A DRONE-BASED COMMUNICATION SYSTEM FOR STRATEGIC AND PUBLIC PROTECTION AND DISASTER RELIEF (PPDR) APPLICATIONS

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **A Drone-Based Communication System For Strategic And Public Protection And Disaster Relief (PPDR) Applications**, submitted by **PRANAV KUMAR OPAL**, to the Indian Institute of Technology, Madras, for the award of the degree of **MTech**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: PPDR, Dead Zone, Spectrum Sensing.

Being in the Corps of Signals for almost a decade, which is the telecommunication arm of the Indian Army, and having served in varied operational terrains in different parts of the country, I have experienced many **challenges in providing communication to the deployed units**. Few of these challenges relate to providing communication in areas with little or no network infrastructure, thickly wooded terrain, etc.

This project work focuses on addressing these voids. I have tried to propose a solution to provide effective communication in the respective scenarios. In doing so, I have incorporated **Drones (Unmanned Aerial Vehicle)** to create an ad-hoc communication support system which can be quickly deployed in inaccessible areas, these areas can be ones which are, although, near well-established communication infrastructure but due to **dead zone deployment** (wherein the transmitter/receiver are so placed that they lack either forward or backward connectivity or in many cases both of them) lacks adequate connectivity from it or ones that lack communication infrastructure altogether.

In the first scenario, we have an area of operation in dead ground where communication is to be provided using the existing communication infrastructure from a nearby area. **In the second scenario**, communication is to be provided in a remote, isolated area where no communication exists in near vicinity.

This proposed setup has **applications outside the military strategic domain** wherein, during many unforeseen emergency situations (viz natural calamities, train accidents forest fires or any large scale congregation), there is a sharp and sudden rise in cellular communication traffic due to ensuing commotion and influx of people. The existing infrastructure is either unable to take on this huge increase in load and gets choked up or has been damaged and therefore unable to provide service.In such a situation, it can be suitably adapted to be used by disaster response forces to operate for their coordination of **Personnel Protection and Disaster Relief (PPDR)** tasks to bring situation under control and prevent any further loss of life or material.

Any credits, I happily share with you, but I take full responsibility for any flaws that might have crept in. We would sincerely welcome the comments and suggestions of everyone in light of which I may further this work into a full-fledged system.

Key Note

This project is a joint effort of two students namely EE17M002 Pranav Kumar Opal and EE17M003 Neeraj Sharma and covers two different scenarios for its application. However this report covers the part of project dealing with WiFi Cloud for communication (for first scenario) . The GSM portion(for second scenario) of the over all project is covered in the report submitted by EE17M003 Neeraj Sharma.

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ABBREVIATIONS

2G	2nd Generation Cellular System
3G	3rd Generation Cellular System
AP	Access Point
ARPU	Average Revenue Per User
ATSC	Advanced Television Systems Committee
AuC	Authentication Centre
AV	Audio Visual
BEE	Berkley Emulation Engine
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CMRTS	Captive Mobile Radio Trunking System
CPU	Central Processing Unit
CRP	Cognitive Radio Platform
DOT	Department of Telecommunication
EIR	Equipment Identity Register
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FPGA	Field Programmable Gate Array
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HDL	Hardware Description Language
HLR	Home Location Register
IEEE	Institute of Electrical and Electronics Engineers
IITM	Indian Institute of Technology Madras
IOT	Internet of Everything
IRiS	Implementing Radio in Software

KUAR	Kansas University Agile Radio
LAN	Local Area Network
LCD	Liquid Crystal Display
LE	Logic Elements
LTE	Long Term Evolution
MARS	Maynooth Adaptable Radio System
ME	Mobile Equipment
MS	Mobile Station
MSC	Mobile Switching Centre
NAT	Network Address Translation
NICT	National Institute of Information and Communications Technology
OFDM	Orthogonal Frequency Division Multiplex
OS	Operating System
OSS	Operations and Support Subsystem
PC	Personal Computer
PCI	Peripheral Component Interconnect
PPDR	Personnel Protection and Disaster Relief
RAM	Random Access Memory
ROM	Read Only Memory
SBC	Single Board Computer
SDR	Software Defined Radio
SIM	Subscriber Identity Module
SS7	Signalling System No 7
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UE	User Equipment
UPnP	Universal Plug and Play
USRP	Universal Software Radio Peripheral
VLR	Visitor Location Register
VOIP	Voice Over Internet Protocol
WAN	Wireless Access Network
WCDMA	Wideband Code Division Multiplex
WI-FI	Wireless Fidelity

WLAN Wireless Local Area Network

WPC Wireless Planning and Coordination

YATE Yet Another Telephony Engine

CHAPTER 1

INTRODUCTION

1.1 General

Our military forces, during operations are deployed in some places devoid of any communication which affects their efficiency on ground due to inadequate coordination means. Also, many unforeseen emergency situations (viz natural calamities, train accidents, forest fires or any large scale public congregation) warrant immediate action by first responders (Public Protection and Disaster Relief-PPDR or Military personnel) to bring the situation under control to prevent any further loss of life or material. During such occasions, there is a sudden increase in cellular traffic leading to its eventual choking/breakdown of system. This paper proposes to offer a temporary, easy and fast-to-setup GSM and Wi-fi based communication system that addresses this communication void to allow our forces (PPDR or Military) to carry out their intended tasks efficiently amidst a broken/no communication infrastructure in place.

1.2 Problem Statement

The circumstances mentioned above and similar incidents warrant immediate action by PPDR forces and lack of an effective communication setup for coordination can prove to be counterproductive leading to wastage of efforts in terms of men and material and leading to chaos.

This situation leads to an inescapable requirement of developing an effective "Public Protection and Disaster Relief (PPDR) Communication System" which can be deployed at the incident site in a much quicker time frame and augment the efforts of rescue and relief by the varied agencies involved in PPDR.

1.2.1 Main features of the proposed PPDR system

The main features are:-

(a) Drone based platform mounted mini-Base station to provide extended coverage of communication.

(b) Capability to support limited voice and data traffic between users.

(c) Capability of connecting to an existing terrestrial network to allow exchange of information with the controlling headquarters on a selective basis.

(d) Adequate redundancy, availability and backup in terms of power support.

(e) Authentication mechanism for only authorised users to connect to the network.

1.2.2 Additional Scenarios To Employ The Same Setup with Certain Modifications/ Customization

The system can be effectively employed in the following scenarios:-

(a) A similar setup with robust authentication and encryption mechanism incorporated for special teams of Armed forces carrying out stealth operations in jungle terrain /border area where either the range is limited due to foliage or no communication infrastructure exists. Addition of HD cameras and sensors atop drone would also provide video surveillance feed besides the voice/data communication for better situational awareness.

(b) Drone with a video feed capability can help locate and rescue survivors trapped in forest fire or allied inhospitable terrain and also help establish a voice communication with the relief workers in order to help the victims better.

(c) A network of such drones can establish an adhoc wide spread communication cum surveillance network in places where establishment of the infrastructure from scratch can be time consuming and uneconomical as the need is temporary and short lived. This can come in especially handy at places of large public gathering like stadiums, concert arenas, rally grounds etc where crowds congregate in large numbers for a limited duration.

1.3 Solution to the Problem Statement

Based on the problem statement, we can divide the area of operation into two parts:-

(a) **Scenario 1**: Providing communication in areas of dead ground with communication infrastructure in vicinity. Dead ground refers to a bowl like area where direct communication link from nearby gets affected due to surrounding physical features thereby leading to a void.

(b) **Scenario 2**: Providing communication in areas with no communication infrastructure at all in vicinity.

CHAPTER 2

LITERATURE SURVEY

2.1 General

For a better and comprehensive understanding of the concepts involved in envisaging and designing the solutions for the problem statement explained above, a comprehensivelitreture survey was carried out covering the following topics and areas:-

(a) Personnel Protection and Disaster Relief (PPDR) networks,

(b) Software Defined Radio,

(c) Single Board Computer (SBC),

(d) GSM networks (Including Open Source GSM implementation),

(e) IEEE 802.11 standard (Wi-Fi).

2.2 Personnel Protection and Disaster Relief (PPDR) Networks

(a) Communication plays an important role in rescue and relief operations during emergency or disaster situations, especially in a country like India which is highly prone to natural disasters like floods, earthquakes, coastal cyclones and also, man-made disasters like railway accidents, terrorist attacks etc. The effectiveness and efficiency of public protection and law enforcement pivots on robust and reliable communication networks.

(b) PPDR agencies, to include police departments, fire departments, paramedics, para-military forces and many others, need resilient communication networks for their day-to-day, emergency and disaster relief operations.

(c) Currently, Indian PPDR agencies rely on narrowband digital trunking technology like TETRA and P25 systems or old analog systems for their communication in the field, which are primarily meant for voice communication. The PPDR communication networks are designed and run by independent state agencies. The PPDR agencies are issued license by Department of Telecommunications (DoT) under Captive Mobile Radio Trunking Service (CMRTS) category. Accordingly spectrum is allocated by Wireless Planning & Coordination Wing (WPC Wing) of DoT in the 300 MHz, 400 MHz or 800 MHz bands.

(d) The current framework has resulted in fragmented spectrum assignments with inefficient use of precious and prime sub-1GHz frequency. Despite consuming large amounts of costly spectrum, it does not meet the evolving needs of the public safety and emergency communication such as access to instant messaging, high-quality images and video, mapping and location services, remote control of robots, and other applications. Moreover, it has been observed that PPDR agencies have their individual networks in place, which work in silos. This results in inability to have seamless communication and information sharing among the PPDR agencies. This is due to the fact that their networks are either not interoperable or they are just not compatible with each other. This deprives the agencies of instant cross-agency coordination and exchange of mission-critical information which eventually results in ineffective mitigation of safety and disaster situation.

(e) To overcome the limitations of current PPDR communication networks, next generation PPDR communication networks should be deployed with enhanced broadband capabilities, unified framework and comprehensive policy.

(f) The key challenges with the existing fragmented model of PPDR communication network identified are listed below:-

(i) Narrowband PPDR networks can support only voice communication.

(ii) Non-interoperable networks due to which PPDR agencies face a challenge to have seamless information sharing with other agencies.

(iii) Limited budget to roll out state of the art digital network based on mission critical technologies.

(iv) Extremely high spectrum license fees for captive users which is up to 10 times the license fees in developed countries.

(v) Long time frame for getting necessary DoT licenses which is minimum 9 months to an average 12 to 18 months to get a CMRTS and spectrum license.

(vi) The PPDR networks in the country are still evolving from analogue to Digital trunking.

2.3 Software Defined Radio

2.3.1 General

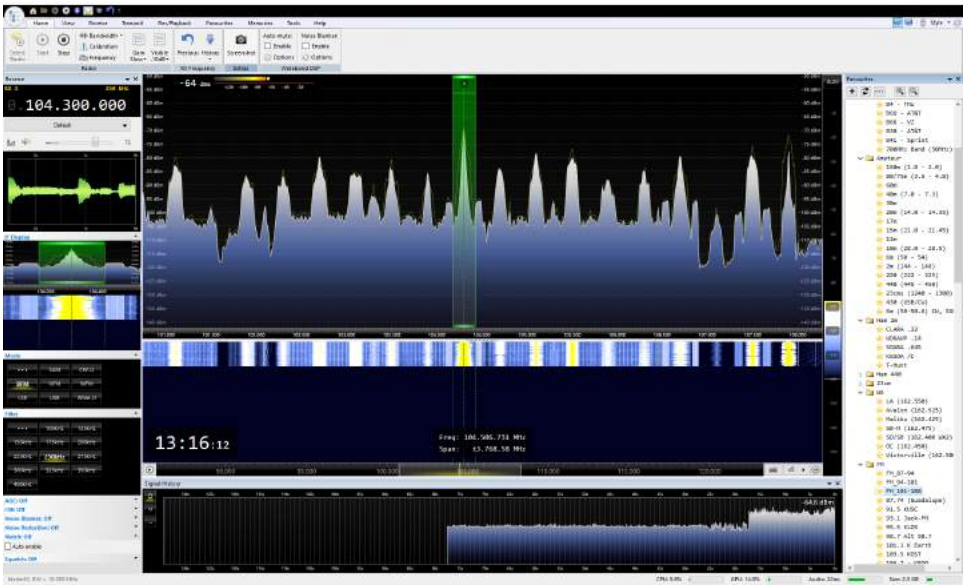

Figure 2.1: SDR Platform.

