

Navigation and Communication for UGV/UAV

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Introduction

- This thesis titled "Navigation and communication for UGV/UAV, consists of two parts:
 - ▶ The navigation part of this thesis includes utilization of various controllers to implement applications on UGV/UAV hardware.
 - ▶ The communication part explores the use of SATCOM and NBLoT for communicating with UAV and UGV.
- UGV and UAV kits are ideal low-cost prototype systems for testing software before scaling it up and putting it on a real ground vehicle or a more complicated UAV system.

UGV kit hardware

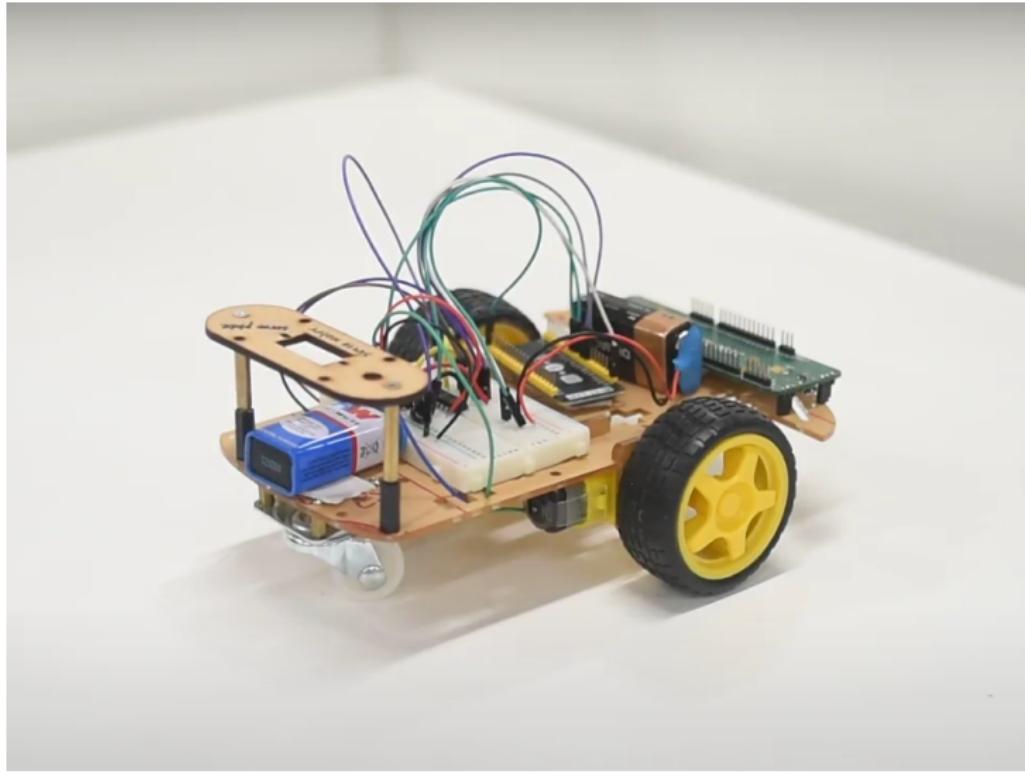


Figure 1: UGV kit hardware

UAV kit hardware

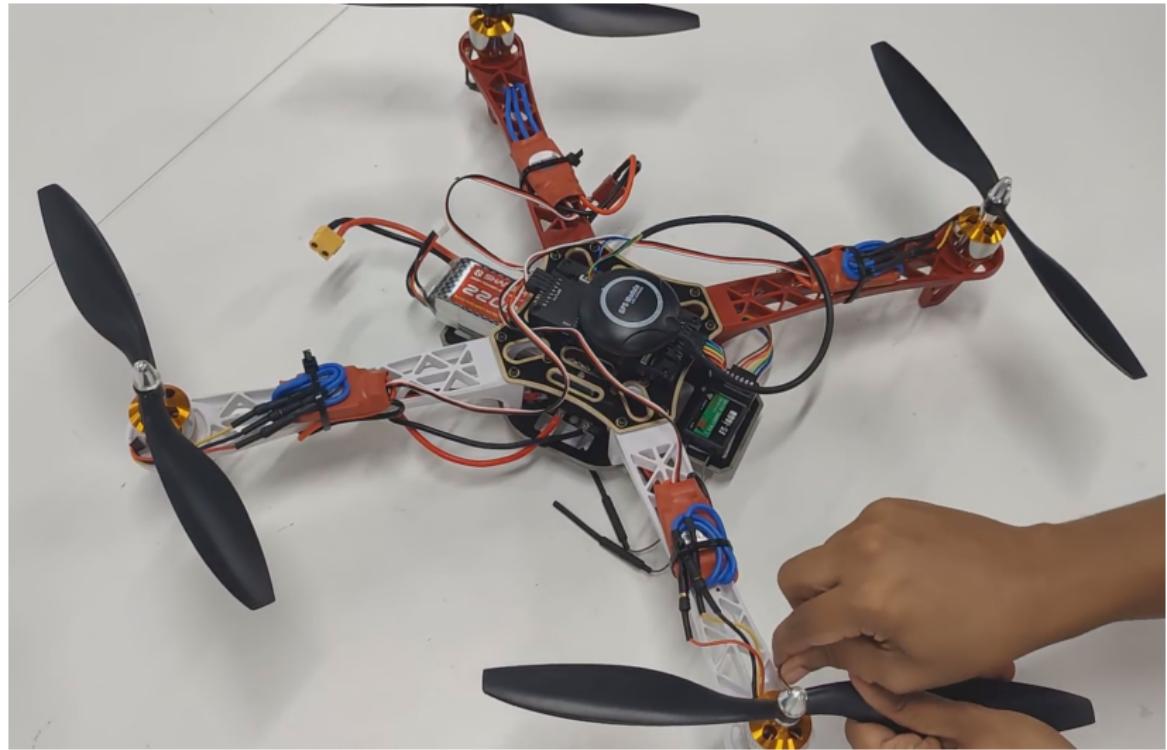


Figure 2: UAV kit hardware

Controllers

Parameters	Arduino Uno	Raspberry Pi 3B	ESP-32
Processor	ATMega328P	Quad-core Broadcom BCM2837 (4 × Cortex-A53)	Xtensa Dual-Core 32-bit LX6 with 600 DMIPS
GPU	-	Broadcom VideoCore IV @ 250 MHz	-
Operating voltage	5V	5V	3.3V
Clock speed	16 MHz	1.2GHz	26 MHz – 52 MHz
System memory	2kB	1 GB	<45kB
Flash memory	32 kB	-	up to 128MB
EEPROM	1 kB	-	-
Communication supported	IEEE 802.11 b/g/n Bluetooth via Shield	IEEE 802.11 b/g/n Bluetooth, Ethernet Serial	IEEE 802.11 b/g/n
Development environments	Arduino IDE	Any linux compatible IDE	Arduino IDE, Lua Loader
Programming language	Embedded C, C++	Python, C, C++, Java, Scratch, Ruby	Embedded C, C++
