the impact of security, particularly on the larger coverage area. A detail planning will be required prior to deployment.

Spectrum allocation is a major challenge in the African continent, and South Africa is no exception. The spectrum allocations are taking longer than anticipated. Currently, service providers are re-farming their 2G spectrum, for LTE deployments. Although this should not be case for the DOD, the frequency band at which the deployment will use, will be dependant on the operations, hence a number of bands must be allocated.

V. CONCLUSION

The ability of the LTE system to provide high bandwidth wireless access was assessed. A compact and

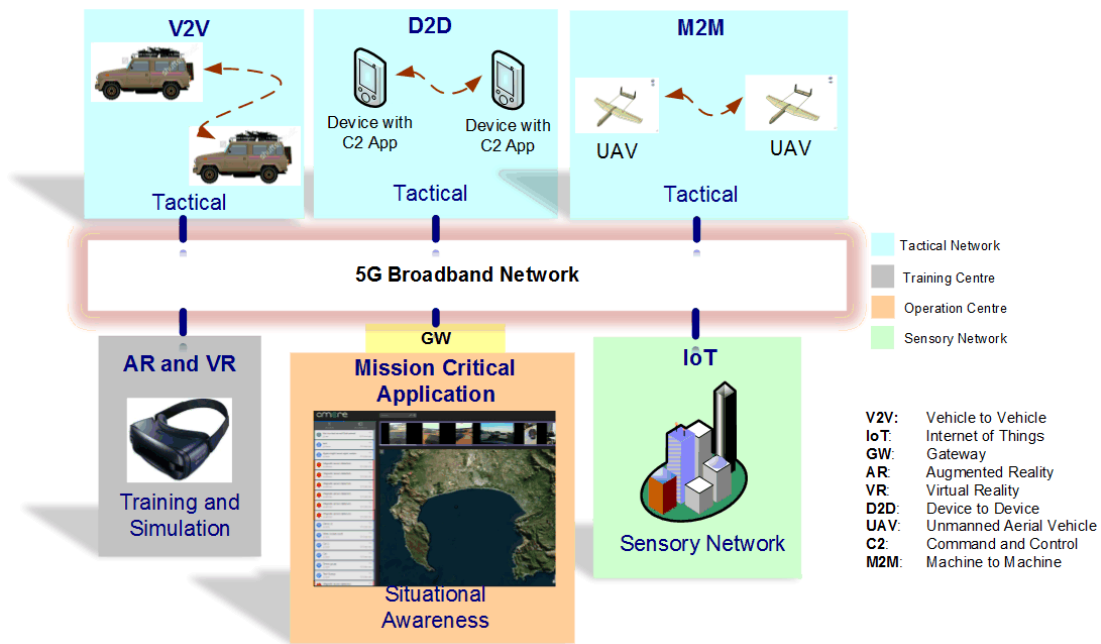


Fig. 5. Future C2 deployment over the promised 5G technologies

portable LTE system (easy to transport by commercial vehicle and quickly to deploy) was used, which combined the basic functions of the LTE core network and the radio interface. Three experiments were prepared and executed in different deployment environments: bushveld, inner city and maritime and multimedia services were used to determine the radius of a coverage area.

The LTE system has a potential for certain short range area coverage uses in which multimedia services are required. Using a single cell 400 MHz band LTE system, a coverage area of radius 10 km was achieved in a bushveld foliage area, and 11 km in maritime with LOS, while a 15 km range was achieved in inner city with Non-LOS. However, there was a potential of this band to interfere with other emergency services around the deployed region.

Also presented, is the envisioned C2 deployment services over the promised 5G technologies. Services such as M2M, V2V, AR and VR, D2D, mission critical applications are envisaged as playing a pivotal role in situational awareness scenarios, in which the 5G technologies promises to support.

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