(a) The software defined radio (SDR) receiver uses software to perform many of the basic functions of the receiver. Using software, it is easy to reconfigure and use the software on many platforms.

(b) The SDR technology is able to provide some significant advantages over traditional hardware based radio designs. Using the power of digital processing, software defined radios are being used in many different applications in many different areas.

(c) The basic concept of the SDR is that the radio can be totally configured or defined by the software so that a common platform can be used across a number of wireless systems and at the same time change the configuration of the radio for the function required at a given time. There is also the possibility that it can then be re-configured as upgrades as the standards evolve, or if it is required to meet another function, or if the scope of its operation is changed.

(d) The SDR concept is applicable in many areas :-

- **(i) Mobile communications**. SDRs are very useful in areas such as mobile communications. By upgrading the software it is possible to apply changes to any standards and even add new waveforms purely by upgrading the software and without the need for changes to the hardware. The software updates can even be done remotely, thereby providing considerable savings in cost.
- **(ii) Research & development**. SDR is very useful in many research projects. The radios can be configured to provide the exact receiver and transmitter requirements for any application without the need for a total hardware design from scratch.
- **(iii) Military**. The military have made much use of SDR technology enabling them to re-use hardware and update signal waveforms as needed.
- **(iv) Amateur radio** operations have successfully employed SDR technology, using it to provide improved performance and flexibility.
- **(v)** There are very many other applications that can make use of SDR technology, enabling the radio to be exactly tailored to the requirements using software adjustments.

(e) As processing power becomes cheaper, SDR based radios are being increasingly used for high end applications and also moving into lower end radios as well.

(f) One of the major advantages of SDR technology is that it can be configured to exactly meet the requirements of the user (small changes to the software can make the radio fit the requirements exactly). Also with open source software like the GNU software, it is becoming easy to implement.

2.3.2 Advantages/Disadvantages of SDR Technoogy

(a) Some of the salient advantages of SDR technology are as follows:-

- **(i)** It is possible to achieve high levels of performance.
- **(ii)** Performance can be changed by updating the software (it will not be possible to update hardware dependent attributes though).
- **(iii)** It is possible to reconfigure radios by updating software.
- **(iv)** The same hardware platform can be used for different radios.

(b) Disdvantages of SDR technology are as follows:-

- **(i)** Analogue to digital converters limit top frequencies that can be used by the digital section.
- **(ii)** For very simple radios the basic platform may be too expensive.

2.3.3 Existing SDR Platforms

There are a large number of experimental SDR platforms that have been developed to support individual research projects. The various experimental SDR platforms have made different choices in how they have addressed the issues of flexibility, partitioning, and application. Some of the popular ones are as follows:-

(a) **Universal Software Radio Peripheral (USRP)** The USRP is one of the most

Figure 2.2: USRP

popular SDR platforms currently available and it provides the hardware platform for the GNU Radio project. The first USRP system, released in 2004, was a USB connected to a computer with a small FPGA. The FPGA was not only used primarily for routing information but also allowed some limited signal processing. The USRP could realistically support about 3 MHz of bandwidth primarily due to the performance restrictions of the USB interface. The second generation platform was released in September 2008 and utilizes gigabit Ethernet to allow support for 25 MHz of bandwidth.The system includes a capable Xilinx Spartan3 device which allows for local processing. The radio-frequency performance of the USRP is limited and is more directed toward experimentation rather than matching any communications standard.

(b) Kansas University Agile Radio (KUAR) The KUAR platform was designed

Figure 2.3: KUAR

to be a low-cost experimental platform targeted at the frequency range 5.25 to 5.85 GHz and a tunable bandwidth of 30 MHz. The platform includes an embedded 1.4 GHz general purpose processor, Xilinx Virtex2 FPGA and supports gigabit Ethernet and PCI-express connections back to a host computer. This allows for almost all processing to be implemented on the platform, minimizing the host-interface communications requirements. The platform was designed to be battery powered thus allowing for untethered operation, The KUAR utilizes a modified form of the GNU Radio software framework to complete the hardware platform.

(c) NICT SDR Platform The Japanese National Institute of Information and

Figure 2.4: NICT SDR

Communications Technology (NICT) constructed a SDR platform for trial of next generation mobile networks. The platform has two embedded processors, four Xilinx Virtex2 FPGA, and RF modules that could support 1.9 to 2.4 and 5.0 to 5.3 GHz. The signal processing was partitioned between the CPU and the FPGA, with the CPU taking responsibility for the higher layers. An objective of this platform was to explore selection algorithms to manage handover between existing standards. To this end, a number of commercial standards were implemented, for example, 802.11a/b/g, digital terrestrial broadcasting (Japanese format), WCDMA, and a general OFDM communication scheme.

(d) Berkeley Cognitive Radio Platform This platform is based around the Berkeley emulation engine (BEE2) which is a platform that contains five high-powered Virtex2 FPGAs and can connect up to eighteen daughterboards. In the Cognitive Radio Platform, radio daughterboards have been designed to support up to 25 MHz of bandwidth in an 85 MHz range in the 2.4 GHz ISM Band. The RF modules have highly sensitive receivers and to avoid self-generated noise operate either concurrently at different frequencies (FDD) or at the same frequency in time-division duplex (TDD) mode. This cognitive radio platform requires only a low-bandwidth connection to a supporting PC as all signal processing is performed on the platform.

(e) Maynooth Adaptable Radio System The Maynooth adaptable radio system

Figure 2.5: Berkeley CRP

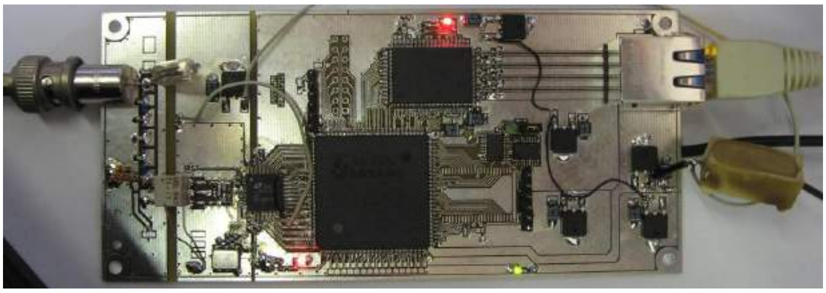

Figure 2.6: MARS

(MARS) has been in development since 2004 and had the original objectives of a programmable radio front-end that was to be connected to a personal computer (PC) where all the signal processing is implemented on the computers general purpose processor. The platform was to endeavor to deliver a performance equivalent to that of a future mobile telephony base station and the wireless communication standards in the frequency 1700 to 2450 MHz The software framework selected for initial development was the IRiS framework (Implementing Radio in Software).

(f) BladeRF x40 The BladeRF x40 is a low-cost USB 3.0 Software Defined Radio. The 40K LE option makes the BladeRF the essential low-cost RF transceiver kit for both hobbyists, and RF enthusiasts. Out of the box, the bladeRF can tune from 300 MHz to 3.8 GHz without the need for extra boards. Through open source software such as GNU Radio (live image), the bladeRF can be placed into immediate use. With its flexible hardware and software, the bladeRF can be configured to operate as a custom RF modem, a GSM and LTE picocell, a GPS receiver, an ATSC transmitter, or a com-

Figure 2.7: BladeRF

bination Bluetooth/Wi-Fi client, without the need for any expansion cards. All of the bladeRF host software, firmware, and HDL is open source, and available on GitHub.

It was decided to use BladeRF x40 as the SDR as part of our project.

2.4 Single Board Computer (SBC)

Figure 2.8: SBC

(a) A single-board computer (SBC) is built on a single circuit board and contains functional computer components including the microprocessor, input/output (I/O) and memory. SBC computers typically provide a fan-less, low-power computing solution and a low profile architecture. Right from the mobile phone in your pockets to high end gaming consoles, including tablets, PCs, iPod, etc, everything is basically a single board computer.

(b) There is a difference between traditional computers and single board computers. Full-fledged computers (like PCs and Mac) have a motherboard. On the motherboard, we will essentially find a processor (like the Intel® Core™, AMD® Athlon™, etc.), and other circuitry associated with that. We will also find slots for other peripherals like RAM, ROM, Hard Disk, LAN Card, CPU Fan, Heat Sink, LCD monitor, etc. These peripherals need to be attached to the motherboard separately in order to make the PC/Mac fully functional.

(c) However, Single board computers consist of everything on a single board itself. On the board, we have a processor and all other necessary peripherals and circuitry as well. We have onboard RAM, ROM, flash storage, AV ports, Ethernet port, etc. This means that one board is sufficient to act as a full-fledged computer. They can boot into an operating system (OS) like Linux, Android, etc. and operate like any other computer. Being lightweight and specific, they have found huge application in smartphones, tablets and other consumer products with specific application based requirements.

(d) These single board computers are not as powerful as the current day PCs, laptops or Mac, and hence do not dissipate much heat. In addition to that, the processors are designed in order to generate less heat and consume less power.

(e) There are several reasons one might opt to use a single board computer as mentioned below:-

(i) Portability It being one of the major features. One can carry around a small computer like smartphone in the pocket everywhere one goes. These devices are pretty intuitive to use as well.

(ii) Power They consume less power and energy as compared to traditional computers.

(iii) Cost The most attractive feature is being cost effective. This makes them suitable for developer applications as well for development of new apps, testing, debugging, hardware development,etc.

(f) There are some notable single board computers available in the market for both, hardware and software development. Some of them include **Raspberry Pi, The Beagles (BeagleBoard, BeagleBoard xM, BeagleBone, BeagleBone Black), PandaBoard, MK802, MK808, Odroid, Cubieboard , MarsBoard, Hackberry, Udoo, MinnowBoard**. All of them have a different configuration in terms of power and processing speeds besides peripheral slots and depending on requirement of application and cost factor they can be appropriately chosen.

It was decided to use Raspberry Pi (3B model) for the project as it was a very popular and readily available SBC (an old unit was lying in one of our sister labs from where it was borrowed) with a strong online community support and the initial trials of the project work were carried out using the same. However due to absence of a USB 3.0 support, which was critical for the project in linking up of SDR with SBC as USB 2.0 was found inadequate, on any one of its models it was decided to use the next available SBC which meets the technical and cost requirements, Odroid XU4.

Figure 2.9: Raspberry Pi

2.5 GSM Networks

2.5.1 General

(a) The GSM system was designed as a second generation (2G) cellular phone technology. One of the basic aims was to provide a system that would enable greater

Figure 2.10: Odroid-XU4

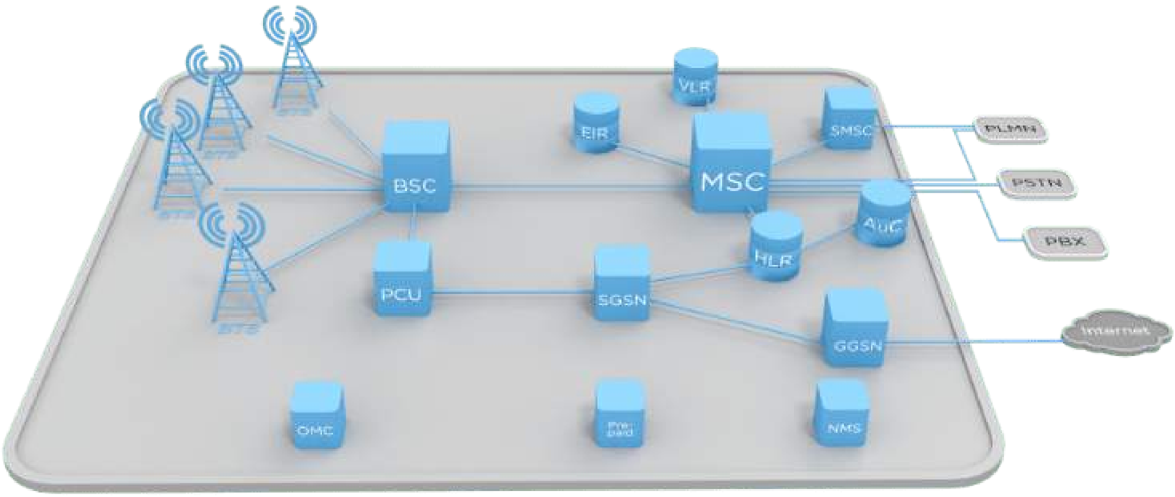

Figure 2.11: GSM Networks

capacity to be achieved than the previous first generation analogue systems. GSM achieved this by using a digital TDMA (Time Division Multiple Access approach). By adopting this technique more users could be accommodated within the available bandwidth. In addition to this, ciphering of the digitally encoded speech was adopted to retain privacy.