I/O Connectivity	SPI I2C UART GPIO	SPI DS1 UART SDIOCSI GPIO	UART, GPIO

Table 1: Comparison between Arduino Uno, Raspberry Pi 3B and ESP-32

Controllers (Vaman)

- On-board dual processor (ARM + FPGA)
- On-board WiFi/BT/BLE connectivity with ESP32
- μ SD card support
- On-board inertial measurement unit
- On-board BMO055 smart fusion sensor
- On-board DPS310 provides pressure, humidity and temperature monitoring

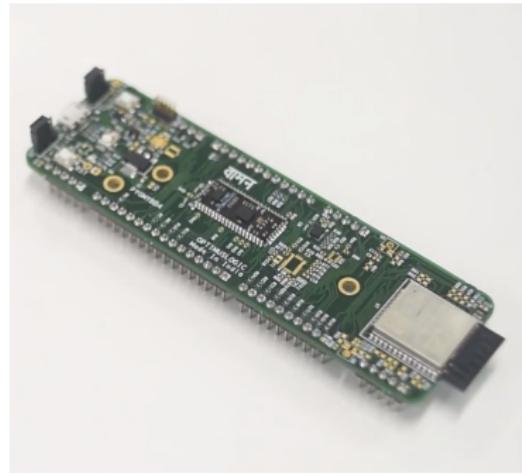


Figure 3: Vaman - Pygmy BB4

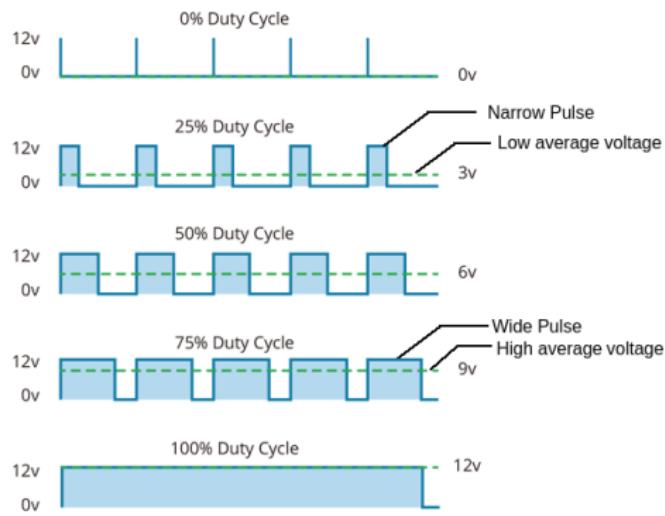
Motor control using PWM

- A pulse width modulation speed control system works by sending a series of "ON-OFF" pulses to the motor. The frequency of square wave is kept constant while varying the duty cycle (the fraction of time that the output voltage is "ON" compared to when it is "OFF").
- By changing the width of the ON duration, one can control the average DC voltage applied to the motor. The below equation (1) gives the relation between the Duty cycle (D) and the average voltage:

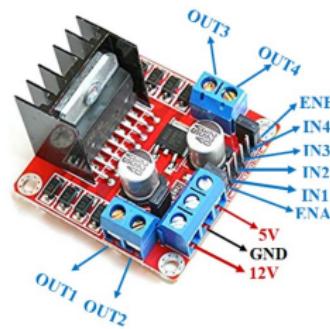
$$V_{dc} = \frac{1}{T} \int_0^T v_{PWM}(t) dt \quad (1)$$

$$\begin{aligned} V_{dc} &= \frac{1}{T} \left(\int_0^{DT} v_{\max} dt + \int_{DT}^T v_{\min} dt \right) \\ &= \frac{1}{T} (D \cdot T \cdot v_{\max} + T (1 - D) v_{\min}) \\ &= D \cdot v_{\max} + (1 - D) v_{\min} \end{aligned}$$

Motor control using PWM (Continued)



(a) PWM speed control



(b) Dual motor driver module (L298N)

ESP32 Based Application-1

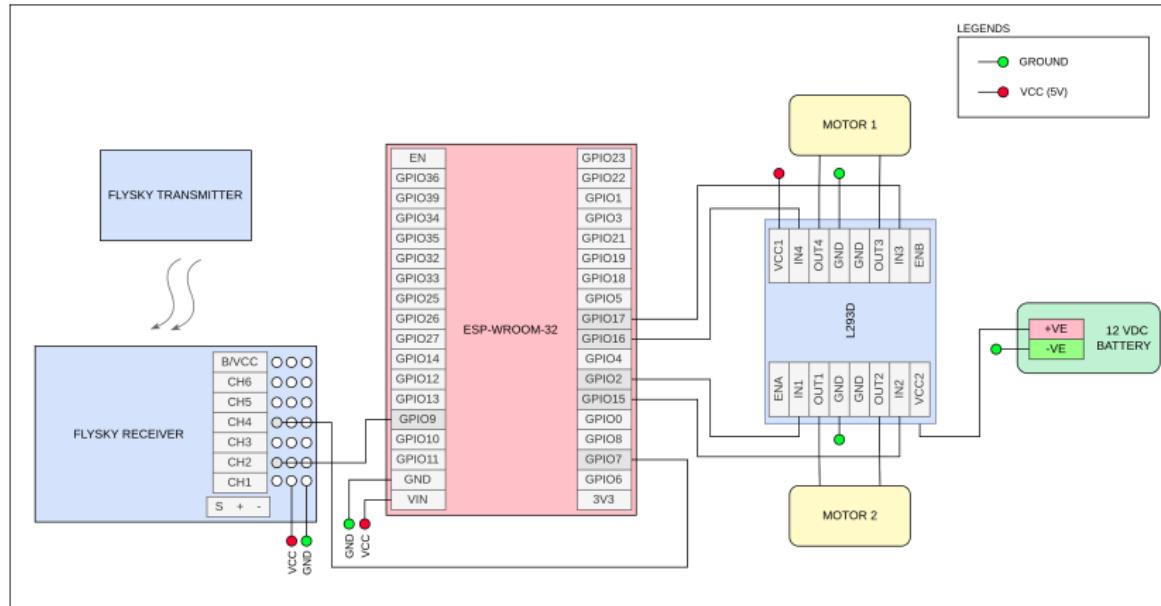


Figure 5: UGV Navigation using Fly-sky transmitter & receiver (ESP32)

ESP32 Based Application-2

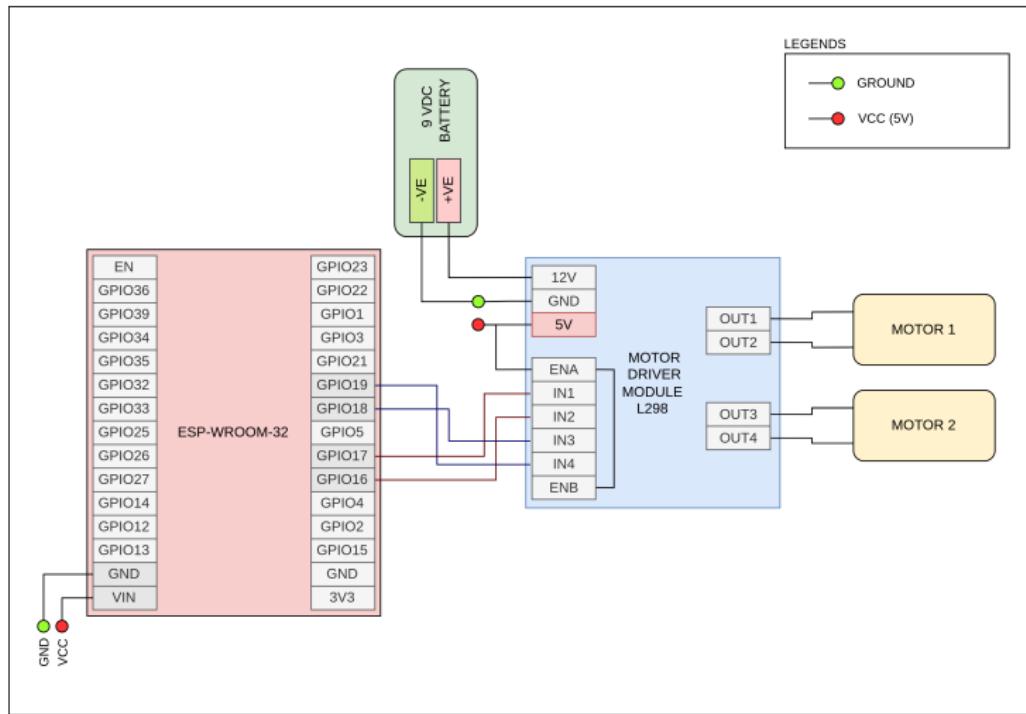


Figure 6: UGV Navigation using Android phone (ESP32)(Manual and Speech)