(b) Speech or voice calls are the primary function for the GSM cellular system. To achieve this the speech is digitally encoded and later decoded using a vocoder.

(c) In addition to the voice services, GSM cellular technology supports a variety of other data services. Although their performance is nowhere near the level of those provided by 3G/4G, they are nevertheless important and useful. A variety of data services are supported with user data rates up to 9.6 kbps. Services including fax, videotext and teletext can be supported.

(d) GSM cellular technology uses 200 kHz RF channels. These are time division multiplexed to enable up to eight users to access each carrier. In this way it is a TDMA / FDDA system.

(e) The Base Transceiver Stations (BTS) are organized into small groups, controlled by a Base Station Controller (BSC) which is typically co-located with one of the BTSs. The BSC with its associated BTSs is termed the Base Station Subsystem (BSS).

(f) Further into the core network is the main switching area. This is known as the Mobile Switching Centre (MSC). Associated with it is the location registers, namely the Home Location Register (HLR) and the Visitor Location Register (VLR) which tracks the location of mobiles and enables calls to be routed to them. Additionally there is the Authentication Centre (AuC), and the Equipment Identity Register (EIR) that are used in authenticating the mobile before it is allowed onto the network and for billing.

(g) The last component in the network is the user hand-set (ME - mobile equipment / MS – Mobile Station/ UE – User Equipment). One important feature that was first implemented on GSM was the use of a Subscriber Identity Module (SIM). This card carried with it the user's identity and other information to allow the user to upgrade a phone very easily, while retaining the same identity on the network. It was also used to store other information such as "phone book" and other items. This item alone has allowed people to change phones very easily, and this has fueled the phone manufacturing industry and enabled new phones with additional features to be launched. This has allowed mobile operators to increase their average revenue per user (ARPU) by ensuring that users are able to access any new features that may be launched on the network requiring more sophisticated phones while retaining their number identity.

2.5.2 GSM System Overview

The table below summarises the main points of the GSM system specification, showing some of the features of technical interest.

Specifications	**Details**
Multiple access technology	FDMA / TDMA
Duplex technique	FDD
Uplink frequency band	890-915 MHz(basic 900 MHz band only)
Downlink frequency band	933-960 MHz(basic 900 MHz band only)
Channel spacing	200KHz
Modulation	GMSK
Speech coding	Various - original was RPE-LTP/13
Speech channels per RF channel	8
Channel data rate	270.833Kbps
Frame duration	4.615

Table 2.1: GSM Specifications

2.5.3 GSM Network Architecture

It can be grouped into four main areas:

(a) Network and Switching Subsystem (NSS)

(b) Base-Station Subsystem (BSS)

(c) Mobile station (MS)

(d) Operation and Support Subsystem (OSS)

2.6 Open source GSM Implementation

(a) A number of commercial and open source software options are available online for GSM network implementation to establish a small GSM network with a limited range by configuring the various sub-systems of GSM architecture, as explained above, in the software domain and integrating an omnidirectional / directive radio for necessary transmission and reception.

(b) Some of the available different options that were read and examined are as follows:-

- **(i)** OpenBTS (Open Base Transceiver Station)
- **(ii)** OsmocomBB.
- **(iii)** YateBTS.

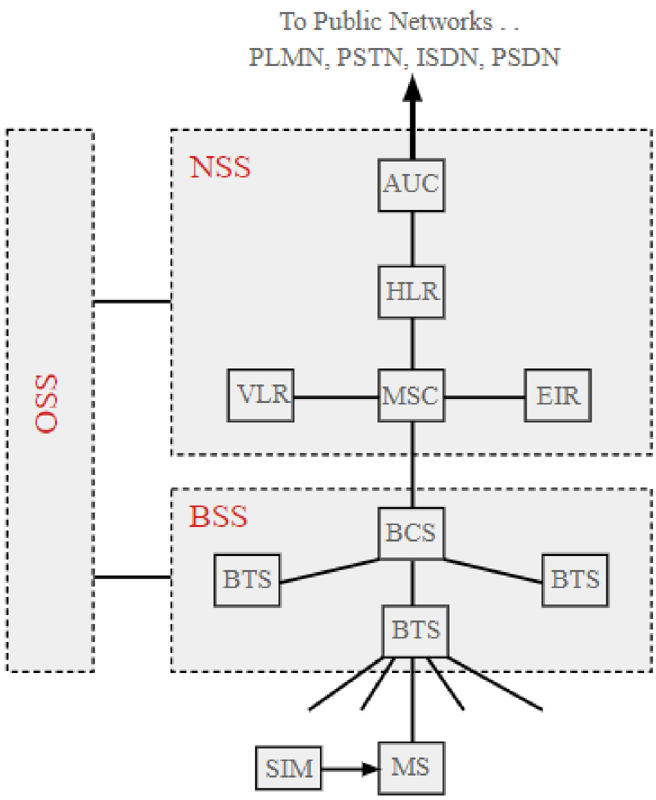

Figure 2.12: GSM Architecture

(c) OpenBTS (Open Base Transceiver Station)

(i) It is a software-based GSM access point, allowing standard GSM-compatible mobile phones to be used as SIP endpoints in Voice over IP (VoIP) networks.

(ii) OpenBTS is open-source software developed and maintained by Range Networks. OpenBTS replaces the conventional GSM operator core network infrastructure from layer 3 upwards.

(iii) Instead of relying on external base station controllers for radio resource management, OpenBTS units perform this function internally.

(iv) For more information on this look up the Reference section in the end.

(d) OsmocomBB.

i OsmocomBB is an Free Software / Open Source GSM Baseband software implementation.

ii It intends to completely replace the need for a proprietary GSM baseband software, such as drivers for the GSM analog and digital baseband (integrated and external) peripherals, GSM phone-side protocol stack, from layer 1 up to layer 3.

iii For more information on this look up the Reference section in the end.

(e) YateBTS.

(i) It is a sof**tware implementation of a GSM/GPRS radio access network based on Yate .**

(ii) It is compatible with both GSM/GPRS SS7 MAP and LTE IMS core networks integrated in our YateUCN unified core network server.

(iii) YateBTS offers a unique approach, different from that of traditional radio access networks, with increased flexibility, scalability and is easily upgradable with new features. It has two parts, MBTS (Lower layer) that handles GSM aspects and connects to radio transceiver using socket interface, Network layer that carries out the network support and connectivity.

(iv) YATE (Yet Another Telephony Engine) supports Voice, data, video and IM. It is written in C++ and licensed under GNU GP License.

(v) For more information on this look up the reference section in the end.

It was decided to use Yate/YateBTS as the open source software implementation on Odroid XU4 (SBC) as part of our project as it has an open and active online community forum and implementation codes are more comprehensive and easier to understand. The code for implementation was directly written on Linux after loading the necessary files/updates through interface commands as explained in later chapters.

2.7 IEEE 802.11 standard (Wi-Fi and WLAN)

(a) IEEE 802.11 refers to the set of standards that define communication for wireless LANs (wireless local area networks, or WLANs). The technology behind 802.11 is branded to consumers as Wi-Fi.

(b) IEEE 802.11 is overseen by the IEEE, IEEE LAN/MAN Standards Committee (IEEE 802). The current version of the standard is IEEE 802.11-2007.

Figure 2.13: WiFi

(c) IEEE 802.11 is the set of technical guidelines for implementing Wi-Fi. Selling products under this trademark is overseen by an industry trade association by the name of the Wi-Fi Alliance. There is only one standard (IEEE 802.11-2007) but many amendments. Commonly known amendments include 802.11a, 802.11b, 802.11g, and 802.11n. By releasing updated variants, the overall technology has been able to keep pace with the ever growing requirements for more data and higher speeds, etc.

(d) Wi-Fi wireless connectivity is an established part of everyday life. All smartphones have it incorporated into the phone enabling low cost connectivity to be provided. In addition to this, computers, laptops, tablets, cameras and many other devices use Wi-Fi including many Internet of Things (IoT) sensors and nodes.

(e) There are two types of WLAN network that can be formed using a WiFi system:-

(i) Infrastructure networks The infrastructure application is aimed at office areas or to provide a "hotspot". The WLAN equipment can be installed instead of a wired system, and can provide considerable cost savings, especially when used in established offices. A backbone wired network is still required and is connected to a server. The wireless network is then split up into a number of cells, each serviced by or Access Point (AP) which acts as a controller for the cell. Each Access Point may have a range of between 30 and 300 metres dependent upon the environment and the location of the Access Point.

(ii) Ad-hoc networks These are formed when a number of computers and peripherals are brought together. They may be needed when several people come together and need to share data or if they need to access a shared printer without the need for having to use wire connections. In this situation the users only communicate with each other and not with a larger wired network. As a result there is no Access Point and special algorithms within the protocols are used to enable one of the peripherals to take over the role of master to control the network with the others acting as slaves.

(f) Wi-Fi Hotspots One of the advantages of using Wi-Fi IEEE 802.11 is that it is possible to connect to the Internet when out and about. Public Wi-Fi access is everywhere - in cafes, hotels, airports, and many other places. This hotspot functionality allows limited mobility for the users of the network facilitating their tasks. *It is this hotspot mobility feature that has been extensively exploited in the project to create a cloud of communication for the intended users of the network envisaged as part of the project.*

Standard	Frequency Band	Bandwidth	Modulation Scheme	Channel Arch.	Maximum Data Rate	Range
802.11	2.4 GHz	20 MHz	BPSK to 256-QAM	DSSS, FHSS	2 Mbps	20 m
b	2.4 GHz	21 MHz	BPSK to 256-QAM	CCK, DSSS	11 Mbps	35 m
a	5 GHz	22 MHz	BPSK to 256-QAM	OFDM	54 Mbps	35 m
g	2.4 GHz	23 MHz	BPSK to 256-QAM	DSSS, OFDM	54 Mbps	70 m
n	2.4 GHz, 5 GHz	24 MHz and 40 MHz	BPSK to 256-QAM	OFDM	600 Mbps	70 m
ah	900 MHz	1, 2, 4, 8, and 16 MHz	BPSK to 256-QAM	SC, OFDM	40 Mbps	1 km

Figure 2.14: WiFi Variants

CHAPTER 3

PROVIDING COMMUNICATION IN AREAS OF DEAD GROUND WITH COMMUNICATION INFRASTRUCTURE IN NEAR VICINITY (SCENARIO 1)

3.1 Modules

3.1.1 WiFi Router

For the purpose of the experimental setup, we will be using **D-Link DIR-615 Wireless N-300 Router**. The detailed specifications of the router are further listed in the subsequent paragraphs. Any programmable wireless router broadly meeting these specifications can be used for the setup.

The technical specifications of **D-Link DIR-615 Wireless N-300 Router** are as follows:-

(a) DIR615FrontView.

(b) DIR615RearView.

S.No.	Details
1	Ports Four 10/100 LAN ports • One 10/100 WAN (Internet) port
2	Antenna 5 dBi External Antenna
3	Standards IEEE 802.11n/g/b • IEEE 802.3 • IEEE 802.3u • IEEE 802.3x
4	Advanced Features Web Setup Wizard • UPnP support • Active Firewall - Network Address Translation (NAT) • Repeater Mode
5	LEDs Power LED
6	Security WPA and WPA2 (Wi-Fi Protected Access) Wi-Fi Protected Setup (WPS) - PIN
7	Minimum System Requirements Windows 7/Vista/XP SP3, or Mac OS X 10.4 or higher • Microsoft Internet Explorer 6 or higher, Firefox 1.5 or higher or other Java-enabled browser • Network Interface Card • Cable or DSL Modem • Subscription with an Internet Service Provider
8	Weight 249 grams (8.78 ounces)
9	Dimensions (L x W x H) 175 x 150 x 31 mm (6.89 x 5.9 x 1.22 inches)
10	Temperature Operating: 0 to 40 degreeC (32 to 104 degreeF) • Storage: -20 to 65 degreeC (-4 to 149 degreeF)
11	Power Input: 100 to 240 V AC, 50/60 Hz
12	Consumption: 12 V 0.5 A

Table 3.1: Wireless Router Specifications

3.1.2 Internet 4G Dongle (Hotspot)

For the purpose of the experimental setup, we will be using `Jio 4G Dongle (Hotspot)`.The detailed specifications of this are further listed in the subsequent paragraph. Any programmable Internet 4G Dongle (Hotspot) broadly meeting these specifications can be used for the setup.

The technical specifications of Jio Internet 4G Dongle (Hotspot) are as follows:-

S.No.	Details
1	Model JMR 540
2	No of Devices supported Recommended 10 via WiFi , 1 via USB Tethering
3	External Interface MicroSD MicroUSB Port NanoSIM
4	Standards WAN: LTE (2300/1800/850 MHz)IEEE 802.11 b/g/n 2.4G only
5	Dimensions 96.6 X 65.2 X 15 mm
6	PowerInput: 100 to 240 V AC, 50/60 Hz
7	Battery Capacity 2600 mAH

Jio Internet 4G Dongle (Hotspot) Specifications

Figure 3.2: Jio 4G Dongle.

3.1.3 Power Supply

For the purpose of the experimental setup, we will be using `3 Cells,12V, 1300mAh battery`.

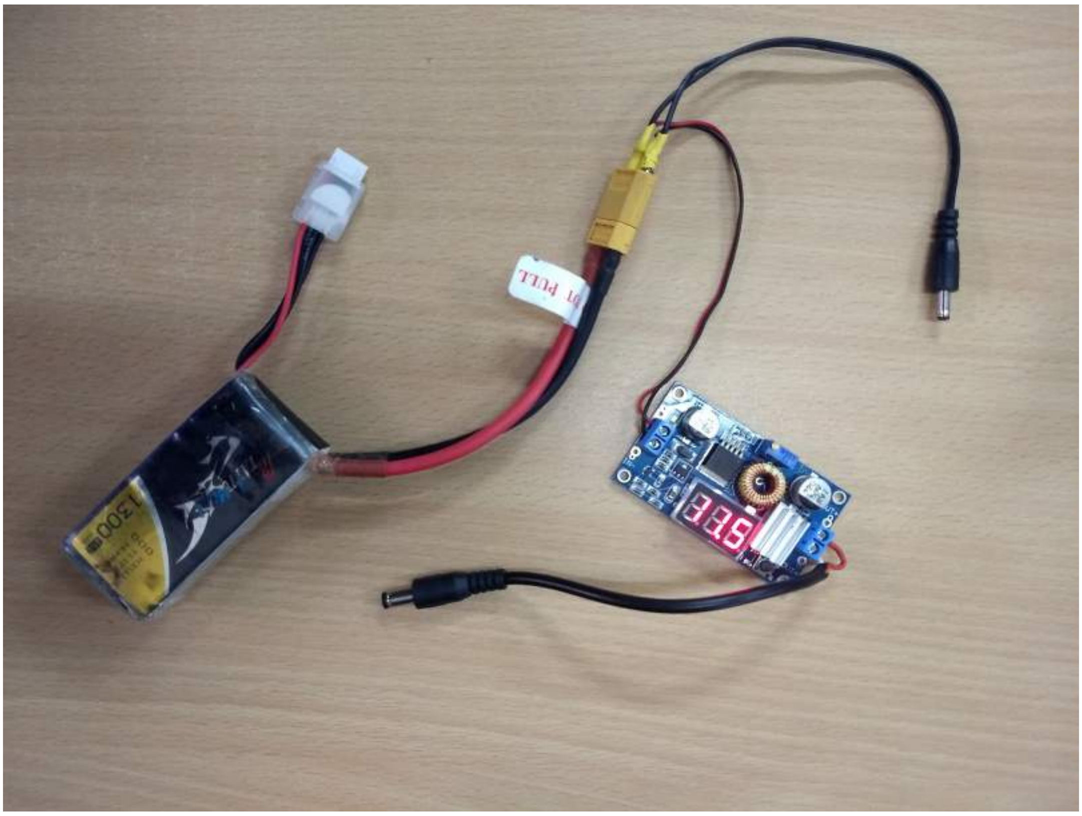

Figure 3.3: Power Supply SetUp.

3.2 Experimental Set Up For Experiment 1A (Without Using Drone)

The procedure to program specific experimental settings to execute the extension of Hotspot (Jio 4G Dongle) signals over to Wireless Router (D-Link DIR-615 Wireless N Router) involves the following steps:-

3.2.1 Setting Up Internet Dongle

Setting Up the Hotspot (Jio 4G Dongle) involves opening Jio login page via link “http://jiofi.local.html”.Enable UpnP in network settings. Keep a note of device IP address.

3.2.2 Setting Up WiFi Router

Step 1. Upgrade the software of the D-Link router after log-in.

Step 2. Setting Up the D-Link router involves opening the network configuration page of D-Link router using its default IP address. Then, go to the “Wireless” settings. Change the SSID and pre-shared key (if desired) at this point of time. Further, go to the “Wireless Repeater” settings and do the following :-

Step i. Enable the repeater "enable" option.

Step ii. Click on the site survey icon.

Step iii. Select the “Jio-Fi” option from the list of available Wi-Fi signals and click the “Next” icon.

Step iv. Enter the Jio device password and click “Next” icon.

Step v. Change the IP address of D-Link router to an IP address which is not same as the IP address of Jio-Fi dongle, however, in the same range, viz, 192.168.220.150 (Jio-Fi IP address) then set it as 192.168.220.152 (D-Link IP address).

Step vi. Click “Finish”and the system will then reboot in around 35 seconds duration.

Step 3. Once the system reboots, it is ready to be used as a repeater station and will extend the signals of Jio-Fi.

Step 4. Download and install android mobile phone application namely Network Info Cell Lite in your Android handset. The same will be used to measure the strength of signal at various distances as we move in the area of coverage of the wireless router.

Step 5. Connect any device (eg mobile phone) to the D-Link router and it can access internet connection of the Jio-Fi dongle beyond its regular range of 10-12 mts due to the Wireless router acting as its repeater to extend the range much beyond.

3.3 Experimental Set Up For Experiment 1B (Using Drone)

It includes the procedure wherein the setup of the Experiment No 1A is mounted on a drone and the similar experiment as Experiment No 1A is carried out while drone is hovering over an area to execute the extension of Hotspot (Jio 4G Dongle) signals over to Wireless Router (D-Link DIR-615 Wireless N Router).

The flight/hovering of drone though forms an important part of the setup , however will not be analysed for its control/manouvre as part of this experiment.

3.4 Experiment 1A/1B

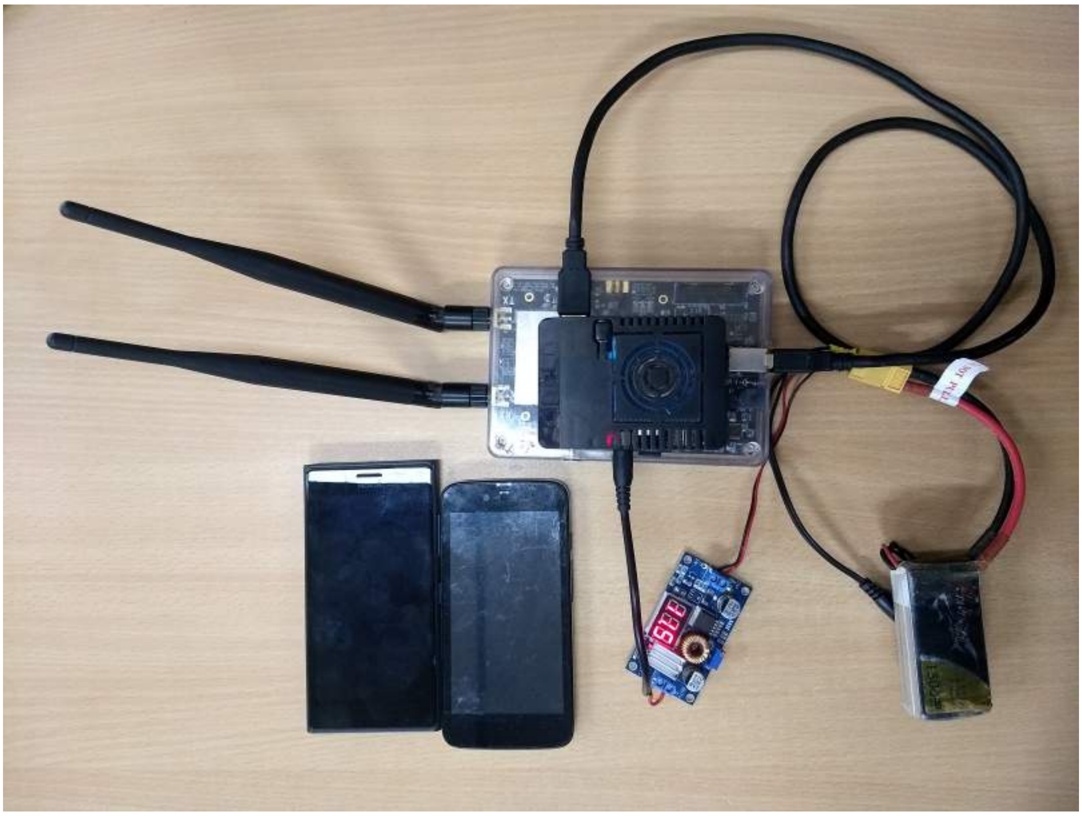

Figure 3.4: Experiment 1 SetUp.

(a) Once the handset is connected to the router which in turn has wireless connectivity with the 4G internet dongle, start moving the handset away from the router and note reading of the Wifi signal in the Network Info Cell Lite application (downloaded earlier in the handset) at regular intervals and observe the change in the values.

(b) Download applications `Server` or `Intercom` for Android to make voice comn with other users in the network or else use applications like `WatsApp`, `Google Duo` or `Viber` for making voice, video and data calls with other users in your network or outside. Using the WiFi cloud which has further got backward connectivity on cellular backbone (using hotspot), voice, video and data calls can be made with anyone on internet. Even if cellular backbone connectivity is out, internet calls can still be made.

CHAPTER 4

PERFORMANCE ANALYSIS

4.1 General

This section deals with the on-ground deployment of the communication prototype that has been integrated using different modules for both categories of the experiment as explained in Chapters III and IV above and carrying out capturing and analysis of its output performance under various heads which give a measure of its utility and validates its applicability for the objective it has been designed for.

Both these experimental deployments as described further in subsequent paragraphs are the two prime use cases that have been envisaged to enable provision of a communication grid to military or other service personnel (including NDRF), operating in diverse terrains and conditions devoid of immediate communication, so as to enable them to carry out their intended tasks unencumbered.

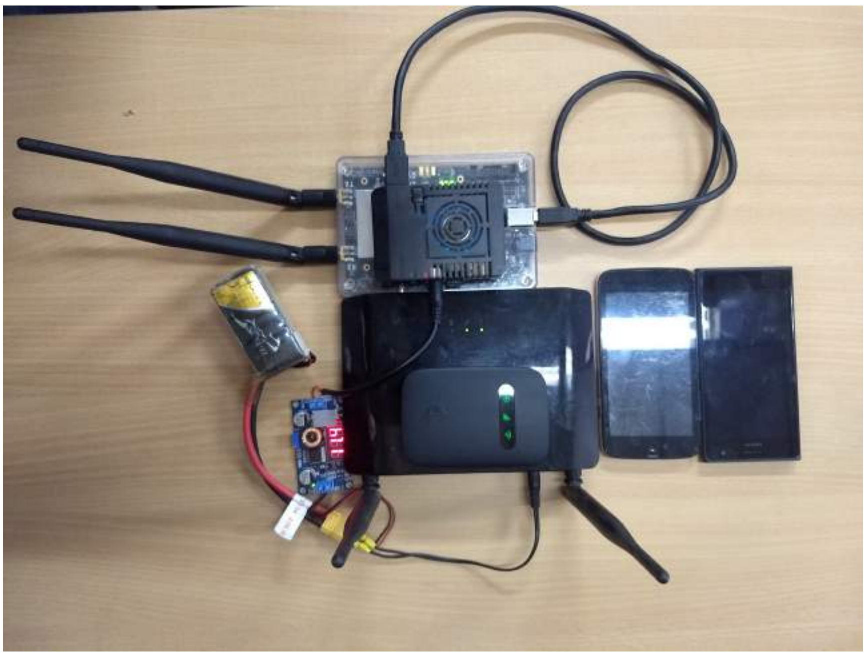

Figure 4.1: Final Lab SetUp.

Figure 4.2: Drone SetUp.

4.2 Performance metrics

The experimental setups were made operational and deployed in open fields in the campus to gauge its performance for **Experiment 1A/1B: Providing Communication in Areas of Dead Ground With Communication Infrastructure in Near Vicinity (SCENARIO 1)**

(a) **Maximum Range** (LOS distance of the User Equipment (Mobile handsets) from the transmitter) **in metres**.