ESP32 Based Application-3

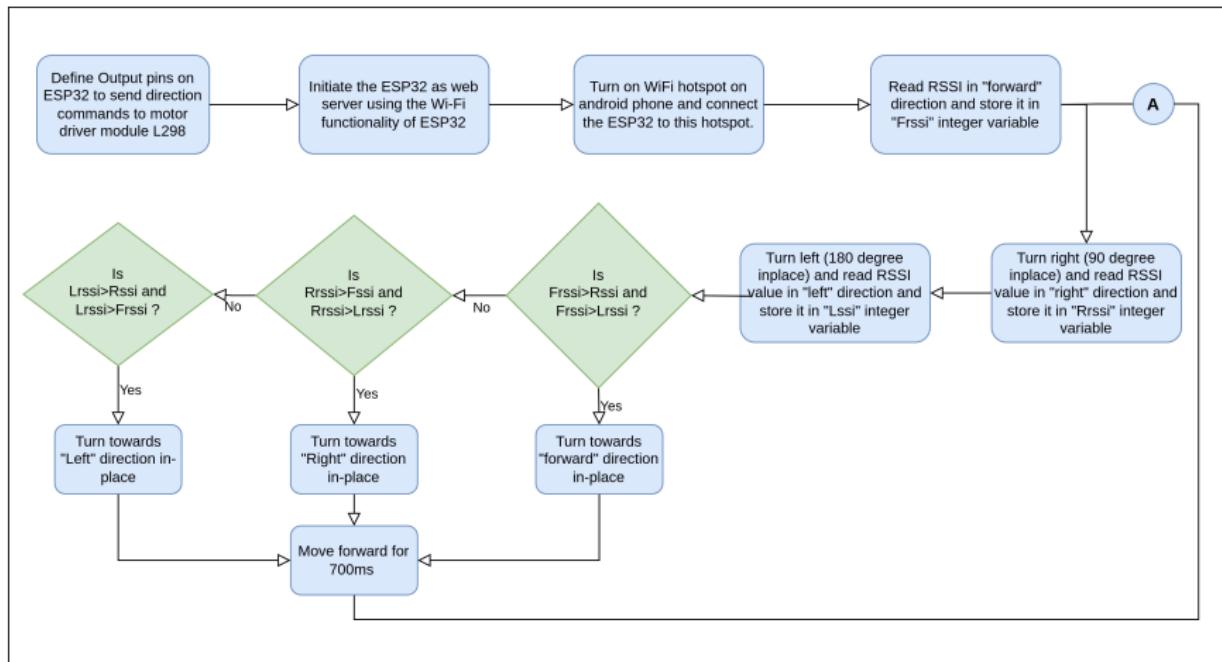


Figure 7: UGV beacon tracking

ESP32 Based Application-4

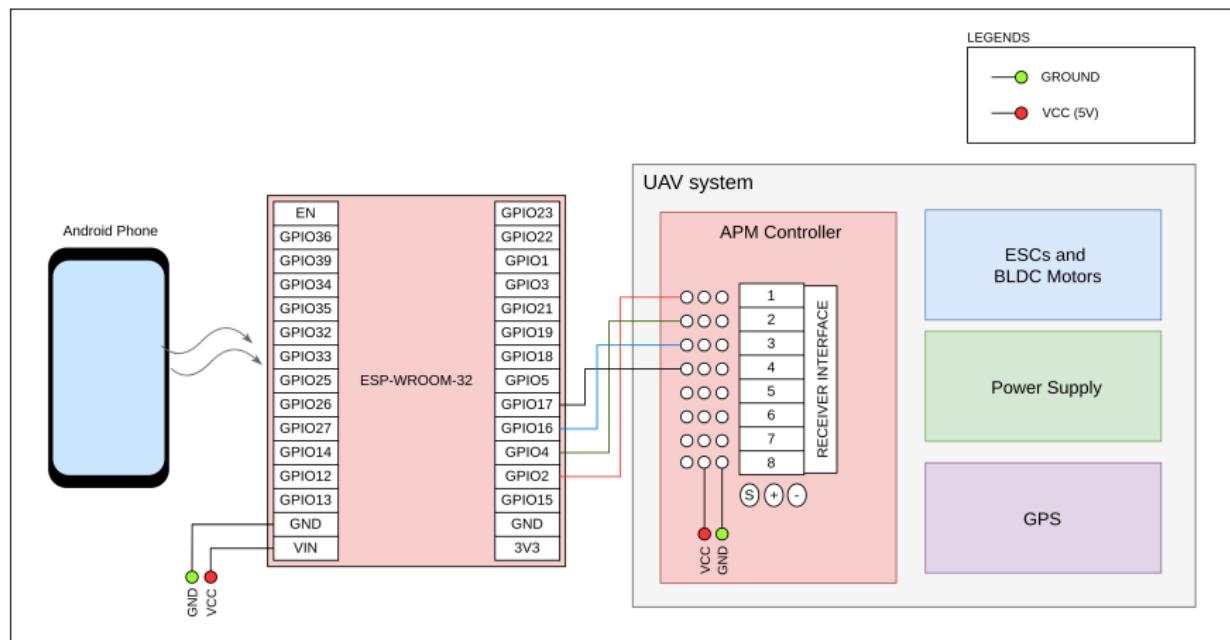


Figure 8: UAV Navigation using ESP32 and Android phone

Vaman Based Application-1

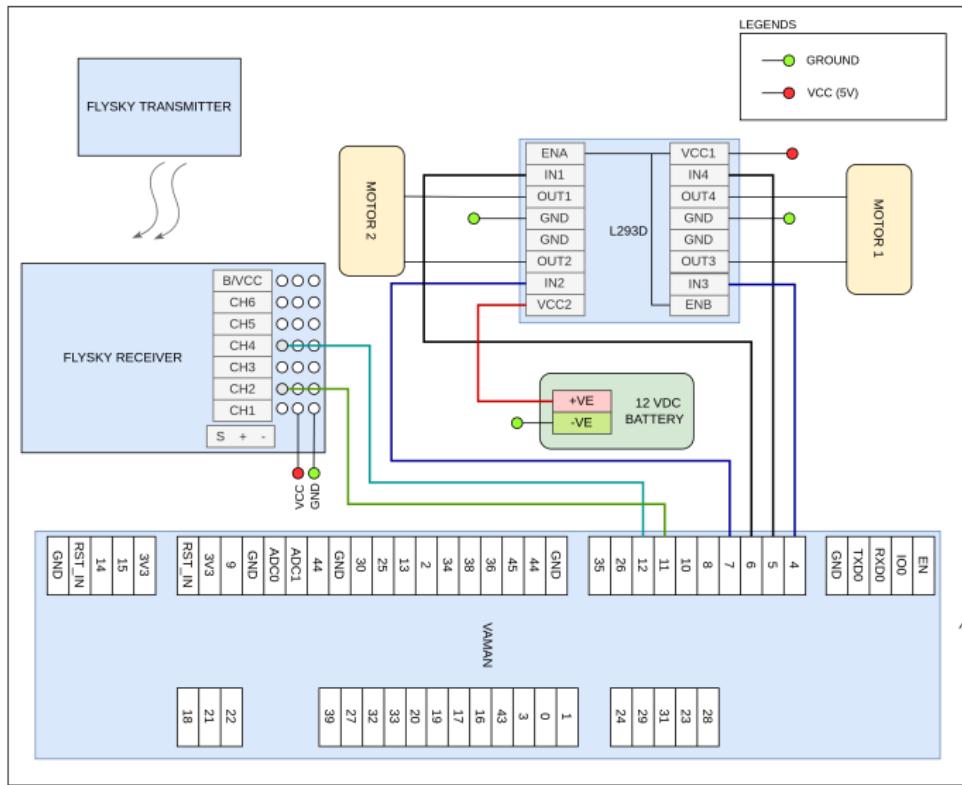


Figure 9: UGV Navigation using Fly-sky transmitter &

Vaman Based Application-2

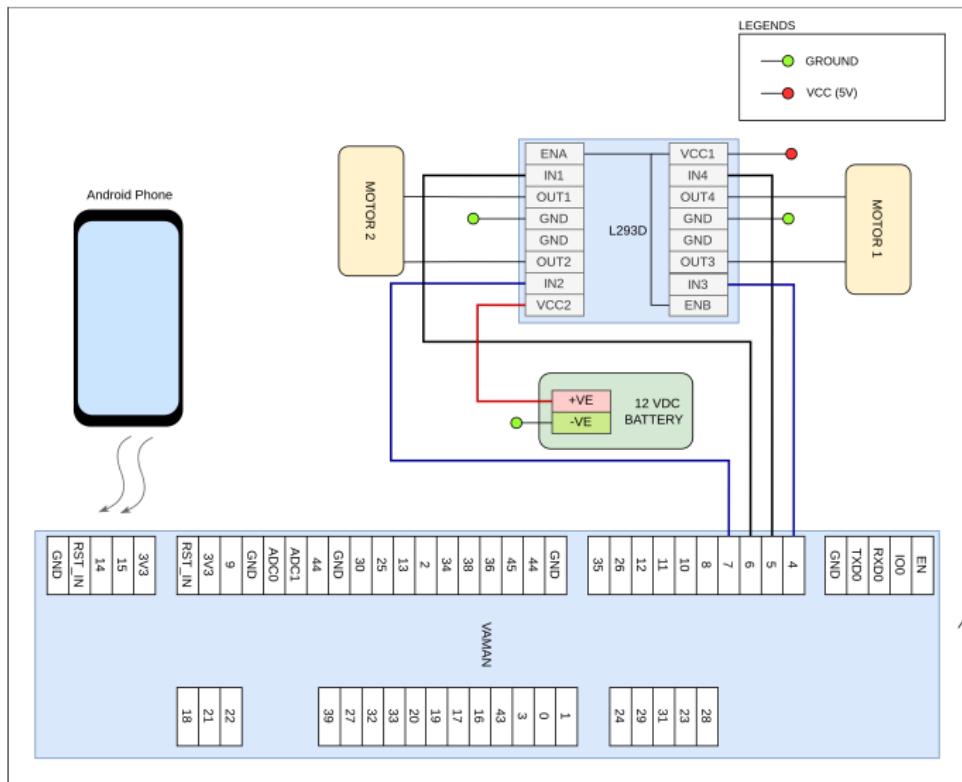


Figure 10: UGV Navigation using Android phone (Vaman)

SATCOM for UAV Communication

- Satellite Communication (SATCOM) can be used for UAV for remote access/control as well as transmit and receive data without requiring it to return to the operator.
- Convinced by the potential of 5G, Satellite industry has shown increased interest and participation in 3GPP to integrate satellite infrastructure with terrestrial network of 5G