(b) **Signal Strength of the Transmitter** (which was kept at its maximum of 20dBm (High mode) to obtain maximum range in) **in dBm**.

(c) **RSSI(Received Signal Strength Indicator)** (at periodic distances from the transmitter) **in dBm**.

(d) **Link Speed** (at periodic distances from the transmitter) **in Mbps**.

4.3 Performance Metrics Explained

4.3.1 Range

It refers to the maximum straight line LOS distance (in metre) between the transmitter and the UE for the established call to remain intelligible and without interruption.

4.3.2 Signal Strength of the Transmitter

The power of the transmitter (**D-Link DIR-615 Wireless N-300 Router** and **Nuand BladeRF x40**) has been set to their maximum permitted value for the experiment and are transmitting at 20dBm and 6 dBm respectively. Therefore this metric remains constant for both experiments.

4.3.3 RSSI (Received Signal Strength Indicator in dBm)

RSSI is a measurement of the power present in a received radio signal.It is usually invisible to a user of a receiving device.However, because signal strength can vary greatly and affect functionality in wireless networking, devices often make this measurement available to users.

4.3.4 Link Speed

It measures the quality of the link through the rate of data exchange between the transmitter and the UE .

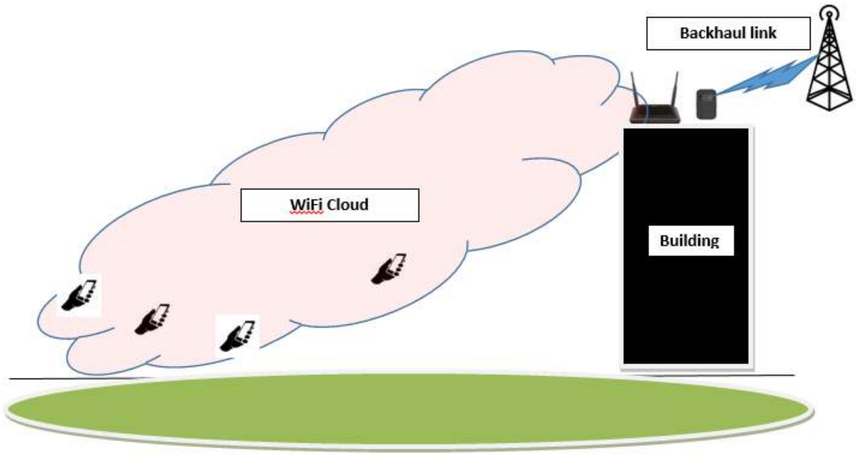

Figure 4.3: Concept For Experiment 1A.

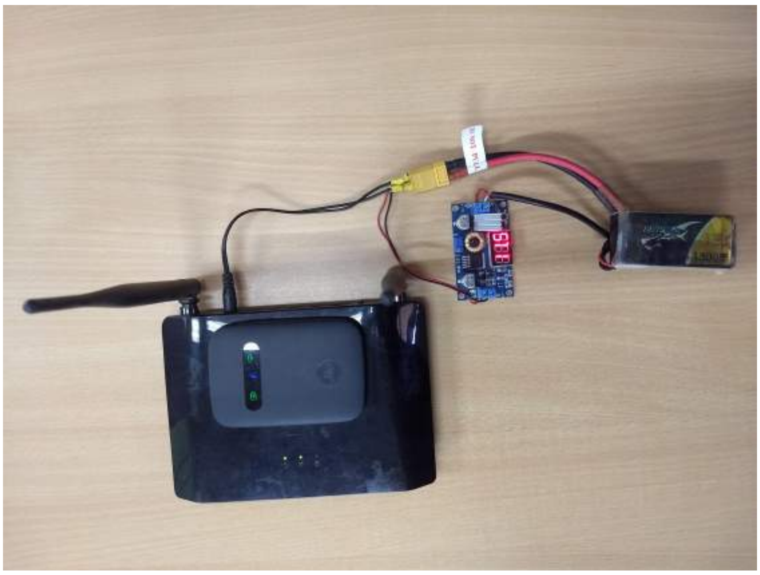

Figure 4.4: SetUp For Experiment 1A.

4.4 EXPERIMENT 1A: PROVIDING COMMUNICATION IN AREAS OF DEAD GROUND WITH COMMUNICATION INFRASTRUCTURE IN NEAR VICINITY USING STATIC PLATFORM (SCENARIO 1)

4.4.1 General

The setup for this experiment, as explained in paragraph 3.2 above, was initially established at the roof top of Engineering Design (ED) Department building in one corner overlooking the “Chemplast cricket grounds” and subsequently on the roof top of

Biotechnology Department Building overlooking the fields of Hockey, Football and Cricket grounds. This provided a clear view and LOS for the measurements to be carried out. The setup is as illustrated below followed by pictures of the site/setup to appreciate the general layout.

4.4.2 Experimental Readings

The experimental reading of **Experiment 1A** are as follows:-

S.No.	**Details**	**Readings**
1	Date	29 Apr 2019
2	TOD	0700-1000h
3	Temp	32 Degree C
4	Duration	3 hours
5	General Location	Biotechnology Building Roof top and Hockey, Football and Cricket grounds
6	Tramsmitter Signal Strength	20dBm

Table 4.1: Experiment 1A

S.No.	**Loc of Spot**	**Distance**	**RSSI (dBm)**	**Link Speed (Mbps)**	**Call Quality (MOS 1-5)**
1	Roof Top	1	-26	6	5
2	Football Field Near Goal Line	50	-65	5	5
3	Football Field Near Goal Line(+10m)	60	-72	5	5
4	Football Field Near Goal Line(+10m)	70	-78	5	3
5	Football Field Near Goal Line(+10m)	80	-80	3	3
6	Football Field Near Half Line	90	-102	1	2
7	Football Field Beyond Half Line	100	No Signal	-	-

Table 4.2: Measurements of Experiment 1A

4.5 EXPERIMENT 1B: PROVIDING COMMUNICATION IN AREAS OF DEAD GROUND WITH COMMUNICATION INFRASTRUCTURE IN NEAR VICINITY USING DRONE PLATFORM (SCENARIO 1)

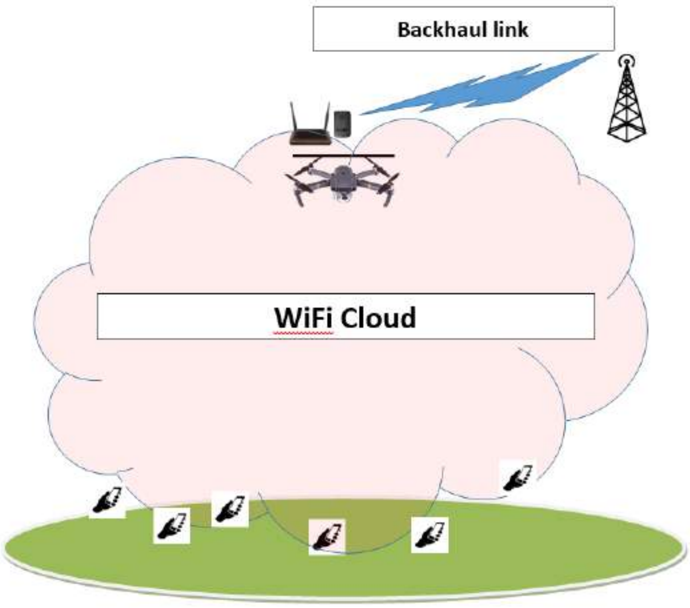

Figure 4.5: Concept For Experiment 1B.

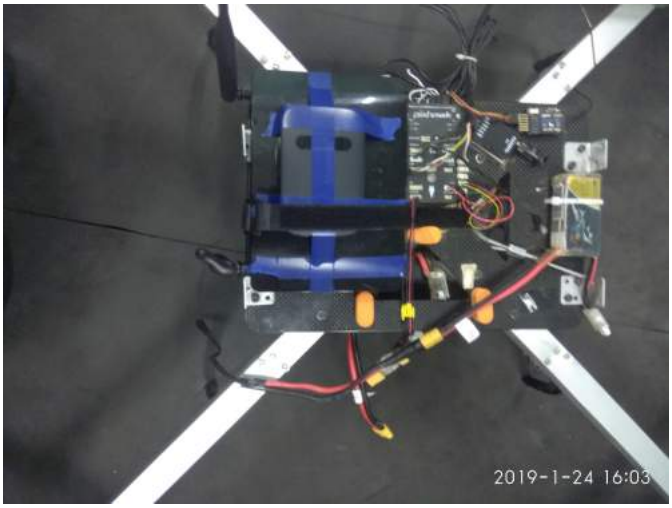

Figure 4.6: SetUp For Experiment 1B.

4.5.1 General

The setup for this experiment, as explained in paragraph 3.2 above, was initially established at Chemplast cricket grounds and the Football ground and subsequently on the roof top of Biotechnology Department Building overlooking the fields of Hockey, Football and Cricket grounds. This provided a clear view and LOS for the measurements to be carried out. The setup is as illustrated below followed by pictures of the site/setup to appreciate the general layout.

4.5.2 Experimental Readings

The experimental reading of **Experimant 1B** are as follows:-

S.No.	**Details**	**Readings**
1	Date	30 Apr 2019
2	TOD	0700-1000h
3	Temp	31 Degree C
4	Duration	3 hours
5	General Location	Biotechnology Building Roof top and Hockey, Football and Cricket grounds
6	Tramsmitter Signal Strength	20dBm

Table 4.3: Experiment 1B

Key Notes Experiment 1A & 1B

(a) The Wifi signal deteriorated faster beyond a certain distance (here close to Football Field half Line) but until there the quality of VOIP call was reasonable. Beyond the half line the signal just disappeared.

(b) The experimental readings tabled above are the most recent ones that were taken.

(c) The readings on each spot are actually an average of minimum 3 readings taken in and around that spot.

(d) A number of such like experiments were done for taking down the readings and those are generally in the same range with minor variations.

S.No.	Loc of Spot	Distance	RSSI (dBm)	Link Speed (Mbps)	Call Quality (MOS 1-5)
1	Roof Top	1	-27	6	5
2	Football Field Near Goal Line	50	-68	5	5
3	Football Field Near Goal Line(+10m)	74	-72	4	4
4	Football Field Near Goal Line(+10m)	81	-78	4	3
5	Football Field Near Goal Line(+10m)	87	-80	3	2
6	Football Field Near Half Line	90	-103	1	1
7	Football Field Beyond Half Line	100	No Signal	-	-

Table 4.4: Measurements of Experiment 1B

CHAPTER 5

CONCLUSION

1 The setup envisaged, prototyped and demonstrated as part of the project **A DRONE-BASED COMMUNICATION SYSTEM FOR STRATEGIC AND PPDR APPLICATION** is the first step towards finding a working solution for addressing the critical requirement of robust and reliable communication for the forces responding to a mission-critical and time-critical task of tactical or humanitarian interest.

2 A sound, robust and adaptable communication grid is the mainstay for any operating forces in any kind of operation; failing which the intended results are not commensurate to the efforts. Therefore such systems which address this core need must be given due consideration and further evolved. It is imperative that repeated trials of the system be carried out to understand and address its shortcomings and transform it into a fool-proof system.

3 In the project report and demonstration only limited capabilities have been showcased, however with proper industry involvement and backing, a more useful and value-added system can be commercially developed, to meet domain specific needs, incorporating many additional features of scaling in capacity and quality, HD video and audio capturing, enhanced VOIP capabilities, encryption and self-destruct mechanisms.

4 There are certain limitations with the present setup as it is a base-model architecture at the cheapest cost available viz

(a) The present GSM software engine YateBTS only supports two concurrent calls ie four users, although more number of users can still be connected to avail SMS service.

(b) The present battery pack provides limited power to handle the two experimental setups and therefore is a limiting factor.

(c) A tether-less drone also has a limited flying time which affects the system and its range, however a tethered drone does not have this problem and can extend the operational time although it suffers from mobility issues.

(d) The limited power output of the SDR and the router coupled with omnidirectional antennas limit the range which can be overcome by using a power amplifier and more directive antennas depending on the requirement.

5 The issues mentioned in paragraphs above need to be tackled systematically by the industry partner involved in developing a more effective and useful communication system that will come in handy to the operating forces and meet their specific requirements without compromising on qualitative issues.

6 Aerial platforms based systems have tremendous advantages over static platforms especially on grounds of mobility and portability. Drones are the next generation platforms to be used for all kinds of services viz transport, delivery, weapons, medical, communication etc and therefore need to be suitably developed to force-multiply the service it needs to cater to. A stable platform makes a huge impact on the quality of service and therefore is equally important.

6.7 A sound communication grid will enable the respective forces operating on ground, be it military or non-military, to meet their intended objective in a more coordinated manner and in a shorter time-frame. In most emergency situations it can prove to be critical in minimizing the casualties of men and material alongside collateral damage. Therefore such communication systems need to be given due significance towards further and holistic development.

APPENDIX A

WEIGHTS OF VARIOUS HARDWARE USED IN THE PROJECT

(a) JioFi Dongle 100gms.

(b) D-Link DIR 615 Router 210gms.

(c) ODROID-XU4 90gms.

(d) BladeRF 270gms.

(e) Battery Eliminator Circuit 42 gms.

(f) Bty (1300mAH) 125gms.

(g) Bty (6200mAH) 430gms.

APPENDIX B

PAPER SUBMITTED FOR TENCON 2019

IMPLEMENTATION OF A DRONE-BASED COMMUNICATION SYSTEM FOR STRATEGIC AND PPDR APPLICATIONS

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Abstract—**Our military forces, during operations are deployed in some places devoid of any communication which affects their efficiency on ground due to inadequate coordination means. Also, many unforeseen emergency situations (viz natural calamities, train accidents, forest fires or any large scale public congregation) warrant immediate action by first responders (Public Protection and Disaster Relief-PPDR or Military personnel) to bring the situation under control to prevent any further loss of life or material. During such occasions, there is a sudden increase in cellular traffic leading to its eventual choking/breakdown of system. This paper proposes to offer a temporary, easy and fast-to-setup GSM and Wi-fi based communication system that addresses this communication void to allow our forces (PPDR or Military) to carry out their intended tasks efficiently amidst a broken/no communication infrastructure in place.**

I. Introduction

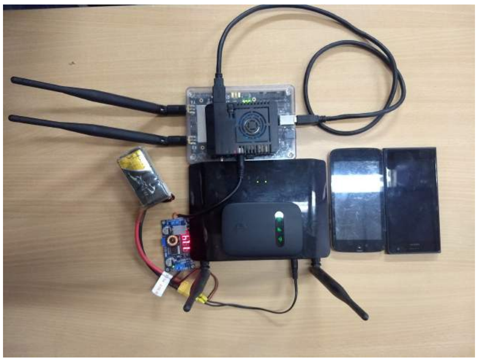

Fig. 1: Light-Weight SDR based Basestation.

In this work, we have demonstrated how Drones (Unmanned Aerial Vehicle) can create an ad-hoc communication support system that can be quickly deployed in inaccessible areas. These areas can be ones which are, although, near well-established communication infrastructure but due to **dead zone deployment of forces** (wherein either their transmitter or receiver or both are so placed that they lack either forward or backward connectivity or in many cases both of them) lacks adequate connectivity from it or are areas that lack communication infrastructure altogether.

Fig. 2: Drone D-Point0 (Audaxus) Wingspan-2m.

In the first scenario, we have an area of operation of forces in dead ground where communication is to be provided using the existing communication infrastructure from a nearby area. **In the second scenario**, communication is to be provided in a remote, isolated area where no communication exists in near vicinity.The additional **provision of spectrum sensing**, incorporated in the system, to detect free frequency bands to establish interference-free communication for our setup also serves an additional strategic advantage of detecting occupied frequency bands as a measure of electronic surveillance/sensing of enemy forces.

This proposed setup has **applications outside the military strategic domain** also, especially in areas affected by natural or man-made calamities where the communication infrastructure has been damaged. It can be suitably adapted to be used by disaster response forces to operate for their coordination of **Personnel Protection and Disaster Relief (PPDR)** tasks.

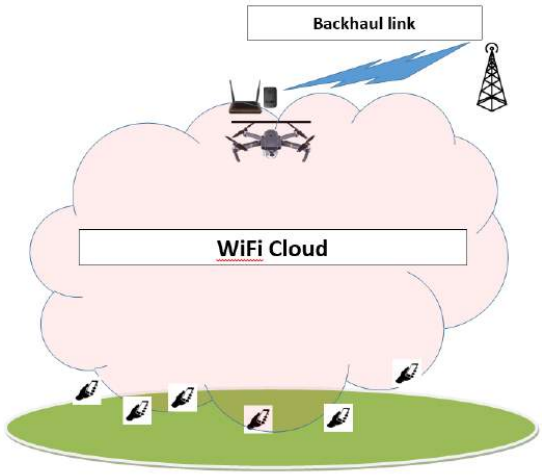

Fig. 3: SCENARIO 1.

II. SCENARIO 1: PROVIDING COMMUNICATION IN AREAS OF DEAD GROUND WITH COMMUNICATION INFRASTRUCTURE IN NEAR VICINITY

A. Modules

For the purpose of the experimental setup, we will be using the following:-

- i `D-Link DIR-615 Wireless N-300 Router`,(any programmable wireless router with similar specifications can also be used for the setup.
- ii `Jio 4G Dongle (Hotspot)`.
- iii `3 Cells,12V, 1300mAh battery`.

B. Set Up For Experiment 1A (Without Using Drone)

The procedure to program specific experimental settings to execute the extension of Hotspot (Jio 4G Dongle) signals over to Wireless Router (D-Link DIR-615 Wireless N Router) involves the following steps:-

- Step 1 Upgrade the software of the D-Link router after log-in.
- Step 2 Setting Up the Hotspot (Jio 4G Dongle) involves opening Jio login page via link "http://jiofi.local.html". Enable UpnP in network settings. Keep a note of device IP address.
- Step 3 Setting Up the D-Link router involves opening the network configuration page of D-Link router using its default IP address.Then ,go to the "Wireless" settings.Change the SSID and pre-shared key (if desired) at this point of time. Further, go to the "Wireless Repeater" settings and do the following :-
  - i Enable the repeater "enable" option.
  - ii Click on the site survey icon.
  - iii Select the "Jio-Fi" option from the list of available Wi-Fi signals and click the "Next" icon.
  - iv Enter the Jio device password and click "Next" icon.
  - v Change the IP address of D-Link router to an IP address which is not same as the IP address of Jio-Fi dongle ,however, in the same range, viz, 192.168.220.150 (Jio-Fi IP address) then set it as 192.168.220.152 (D-Link IP address).
  - vi Click "Finish".System will then reboot in around 35 seconds duration.
- Step 4 Once the system reboots, it is ready to be used as a repeater station and will extend the signals of Jio-Fi.
- Step 5 Download and install android mobile phone application namely Network Info II in your Android handset. The same will be used to check the strength of signal at various distances as we move in the area of coverage of the wireless router.
- Step 6 Connect any device (eg mobile phone) to the D-Link router and it can access internet connection of the Jio-Fi dongle beyond its regular range of 10-12 mts due to the Wireless router acting as its repeater to extend the range much beyond.

C. Set Up For Experiment 1B (Using Drone)

It includes the procedure wherein the setup of the Experiment No 1A is mounted on a drone and the similar experiment as Experiment No 1A is carried out while drone is hovering over an area to execute the extension of Hotspot (Jio 4G Dongle) signals over to Wireless Router (D-Link DIR-615 Wireless N Router).

The flight/hovering of drone though forms an important part of the setup , however the piloting aspects will not be covered in this report.

D. Experiment 1B

Once the handset is connected to the router which in turn has wireless connectivity with the 4G internet dongle, start moving the handset away from the router and note reading of the Wifi signal in the measurement app (Network Info II / Network Info cell Lite application - downloaded in the handset) at regular intervals and observe the change in the values.

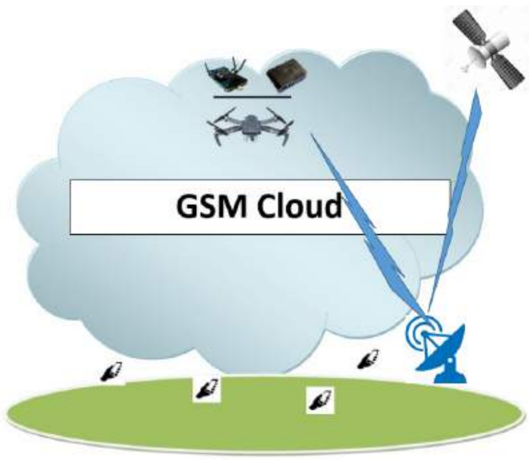

Fig. 4: SCENARIO 2.

III. SCENARIO 2: PROVIDING COMMUNICATION IN AREAS WITH NO COMMUNICATION INFRASTRUCTURE IN NEAR VICINITY

A. Modules

For the purpose of the experimental setup, we will be using

- i BladeRF is an affordable USB 3.0 Software-Defined Radio platform. For the experimental setup, we use `BladeRFx40`.
- ii We use `ODROID XU4` which is an Single Board Computer (SBC).
- iii A `Sony 32 GB,Class 10`SD card is used. Any SD card meeting these specifications can be used for the setup.
- iv We use `Zebronics ZEB-201CR` card reader.
- v `3 Cells,12V, 1300mAh battery`.

B. Set Up For Experiment 2A (In Lab)

The procedure to program specific experimental settings to execute the extension of GSM network signals and involves the following steps:- **Setting Up Odroid XU4** To set up the Odroid system, we need to do the following steps:-

- Step 1 Go to https://wiki.odroid.com/odroid-xu4/os_images/linux/ubuntu_4.14/ubuntu_4.14 and further download the operating system image for XU4 from https://odroid.in/ubuntu_18.04lts/XU3_XU4_MC1_HC1_HC2/ onto any desktop/laptop.
- Step 2 Download `Balena Etcher` software on to desktop/laptop for flashing the above downloaded OS image on to a card sd card.
- Step 3 Insert an SD card to the desktop/laptop using the card reader and run the Balena etcher sofware for flashing the OS image ontothe SD card.
- Step 4 Unmount the flashed SDcard from the system and insert it to the SD card slot of the Odroid XU4 system.
- Step 5 Boot Up the system and update the system.

C. Setting Up BladeRF

To set up the BladeRF for Yate and YateBTS , we need the following commands:-

```
sudo apt update
sudo apt upgrade
sudo apt install git
sudo apt apache2
sudo apt php
sudo apt install bladerf
sudo apt bladerf-firmware-fx3
sudo apt bladerf-fpga-hostedx40
sudo apt libbladerf1
sudo apt automake
sudo apt libbladerf-dev
#sudo bladeRF-cli -i
sudo apt install subversion
sudo apt autoconf
sudo apt libusb-1.0-0-dev
sudo apt libgsm1-dev
sudo apt install g++ gcc
sudo apt install make

cd /usr/src/;then
sudo svn checkout http://
voip.null.ro/svn/yate/trunk yate
cd /usr/src/yate/;then
sudo svn up
sudo ./autogen.sh
sudo ./configure
sudo make -j4
sudo make install-noapi
sudo ldconfig

cd /usr/src/;then
sudo svn checkout http://
voip.null.ro/svn/yatebts/trunk yatebts
cd /usr/src/yatebts;then
sudo svn up
sudo ./autogen.sh
sudo ./configure
sudo make install
sudo ldconfig

cd /var/www/html/;then
sudo ln -s /usr/local/share/
yate/nipc_web nipc
sudo chmod -R a+w /usr/local/etc/yate/
```

Give executable permissions to /usr/src/yate and /usr/src/yatebts. Then, restart the system.

D. Setting Up Parameters For Yate and YateBTS

To set up the Yate and YateBTS parameter,connect the bladeRF to the Odroid system using USB3.0 cable on to the USB 3.0 port of Odroid XU4.Further we need to do the following steps:-
Open the file `usrlocal/etc/yate/ybts.conf` and set the following parameters:

```
Radio.Band=900
Radio.C0=91
Identity.MCC=001
Identity.MNC=01
Radio.PowerManager.MaxAttenDB=10
Radio.PowerManager.MinAttenDB=0
MinimumRxRSSI=-105
Radio.RSSITarget=-26
```

Open the file `usrlocal/etc/yate/ybts.conf` and set the following parameters:

```
country_code=91
regexp=.*
```

Connecting the Mobile Handsets To The Network
To connect the mobile handsets to the network, we need to do the following steps:-
Open the terminal and run the command `sudo yate -s`.This will start the yateBTS and it will create a GSM network. Open the network setting of the mobile handset and change the automatic selection of the network to manual.It will show the list of the avialable networks.Select the network of the YateBTS. Once done the mobile will get registered on the network and an SMS will be received on the mobile giving the new registered mobile number. This number can then be used for calling or forwading SMS to other mobile numbers in the same network.