- Figure 11 shows a typical 5G terrestrial network:

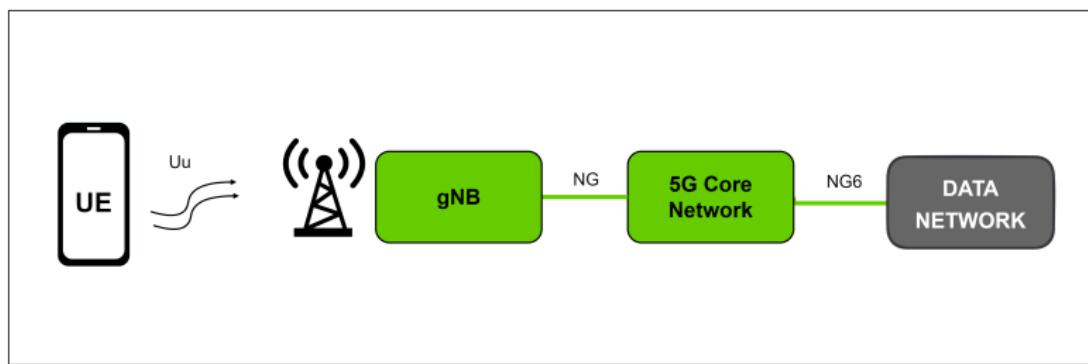


Figure 11: Conventional 5G-NR system

SATCOM for UAV (Continued)

- There are scenarios, where our user equipment (UAV in our case) may not be reachable from its nearest gNB (for example in remote areas like forests, mountainous terrain, etc).
- SATCOM provides a non-terrestrial network infrastructure, enabling communication with such remote devices.
- Latest advancements in the satellite communications have overcome previous constraints.
- New generation of Low Earth Orbit (LEO) constellations have lessened satellite communications latency
- Technological improvements in Geostationary (GEO) satellites have provided high throughput and increased the reliability of GEO satellites.