E. Set Up For Experiment 2B (Using Drone)

It includes the procedure wherein the setup of the Experiment No 2A is mounted on a drone and the communication is setup while drone is hovering over an area to execute the extension of GSM network signals.

F. Experiment 2B

Once the handset is connected to the GSM network, start moving the handset away from the YateBTS and note reading of the parameters such as RSSI, ASU, Power in the measurement app (Network Info II / Network Info cell Lite application - downloaded earlier in the handset) at regular intervals and observe the change in the values.

IV. PERFORMANCE ANALYSIS

This section deals with the on-ground deployment of the communication prototype that has been put together using different modules for both categories of the experiment as explained in previous sections.The goal is to estimate the range at which the system performs satisfactorily.

A. MEASUREMENT OF EXPERIMENTS 1B AND 2B

TABLE I: PROVIDING COMMUNICATION IN AREAS WITH NO COMMUNICATION INFRASTRUCTURE IN NEAR VICINITY USING A STATIC/-DRONE PLATFORM

Location	Distance(m)	RSSI(dBm)	ASU
1	135	-91	11
2	143	-95	9
3	164	-99	7
4	187	-101	7
5	193	-103	5

Under the following system parameters, ie
Frequency = 900 MHz,
Breakpoint Distance = 1 m,
We calculate the value of Path Loss exponent, through Least Squares Method, to be **n = 4.2**

B. LINK BUDGET

Keeping the above parameters under consideration ie
Transmit Frequency = 900 MHz,
Breakpoint distance= 1 m,
Transmit Power = 6 dBm,
GSM Mobile Receiver Sensitivity = -103 dBm
The link budget equation comes out as :
Pr = P(do) - 10n log(d)
Pr = -5 - 42 log(d)

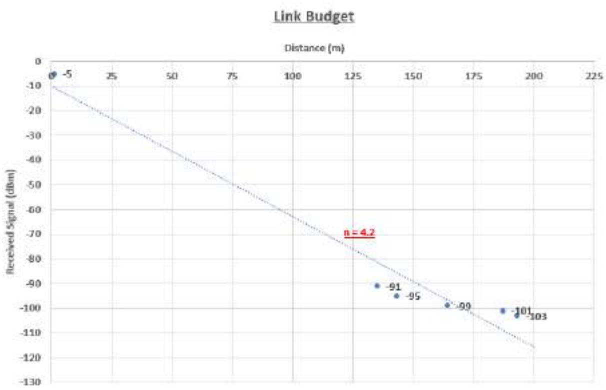

Fig. 5: Link Budget Graph.

Although the **Critical Distance** for the deployment of the setup (Transmitter Height Ht = 25m, Receiver Height Hr = 1m , Wavelength = 0.3) comes out to be 300m; however our field measurements as shown in

Table I above indicate that the signal power falls off proportional to fourth power of distance even within this span most likely due to ground reflections which have a considerate effect.

V. Conclusion

The setup envisaged, prototyped and demonstrated as part of the project **A DRONE-BASED COMMUNICATION SYSTEM FOR STRATEGIC AND PPDR APPLICATIONS** is the first step towards finding a working solution for addressing the critical requirement of robust and reliable communication for the forces responding to a mission-critical and time-critical task of tactical or humanitarian interest. A sound, robust and adaptable communication grid is the mainstay for any operating forces in any kind of operation; failing which the intended results are not commensurate to the efforts. Therefore such systems which address this core need must be given due consideration and devloped further. It is imperative that repeated trials of the system be carried out to understand and address its shortcomings and transform it into a fool-proof system. In this paper the concept and demonstration of functionality have been showcased. However with industry involvement,a more useful and value-added system can be commercially developed, to meet domain specific needs, incorporating many additional features of scaling in capacity and quality, HD video and audio capturing, enhanced VOIP capabilities, encryption and self-destruct mechanisms. There are certain limitations, as follows, with the present setup as it is a base-model architecture at the cheapest cost available.

(a) The present GSM software engine YateBTS only supports two concurrent calls ie four callers, although more number of users can still be connected to send SMS.

(b) The present battery pack provides limited power to handle the two experimental setups and therefore is a limiting factor.

(c) A tether-less drone also has a limited flying time which affects the system and its range, however a tethered drone does not have this problem and can extend the operational time although it suffers from mobility issues.

(d) The limited power output of the SDR and the router coupled with omnidirectional antennas limit the range which can be overcome by using a power amplifier and more directive antennas depending on the requirement.

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References

[1] Yong Zeng, Rui Zeng, and Teng Joon Lim (National University of Singapore) *Wireless Communication with Unmanned Aerial Vehciles: Opportuinities and Challenges*, IEEE Communication Magzine.

[2] *Technical requirements for Mission Critical Broadband PPDR Communications*, APT report Document AWG15/OUT-09 dt 29 Aug 2013.

[3] *Next Generation PPDR Communication Networks*, TRAI Consultation paper dated 09 Oct 2017.

[4] *Next Generation PPDR Communication Networks*, TRAI Recommendations dated 04 Jun 2018.

[5] K.Guevara, M.Rodriguez, N.Gallo, G.Velasco, K.Vasudev, and I.Guvenc (Department of Electical and Computer Engineering, Flourida International University, Maimi, 10555 W Flagler Street,USA) *UAV-Based GSM Network for Public Safety Communications*, IEEE SoutheastCon 2015,Apr 9-12,2015-Fort Lauderdale,Flourida.

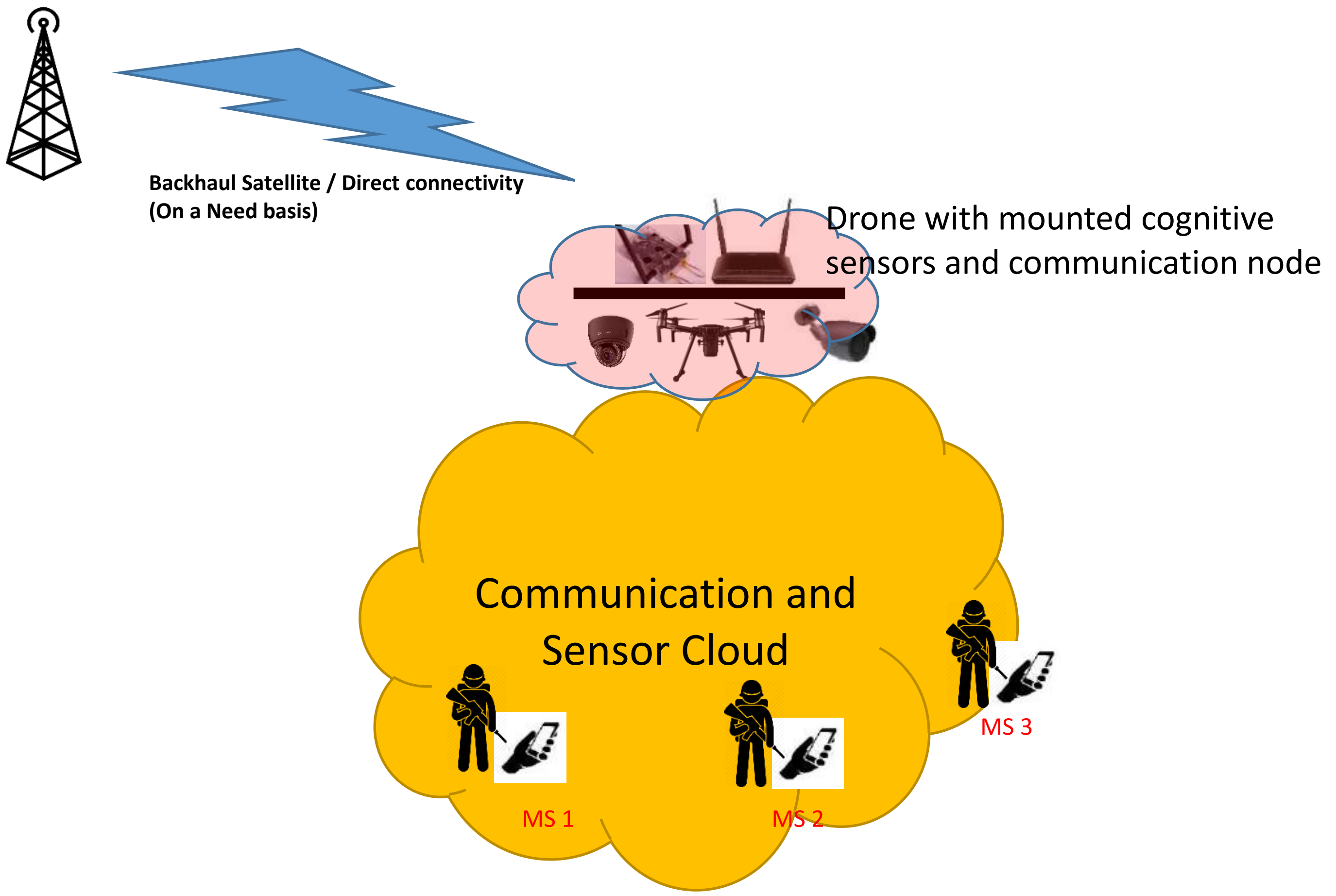
[6] Yeswanth Guddeti, Raghav Subbaraman (IIT Madras), Moein Aaron Schulman and Dinesh Bharadia (UC San Diego) *SweepSense : Sensing 5 GHZ in 5 Miliseconds with Low-Cost Radios*, IEEE SoutheastCon 2015,Apr 9-12,2015-Fort Lauderdale,Flourida.

APPENDIX C

PAPER SUBMITTED FOR DARE TO DREAM - DRDO INNOVATION CONTEST

EYES AND EARS IN THE SKY

DRONE BASED ADHOC COGNITIVE COMMUNICATION CUM SURVEILLANCE SYSTEM (ACCSS)



YOUR FIRST SHOT

1. **"To keep safe from the enemy, you need eyes and ears everywhere"**, this proposition forms the basis of this *Drone-based Adhoc Cognitive Communication cum Surveillance system (ACCSS)* called **"Eyes and Ears in the Sky"** that will enable real-time intelligent scanning of the radio spectrum to allow constant radio and visual monitoring of the objective area and alongside provide seamless connectivity within the patrolling party on ground to suitably react to a developing situation, based on the various sensor feeds received.

SUMMARY

2. Perimeter security through constant surveillance is of paramount importance in the current scenario of perpetual threat near the disputed borders. Remote monitoring needs to be supplemented with patrol teams positioned on ground to react appropriately to neutralize the detected threat.

3. A **cognitive radio-based spectrum sensor** and **visual sensors** in conjunction with a sound and robust communication connectivity is a requirement to interconnect these different elements that constitute such a surveillance grid connecting the sensors with the shooters. The cognitive radio incorporates a **Sense and Send mechanism** that carries out *Instantaneous sensing of spectrum and immediately uses the available white space (frequency spots without any ongoing communication) to establish the communication links* thereby preventing any interference at all.

4. Cognitive spectrum sensing, besides notifying white space, also allows monitoring of the existing radio spectrum in the intended area to intercept any un-friendly (**enemy**) communication operational in that area so as to zero on to these un-friendly elements through **radio and visual triangulation** (*using an Antenna Array on a single drone or multiple Drones or a single drone with multiple closely-timed measurements*) and subsequently neutralize them after thorough combing operations. Thus Cognitive sensing serves a **duality** of establishing own communication and also identifying enemy communication.

5. A flying drone with such a setup provides **real-time** requisite sensor feeds besides a bird's eye view of the intended area to the operating soldiers and also enables operationalizing a communication network between them to coordinate their actions and relay appropriate information to and from their immediate controlling Headquarter. This helps build situational awareness at all levels and enables better and faster decision making.

6. An aerial platform (flying drone) for mounting sensors along with a communication node provides numerous advantages as compared to a ground based setup, viz **enhanced connectivity**, **mobility** for the overall grid based on rolling ahead of operations, better **range** and **coverage** over its integral elements and **scalability** as per requirement of security personnel involved.

<u>WHAT YOU ARE</u>

7. We are serving officers in the telecom arm of the Indian Armed Forces (presently Post Graduate students at Electrical Department of IIT Madras) and we intend to come out with solutions and proposals to enhance the communication setup for all types of military operations to make them more robust, seamless, intelligent and sufficiently available to the last man on ground.