Transparent satellite based NG-RAN architecture

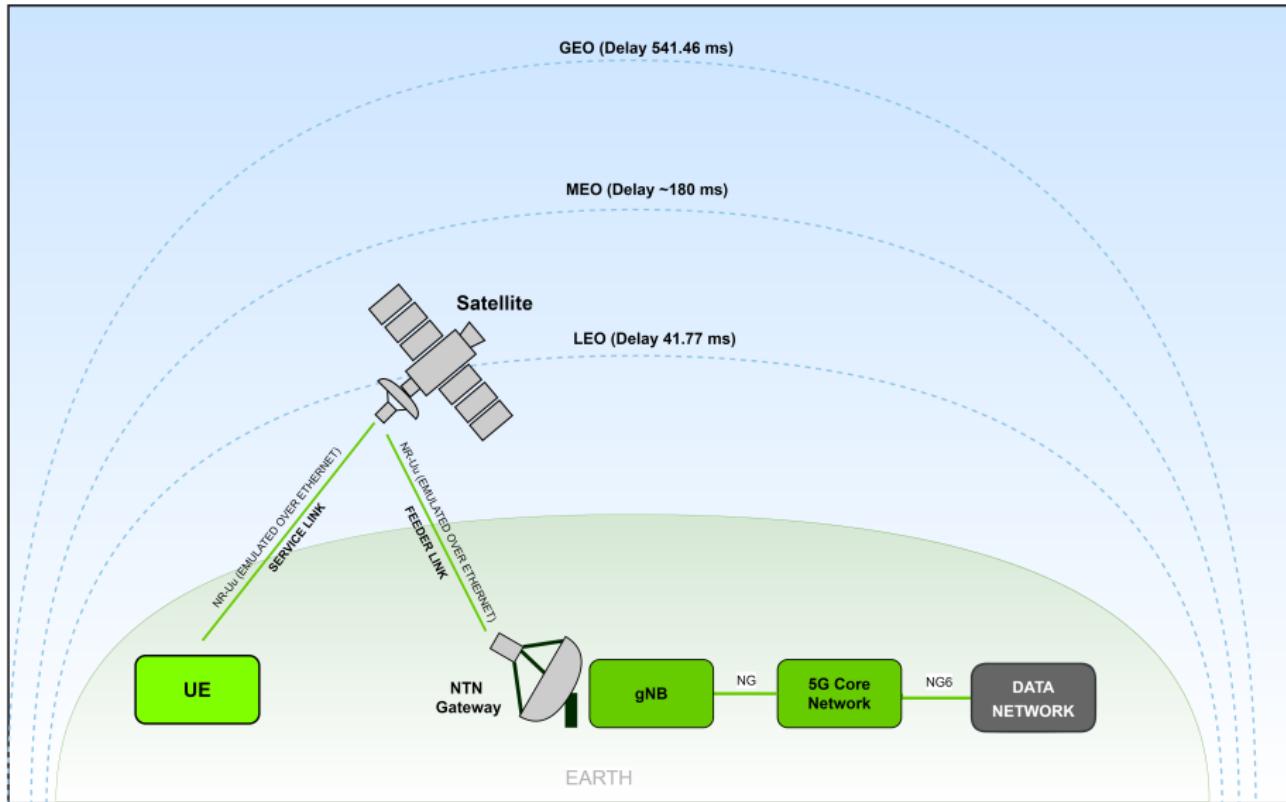


Figure 12: Transparent satellite based NG-RAN architecture

Set-up for Demonstration of SATCOM

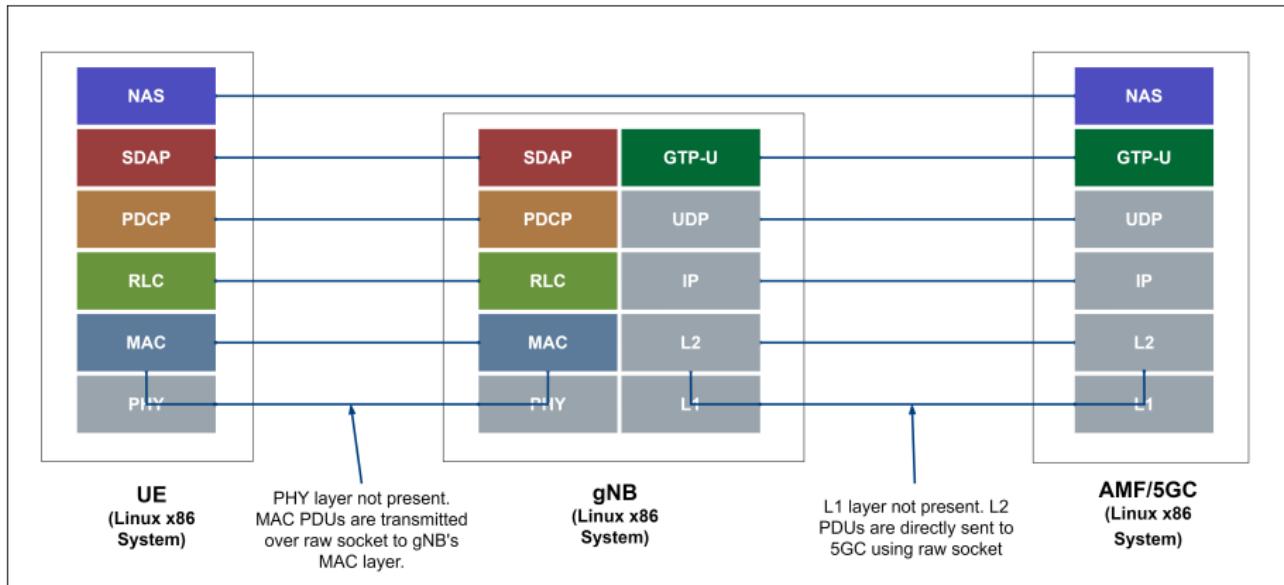
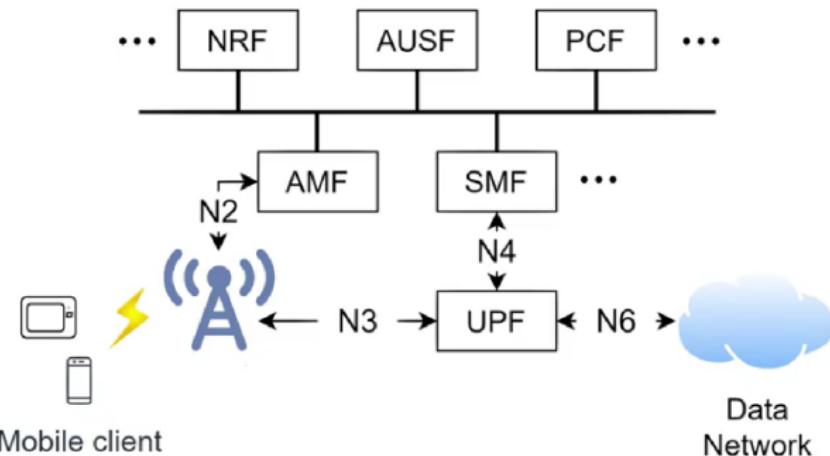


Figure 13: Set-up for Demonstration of SATCOM

Free-5GC Environment

- The Free5GC project is an open-source initiative for mobile core networks of the fifth generation (5G) aimed at construction of the 5G core network (5GC) as described in 3GPP Release 15 (R15) and further.
- In our setup it acts as our 5G core network and runs on a linux-x86 system to provide services to the UE via the gNB as defined by the 3GPP specifications.



Compilation and Execution at gNB

- Exporting environment variables for DPDK (Data Plane Development Kit consists of libraries to accelerate packet processing workloads):

```
export RTE_SDK=<path to DPDK folder installed>
export RTE_TARGET=x86_64-native-linuxapp-gcc
```

- Loading Huge pages:

```
sudo su
echo 4096 > /sys/kernel/mm/hugepages/hugepages-2048kB/
          nr_hugepages
exit
```

- Compiling and running the gNB App:

```
cd ~/Documents/simran_wsp/bs_working/review-bs/5gnrps/src/
      gnbapp/test
make clean
make static -j10
sudo ./gnbapp enp1s0 --- -diersg
```

Compilation and Execution at UE

- Exporting environment variables for DPDK (Data Plane Development Kit consists of libraries to accelerate packet processing workloads)
- Loading Huge pages
- Compiling and running the gNB App:

```
cd /home/greyteal/Documents/simran-wsp/UE/5gnrps/src/ueapp/  
test  
make clean  
make CPUSOC=1 JSON=1 -j10  
sudo ./ueapp enp1s0 0 -- -dierns
```

- Creating a tunnel interface for PDU session:

```
sudo ifconfig tun00 10.60.0.1 up  
sudo ip route add 192.168.134.224 dev tun00
```

- Check the PDU session using ping (5 packets):

```
ping -I tun00 192.168.134.224 -c 5
```

Emulating Satellite round-trip delay

- A satellite in the GEO orbit has a round-trip signal delay of around 542ms.
- The entities in our setup communicate over LAN, hence we used a tool called NetEm to add the specified delay in our interface.
- NetEm allows linux user to add of delay, packet loss, duplication, and more to packets leaving a particular network interface.
- Fixed amount of delay:

```
sudo tc qdisc add dev enp2s0 root netem delay 542ms
```

- Random delay:

```
sudo tc qdisc add dev enp2s0 root netem delay 542ms 20ms
```

- Normal delay distribution:

```
sudo tc qdisc add dev enp2s0 root netem delay 542ms 20ms  
distribution normal
```

Testing the added latency using ping

```
greyteal@greyteal-OptiPlex-3060: ~
greyteal@greyteal-OptiPlex-3060: ~$ ping -I tun00 192.168.134.224 -c 5
PING 192.168.134.224 (192.168.134.224) 56(84) bytes of data.
64 bytes from 192.168.134.224: icmp_seq=1 ttl=64 time=0.643 ms
64 bytes from 192.168.134.224: icmp_seq=2 ttl=64 time=0.741 ms
64 bytes from 192.168.134.224: icmp_seq=3 ttl=64 time=0.764 ms
64 bytes from 192.168.134.224: icmp_seq=4 ttl=64 time=0.768 ms
64 bytes from 192.168.134.224: icmp_seq=5 ttl=64 time=0.686 ms

... 192.168.134.224 ping statistics ...
5 packets transmitted, 5 received, 0% packet loss, time 4076ms
rtt min/avg/max/mdev = 0.643/0.718/0.764/0.047 ms
greyteal@greyteal-OptiPlex-3060: ~$
```

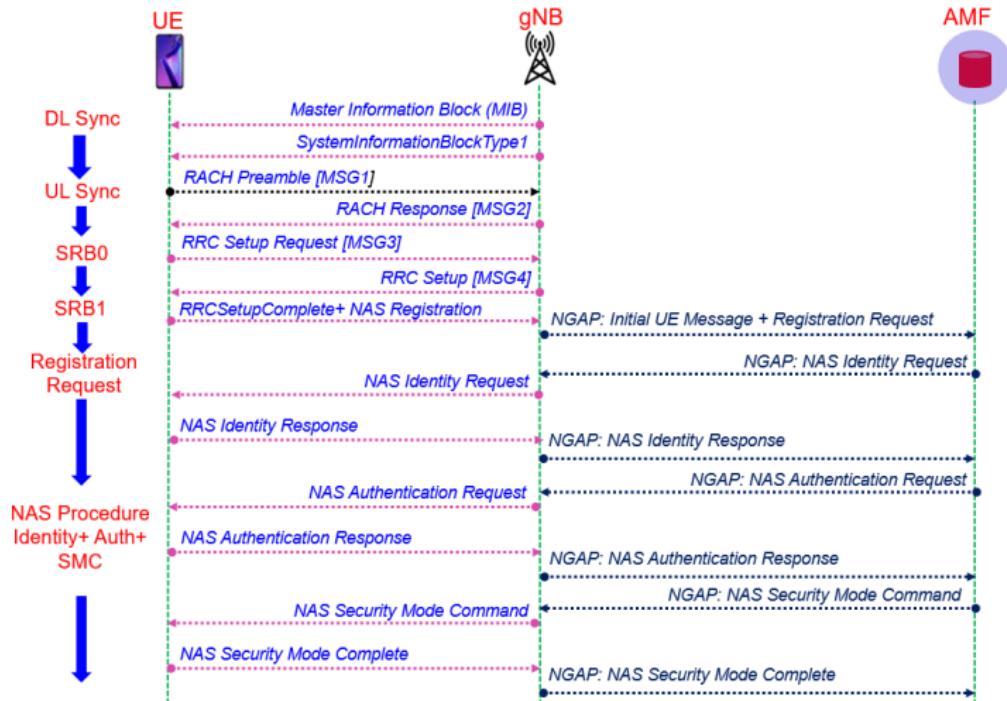
(a) Ping results before adding delay

```
greyteal@greyteal-OptiPlex-3060: ~
greyteal@greyteal-OptiPlex-3060: ~$ ping -I tun00 192.168.134.224 -c 5
64 bytes from 192.168.134.224: icmp_seq=1 ttl=64 time=542 ms
64 bytes from 192.168.134.224: icmp_seq=2 ttl=64 time=542 ms
64 bytes from 192.168.134.224: icmp_seq=3 ttl=64 time=543 ms
64 bytes from 192.168.134.224: icmp_seq=4 ttl=64 time=543 ms
64 bytes from 192.168.134.224: icmp_seq=5 ttl=64 time=543 ms

... 192.168.134.224 ping statistics ...
5 packets transmitted, 5 received, 0% packet loss, time 4001ms
rtt min/avg/max/mdev = 542.471/542.677/542.855/0.162 ms
greyteal@greyteal-OptiPlex-3060: ~$
```