PLAN OF ACTION

8. An area of operation is chosen based on tactical interest and the drone is made airborne over that area from a nearby vantage point. This mobile aerial platform is mounted with cognitive spectrum-scanning Sensor (*based on* ***"SweepSense"[1] technology*** *that allows low cost, rapid Wide Band scanning of desired spectrum*) , Night Vision capable HD cameras and other allied sensors (*IR- Infra Red, Motion , Chemical based etc*) that detects **enemy signature** and passes on this live information along with coordinates to the patrolling team which starts zeroing on to this area to neutralize and sanitize the developing threat.

9. ***"SweepSense"*** *is a new cognitive spectrum sensing technology which is capable of carrying out low-cost, quick scanning of the wide spectrum to capture any burst of communication anywhere on it. It scans 5 GHz wide spectrum in about 5 milliseconds and takes nearly 200 RF spectrum "snapshots" per second allowing it to detect any use of spectrum in this wide range. It is currently the fastest scanning rate among all known methods. It can detect presence of a frequency hopped radio also.*

10. The **enemy signature** comprises the following:-

    (a) Detection of un-friendly communication on specific frequency spots as a result of comprehensive Wide Band radio scanning by Spectrum sensor gives out information about presence of elements other than own forces in the vicinity.

    (b) On-board Radio triangulation enables estimation of general direction and area of presence of enemy elements for the ground troops to pursue and zero on.

    (c) Visual feed provides real time bird's eye view of the intended area of action and help builds up situational awareness as the operation progresses.

    (d) Additional sensors like IR (Infra-Red), Motion etc will add value to the overall picture for the ground troops and the commander.

11. As the patrolling party moves on ground they connect on to the **communication cloud,** created on white space, by the drone and this provides inter-connectivity between all patrolling soldiers allowing them to coordinate their move and execute their plan besides access to the direct feed from the available mounted sensors on their handsets for updated situational awareness.

12. This communication network also allows the patrolling party leader to connect up and share information with their controlling Headquarter for further orders on the operation. The **backhaul relay link** can be established through a satellite link-up

with the Team leader or a direct terrestrial-link through the drone itself depending on the distance involved.

THE BENEFIT

13. The drone-based setup as elucidated above envisages the following operational advantages :-

    (a) Compact ready-to-use **field surveillance cum communication system** providing enemy radio signature and general location, visual and other allied sensor feeds besides establishing own communication network.
    (b) **Cognitive spectrum sensing** allows dual advantage of setting up communication grid on interference-free spots besides detecting any enemy communication activity.
    (c) Aerial platform (flying drone) provides **extended range and connectivity**.
    (d) An antenna array or network of such drones can enable leveraging the technology of **radio and visual triangulation** to zero on to enemy location besides extending the coverage range of the aforementioned services to a much larger area.
    (e) A backhaul link from the drone to an existing, distant communication grid via satellite or terrestrial link-up also extends the **connectivity with rear headquarters** to allow exchange of operational information with them.
    (f) Pre-programmed hand-sets with users allow faster setting up of the communication and sensor grid. These hand-sets are commercial off-the-shelf instruments used by everyone with limited low-key modification for intended use. This allows their easy availability on account of commonality with existing hand-sets available in the open market. .
    (g) **Inbuilt security** through hardware/software authentication allows only authorized user access to the communication network.
    (h) **Inbuilt encryption** mechanism supplemented with periodic encryption keys maintain secrecy of all communication and sensor links.
    (i) An on-board **self-destruct mechanism** with provision of remote triggering for user handset and Drone setup to render the device useless and unreadable in the event of the equipment being captured by the enemy or going out of reach.

WHAT YOU WOULD DO

14. The idea needs extensive work to take a commercial shape meeting all user requirements as listed above. After deliberate brainstorming on drawing board, a prototype (***drone-mounted adhoc communication setup is partially ready with the participant)*** needs to be developed to test the efficacy of the proposal under different test conditions affecting the flying of drone , load capability of sensors and communication node to establish a grid.

15. We also intend to work with Aeronautical lab of DRDO at Pune for testing the system using a tethered drone (to overcome the challenges of flying time limitation).

ANYTHING ELSE

1. **Demonstration of the system** to suitable agencies within Armed Forces to validate the concept will required to be carried out.

2. **Triangulation method** to be evaluated for performance with different array antennas and using multiple drones to validate.

3. An **established PSU will need to be roped in** to help develop the fully functional and ruggedized prototype.

4. The **encryption and self-destruct mechanisms** have to be developed in-house and need to be incorporated in available devices.

5. The **Self-Destruct mechanism** will involve the following and will either be remotely triggered in the event of the system likely to fall in enemy hands or time-activated in the event that it goes out of retrievable reach of our own forces:-

   (a) Permanently disable the Command and Control unit (which is used to control the drone).
   (b) Erase all on-board memory.
   (c) Erase all encryption-related information.
   (d) Physical destruction by some kind of on-board mini explosion that renders the system components irretrievable.

6. The **flying time** of small sized drones is a limitation but the size of the drone will affect its signature on the enemy radar and therefore needs to be enhanced through use of multiple drones or a better battery backup. A tethered drone will enable longer flying time but the size of it will notify its presence through a larger signature and also the issue about mobility of this tethered system along the axis of military operation building up will have to be tackled. Both variants (free flying and tethered will have to be tried to weigh their inter se advantages).

7. An option of **Drone to Drone Hand-off** can be worked on where a fully charged drone is launched which takes on the connectivity load of the air borne drone running low on battery thereby ensuring seamless continuity of communication. Another option would be to develop a system using a tethered drone ab-initio for a limited time and **convert it to a free flying drone** by snapping the cable as the need warrants. These options will be an attempt to overcome the limitation of flying time.

8. This very system, without military-specific modifications of encryption and secrecy, has strong application for **PPDR (Personnel Protection and Disaster Relief) services** to establish own spread out communication grid to coordinate their operations in the wake of a natural disaster when existing terrestrial communication breaks down. This robust grid can be life-critical in their rescue work.

<u>REFERENCES</u>

1. **"SweepSense : Sensing 5 GHz in 5 Milliseconds with Low-Cost Radios"** by Yeswanth Guddeti , Raghav Subbaraman†, Moein Khazraee , Aaron Schulman, and Dinesh Bharadia
   UC San Diego †IIT Madras

APPENDIX D

COMPARISON BETWEEN FIXED WING DRONE AND ROTARY QUADCOPTER

COMPARISON BETWEEN FIXED WING DRONE AND ROTARY QUADCOPTER

SNo	Comparision Parameter	Remarks
1.	**Hovering** By staying put in the air (means hovering),a quadcopter allows to take photographs or keep an electric eye out for trouble.	A quadcopter is better in this regard.
2.	**Take-Off** Quadcopters have an advantage over fixed-wing drones in that there's no wind-up to the pitch. Even small fixed-wing drones need, if not a runway, to be thrown by hand. And once in the air, if you want to inspect, say, a construction site or telephone pole, it's easier for a quadcopter to shoot upward. Fixed wing aircraft require a larger take off and landing zone for flight.This can also lead to more time required for setup, takeoff, and landing.	A quadcopter is better in this regard.
3.	**Greater Maneuverability** Quadcopter can perform vertical takeoffs and landings. They also require less space to take flight, can hover mid-flight, and maneuver up and around objects for easy inspection, mapping, and modeling. This makes them ideal for area mapping due to the number of flight legs often required to get sufficient overlap to make high quality maps. Fixed wing aircraft are not as well suited for area mapping. This is because many turns are needed to fly a grid pattern and get sufficient overlap of a target area. Fixed wing vehicles require larger area for turning, and do not possess the maneuverability of a quadcopter.	A quadcopter is better in this regard.
4.	**More Compact** Quadcopters vehicles don't require the surface area or wingspan that fixed wing aircraft do because they use multiple propellers to maneuver. They are designed to fold down and pack up into smaller cases,making them easier to transport. Even the larger hexacopters and octocopters fold down to a portable size.	A quadcopter is better in this regard.
5.	**Ease of Use** Multi-rotor aircraft are easier to fly for both humans and autopilots. Quick to maneuver, and capable of making movements in any direction, copters have a shorter learning curve for beginners taking flight for the first time.Fixed wing aircraft are harder to fly, both for humans and autopilots, especially in an evolving sense-and-avoid landscape.	A quadcopter is better in this regard.
6.	**Payload** To transport something over long distances quickly, fixed-wing drones are more efficient where in they consumes less fuel for more speed.Quadcopters generally support more weight due to their design,however,it will then need a larger drone which would entail more expensive drone.	Depands on the requirement.

7.	**<u>Speed</u>** Speed of fixed wing drone is far better than a quadcopters which are complete air heavy.The exact speed depands on the quality of the product.But if the requirement is not to go at a high speed then even quadcopter is a better option.	Depands on the requirement.
8.	**<u>Flight Time</u>** Fixed-wing drones are the focus of long-term flights(Facebook in one of the project wants its solar-powered fixed-wing, meant to be a platform to beam internet to remote locales, to spend up to three months in the air at a time)	A Fixed-wing drones is better in this regard.
9.	**<u>Stability</u>** The aerodynamics of quadcopter leaves them more vulnerable to winds. It implies that for use cases where high winds are expected, a heavier, more stable, and more expensive quadcopter will be required. The airframe design of fixed wing aircraft give them greater stability in high winds over quadcopter.	A Fixed-wing drones is better in this regard.
10.	**<u>Safer Recovery From Moto Power Loss</u>** If a fixed wing aircraft loses motor power, in theory it is able to glide down to safety giving the aircraft a better chance of surviving a fall.	A Fixed-wing drones is better in this regard.
11..	**<u>Durability</u>** A quadcopter has more moving parts than a drone with justtwo fixed wings. The comparative ruggedness of fixed-wing makes them appealing for fieldwork like surveys.	A Fixed-wing drones is better in this regard.

LIST OF REFRENCES

1. Yong Zeng, Rui Zeng, and Teng Joon Lim (National University of Singapore) **Wireless Communication with Unmanned Aerial Vehciles: Opportuinities and Challenges** *IEEE Communication Magzine. 18 May 2016, Page 36-42*

2. **Technical requirements for Mission Critical Broadband PPDR Communications***APT report Document, AWG15/OUT-09 dt 29 Aug 2013.*

3. **Next Generation PPDR Communication Networks** *TRAI Consultation dated 09 Oct 2017.*

4. **Next Generation PPDR Communication Networks** *TRAI Recommendations dated 04 Jun 2018.*

5. K. Guevara, M. Rodriguez, N. Gallo, G. Velasco, K. Vasudev, and I. Guvenc (Department of Electical and Computer Engineering, Flourida International University, Maimi, 10555 W Flagler Street,USA) **UAV-Based GSM Network for Public Safety Communications** *IEEE SoutheastCon,Fort Lauderdale,Flourida,Apr 9-12, 2015.*

6. Yeswanth Guddeti, Raghav Subbaraman (IIT Madras), Moein Aaron Schulman and Dinesh Bharadia (UC San Diego)**SweepSense : Sensing 5 GHz in 5 Miliseconds with Low-Cost Radios** *16th USENIX Symposium on Networked Systems Design and Implementation (NSDI '19). February 26–28, 2019, Boston, MA, USA.*

7. Stephen J. Shellhammer (Qualcomm Inc.5775 Morehouse Drive San Diego, CA 92121) **Spectrum Sensing In IEEE 802.22** *28 Jul 2010.*

8. Péter Hell, Miklós Mezei and Péter János Varga Kandó Kálmán (Faculty of Electrical Engineering, Óbuda University, Budapest, Hungary) **Drone communications analysis** *IEEE 15th International Symposium on Applied Machine Intelligence and Informatics, January 26-28, 2017, Herl'any, Slovakia*

9. Syed Ahsan Raza Naqvi, Syed Ali Hassan, Haris Pervaiz, and Qiang Ni **Drone-Aided Communication as a Key Enabler for 5G and Resilient Public Safety Networks***IEEE Communications Magazine, Volume 56, Issue 1, dt 12 Jan 2018, Page 36-42*

10. Satoshi Fujii, Kohei Hiranaka, Seichio Miyagi, Motoki Kyan,Shouichi Tanifuji, Tansuriyavong Suriyon, Zacharie Mbaitiga. Noriaki Yoshikawa, Kensaku Kinoshita. **Integration of drones' communication into an ITSnetwork***ICIIBMS 2017, Track1: Signal Processing, Computer Networks and Telecommunications, Okinawa, Japan..*