(b) Ping results after adding delay

5G-NR Call Flow as per 3GPP standards



5G-NR Call Flow as per 3GPP standards (Continued)



Streaming Video using the setup

Creating video stream at source:

- To create a video stream (using file videoplayback.mp4) from 5GC to UE via gNB, run the following command in terminal of 5GC workstation. This will use UDP to stream video to a given destination IP address and port number.

```
cd ~/Documents #go to video path  
vlc videoplayback.mp4 --sout=udp://10.60.0.1:1234
```

Streaming Video using the setup (Continued)

Viewing video stream at the destination:

- The video packets streamed by source travel through the software stack as shown in Figure xx. To view the stream at destination, run the following command in terminal. This will read the video packets received at the tun00 interface from the SDAP layer of software stack.

```
vlc udp://@:1234 --miface=10.60.0.1:1234
```



Video stream result

Sr No.	Delay between the play command at source and video packets received at the destination (sec)	Delay between the stop command at source and video packets halt at the destination (sec)
1	2.10	1.60
2	2.43	1.97
3	2.04	1.90
4	2.17	2.10
5	2.16	1.7
Average	2.18	1.854

Table 2: Result without ethernet delay

Sr No.	Delay between the play command at source and video packets received at the destination (sec)	Delay between the stop command at source and video packets halt at the destination (sec)
1	2.78	2.57
2	2.58	2.32
3	2.69	2.42
4	2.64	2.74
5	2.85	2.43
Average	2.708	2.496

Table 3: Result with ethernet delay of 542 ms

UGV control using NBLoT setup

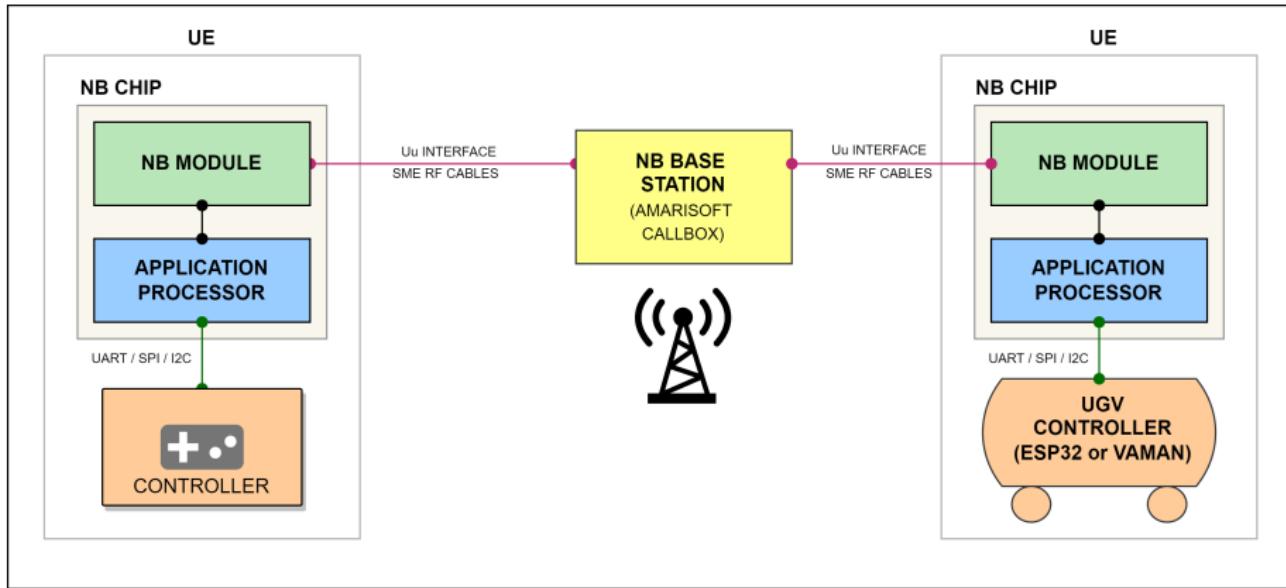


Figure 16: UGV control using NBLoT setup

Conclusion

- The basic principle behind motor control, use of serial interfaces (UART, SPI, I2C) and the inherent software remains similar to that of bigger sophisticated hardware of actual ground/aerial vehicle.
- Thus, The applications implemented on the UGV/UAV using ESP32/VAMAN can be scaled up to work on a real-life ground/aerial vehicle. This makes the UGV/UAV kit a good low cost prototype hardware.
- The 3GPP standards for Non-Terrestrial Network for 5G are only a couple of months away from their release, Thus the SATCOM infrastructure for 5G is not far from being commercial.
- The experimental setup and results shown in this presentation confirms basic compatibility between satellite and 5G system.